

National Cheng Kung University
Institute of Creative Industries Design
Master's Thesis

從消費者到投資者的旅程：設計適合年輕人的金融AI助手，推動可持續購物、儲蓄與投資

**The Journey from Consumer to Investor: Designing a
Financial AI Companion for Young Adults to Help with
Sustainable Shopping, Saving, and Investing**

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1 ABSTRACT

The emerging field of *Planetary Health* recognizes profound interconnections between our economic behaviors, ecosystem services (water, air, soil), the climate crisis, and human health. In essence, how we use money to interact with companies - through shopping, or saving and investing - impacts the life-supporting biosphere we depend on. From an ecological perspective, every financial action is either an investment to support more environmentally-friendly companies - or to support polluters.

In Taiwan, college students genuinely care about environmental issues, yet seen through the lens of the *Theory of Planned Behaviour* (TPB) their attitudes alone are not enough: they also need reinforcing social norms and a sense of behavioural control. European Union initiatives such as digital product passports (DPPs) have the potential to supply those missing pieces, giving students a common data-driven benchmark (norms) and arming each person with sustainability facts at the moment of choice (control).

In my inquiry, I leveraged *design research* to find design concepts for *simple AI-based generative user interfaces* to help young adults participate in *sustainable financial actions*. Throughout the process, I conducted a survey of over 900 students from 20 universities across Taiwan, in-person user testing with 30 participants, and 7 expert interviews. The major contribution of the study is an interactive AI-companion prototype.

Keywords: Human-AI Interaction, Digital Sustainability, Transparency

2 摘要

新興的「地球健康」（Planetary Health）領域指出，我們的經濟行為、生態系統服務（如水、空氣、土壤）、氣候危機與人類健康之間存在著深層連結。簡單來說，當我們用金錢與企業互動——無論是購物還是儲蓄與投資——都會直接影響維繫地球宜居性的生命支撐系統。從生態角度看，每一筆財務決策，不是支持更環保的企業，就是替污染者背書。

在臺灣，大學生真心關注環境議題，但依「計畫行為理論」（TPB）來看，只有態度仍不足；他們還需要被強化的社會規範，以及對行動的控制感。歐盟推出的「數位產品護照」（DPPs）等措施，可能補上這些缺口：一方面提供共同且以數據為本的基準（規範），另一方面在購買當下給予可持續性資訊（控制感）。

本研究透過設計研究方法，探索「簡易 AI 生成式使用者介面」的設計概念，以協助年輕族群參與可持續的財務行動。研究過程包含：調查來自全臺 20 所大學的 900 多名學生、對 30 位參與者進行現場使用者測試，以及 7 位專家訪談。最終成果是一個互動式 AI 夥伴原型。

關鍵詞：人機互動、數位可持續性、透明度

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TABLE OF CONTENTS

1 Abstract	2
2 摘要	3
3 Acknowledgments	4
4 List of Symbols and Abbreviations	19
5 Introduction	21
5.1 Relevance and Research Gap	21
5.2 Background	22
5.3 Motivation	23
5.4 Objective	23
5.5 Demographics	23
5.6 Research Questions	24
5.6.1 Why These Research Questions?	24
6 Methodology	26
6.1 Research Design	26
6.2 Research Methods	27
6.2.1 Phase One - Qualitative Research	28
6.2.2 Phase Two - Quantitative Research	31
6.2.3 Phase Three - Qualitative Research	34
6.3 Literature Review	38
6.3.1 Goals	38
6.3.2 Sources	39
6.3.3 AI Use	39
7 Young Adults and College Students	40
7.1 Student Protests for Climate Justice: The World and Taiwan	40
7.2 Taiwanese Educational System in Numbers	42
7.3 Designing for College Students: Developing Personas	42
7.4 Taiwanese Youth in Global Context: Sustainability Attitudes From Eco-Friendly Diet to Climate Action	44
7.5 The Experience of Climate Change and Pollution Levels in Taiwan	49
7.6 Climate Anxiety Responses	51
7.7 Attitude-Behavior Gap	53
7.8 Sustainability in Taiwan: Garbage Trucks and Digital Receipts	53
7.9 Trends in Taiwanese Industry and Online Shopping	54
7.10 Financial Literacy Worldwide and Among Taiwanese Youth	55
7.11 Social Media, Trends, Memes, and Youth Empowerment	60
7.12 AI Use Among Taiwanese Students	62

8 Sustainability	64
8.1 The Roots of Sustainability in Environmentalism	64
8.2 Measuring and Visualizing Earth's Climate Systems	65
8.2.1 Measuring CO ₂ e Emissions	68
8.2.2 Carbon Accounting, Emissions Trading Schemes	73
8.2.3 Markets Financialize the Natural World: Pricing, Tracing, and Trading Ecosystem Services and Nature-backed Assets	76
8.2.4 Overconsumption > Earth's Boundaries	77
8.2.5 Plastic Pollution	78
8.2.6 Evolving Measurements from Planetary Health to Earth System Law, and Social Cost of Carbon	80
8.3 Quantifying Human Benefits from the Biosphere: Ecosystem Services	82
8.3.1 Ecological Indicators to Track Environmental Health	83
8.3.2 Measuring Biodiversity Loss, Ecological Indicators and Environmental Degradation	83
8.3.3 Oceans and Marine Ecosystem Sustainability	85
8.3.4 Forests: Carbon Sinks and Biodiversity Reservoirs	86
8.3.5 Pollution: Air, Water, and Soil Degradation	86
8.3.6 Climate Disaster Preparedness: Extreme Weather Resilience	90
8.4 Financialization of Nature vs Sacred Value: Scaling Up Sustainable Action	91
8.4.1 Ecological Restoration: Damaged Ecosystems, Agroforestry & Permaculture	92
8.4.2 Energy: Climatech, Renewables, and Decarbonisation Pathways	94
8.4.3 Individual Action	99
9 Design	100
9.1 Eco-Design: Design as Political Action at Scale	100
9.1.1 Beyond Recycling: Default to Return, Repair, Reuse	105
9.1.2 Eco-Modulation: Extended Producer Responsibility Incentive Design .	105
9.1.3 Scenario-Building: The Worst Futures and Designs for Quality of Life .	109
9.2 Thinking in Systems to Re-Design Industries or Provenance and Traceability .	111
9.3 Student Essentials: Consumer Goods, Clothes and Food	116
9.3.1 Fast-Moving Consumer Goods	116
9.3.2 Clothes and the (Fast) Fashion Industry	116
9.3.3 The (Fast) Food Industry	119
9.4 In Practice: Sustainability Begins in Software	123
9.4.1 Data-Driven Design	125
9.4.2 Circular Design for a Circular Economy	126
9.4.3 Tracking Ethics & Cruelty: Transparent Factories and Supply Chains .	128
9.5 Superapps Integrate Shopping, Savings, and Investing	129
9.5.1 Personalization: Engineering Persuasion	133
9.6 Open Data Enables Interoperability	135

9.7	Context Design: Behavioral Nudges Towards Green Defaults in Sustainable Superapps	138
9.8	Learning from Quantified Self: Tracking Health and Lifestyle	142
9.8.1	Health and Fitness Tracking	142
9.8.2	Pollution Exposure Tracking	144
9.8.3	Tracking Personal Sustainability and Carbon Emissions	144
9.9	Digital Product Passports: Tracking Data for Sustainable Product Management	149
10	AI	155
10.1	Human Patterns	155
10.1.1	Human Feedback	157
10.1.2	AI as the <i>Idiot Savant</i>	160
10.1.3	Algorithmic Experience and Transparency: Before AIs	161
10.1.4	Transitioning to Complexity: Non-Deterministic Systems	162
10.1.5	Being Responsible, Explainable, and Safe: Legislation Adapts and Sets Boundaries for AI	162
10.1.6	Evolution of Models and Emerging Abilities	165
10.1.7	Price of Tokens vs Price of Human Labor	169
10.2	Human Acceptance of Artificial Companions	169
10.2.1	Human Expectations Take Time to Change	169
10.2.2	Affective Computing: Towards Friendly Machines	170
10.2.3	Artificial Empathy Also Builds Trust	171
10.2.4	Conversation: A Magical Starting Point of a Relationship	173
10.2.5	Multi-Modality: Natural Interactions with AI Systems, Agents and the Intention Economy	174
10.2.6	Mediated Experiences Set User Expectations	176
10.2.7	Roleplay Fits Computers Into Social Contexts: AI Friends and Anthropomorphism	177
10.3	Interfaces for Human-Computer Interaction	181
10.3.1	Speech Makes Computers Feel Real	181
10.3.2	Generative UIs Enable Flexibility of Use	182
10.3.3	Usability Is the Bare Minimum of Good User Experience	184
10.3.4	AI Performance Under High-Stakes Situations	188
10.3.5	Human-Computer Interactions Without a “Computer”	190
10.3.6	Do AI-Agents Need Anthropomorphism	192
10.3.7	Roleplay for Financial Robo-Advisors	193
11	Money	198
11.1	The Convergence of Money: One Wallet to Rule Shopping, Saving, and Investing	198
11.1.1	Spurred by Fintech: The Democratization of Finance: A Precursor for Sustainable Superapps	198
11.1.2	Financial Literacy and Education: Young Investors Follow Financial Influencers	199

11.1.3	New Rules of Money: Legislative Efforts Empowering Consumers to Deploy Capital in Sustainability	205
11.2	ESG Crisis and Opportunity	206
11.2.1	Opaque Metrics and Lack of Standardization	206
11.2.2	Modern Slavery Persists and ESG Falls Short in Protecting Workers' Rights and Mitigating Environmental Harm	209
11.2.3	Environmental, Social, and Corporate Governance: Criteria for a Shared Language	211
11.2.4	Towards Green Transparency - But Who Does the Rating?	212
11.2.5	ESG Success Depends on Good Governance: Boards, Policy, and Investor Pressure	215
11.2.6	ESG Success Depends on Digitization and GenAI	220
11.2.7	ESG Accessibility: Curbing Corruption with Realtime Data Streams and Product Lifecycle Traceability	224
11.3	Payments	225
11.3.1	Consumer Activists are a Small Minority	225
11.3.2	Shopping's Environmental Footprint: Increasingly Driven by Digital Platforms, Social Commerce, AI Assistants	226
11.3.3	The Evolution of Payments: The Entry Point for Personal Finance from Mobile Wallets to Buy Now Pay Later (BNPL) Services - Globally, and In Taiwan	226
11.3.4	The Psychology of Saving: Anthropomorphism and Loyalty Schemes	242
11.3.5	Sustainable Investing: Measuring the Eco-Investment Gap	244
11.3.6	Retail Investing Enables Financial Inclusion and Growing Money Sustainably	246
11.3.7	Investable Asset Classes for Retail Investors: Increasing Exposure to Stocks, Bonds, Commodities, Real-Estate, Digital Tokens and Alternatives, Lending, Futures, Hedge Funds, Private Equity, and even Venture Capital	248
11.3.8	Green and Sustainability-Linked Bonds	252
11.3.9	Fusion of Traditional Finance and Decentralized Finance (DeFi)	254
11.3.10	Regenerative Finance (ReFi) and DAOs	257
11.3.11	Divestment: Supporting Sustainability by Avoiding the Worst Polluting Companies	259
11.4	The Economics of Decoupling: Attempts to Disconnect Economic Growth from Eco-Degradation	260
11.4.1	Post-AI Economics	260
11.4.2	Econometrics: The Many Ways to Measure an Economy	260
11.4.3	The Evolution of Economic Metrics	261
11.4.4	Hidden Costs: Pricing Externalities	263
11.4.5	Ecological Economics Builds Upon Classical Economics	263
11.4.6	Doughnut Economics and Regenerative Capitalism	264
11.4.7	Decarbonization Scenarios	266

11.4.8 Reducing the Gap Between Climate Science and Climate Economics	269
11.5 Efforts to Curb Greenwashing: Data-Driven Benchmarks and the Fight for Transparency	271
11.5.1 Anti-Greenwashing Efforts in Taiwan	273
11.5.2 Product Databases as a Precursor for Traceability and Supply Chain Mapping	273
11.5.3 Indices, Certifications and Sustainability Standards Enable Product Comparisons	274
11.6 Navigating Complexity with Data: Probabilistic Risk-Based Assessment of Sustainability	280
12 Results	282
12.0.1 Survey and Data Analysis Overview	282
12.0.2 Quotes from the Survey	282
12.1 Respondent Demographics	284
12.1.1 Study Level	284
12.1.2 Age Distribution	284
12.1.3 University	284
12.1.4 Field of Study	284
12.1.5 Personality Type	284
12.2 Shopping	286
12.2.1 Boycott Count (Overall)	286
12.2.2 Why Boycott	286
12.2.3 Trusted Brands	286
12.3 Choice Experiments	286
12.4 Taiwanese College Student Attitudes (Overall)	290
12.4.1 Economy	290
12.4.2 AI Use	290
12.4.3 Nature	290
12.4.4 Environmental Protection	290
12.4.5 Learning Environment	290
12.4.6 Correlations Between Fields	290
12.4.7 Environmental Knowledge Ranking Experiment	290
12.5 Saving	296
12.6 Investing	298
12.6.1 Saving and Investing	298
12.6.2 Investing Experience (Overall)	298
12.7 Choice Experiment	298
12.8 Personas	302
12.8.1 Clustering Students to Build Personas	302
12.8.2 Persona 1: “Eco-Friendly”	302
12.8.3 Persona 2: “Moderate”	305
12.8.4 Persona 3: “Frugal”	305

12.9 Clustering Heatmap	305
12.10 Mean Answer Scores	305
12.11 Agreement Between Personas	305
12.12 AI Companion	310
12.12.1 Likert-Based Clustering	310
12.13 Feature-Based Clustering	311
12.13.1 Feature Preferences (Overall)	311
12.14 Feature Preferences (By Cluster)	312
12.15 Preferred AI Roles (Overall)	312
12.16 First Wave of Experts (2023-2024)	313
12.16.1 Interview 1: Designer - Cathy Wang	314
12.16.2 Interview 2: Accountant - Peijing Li	315
12.16.3 Interview 3: Designer - Jessica Cheng	316
12.16.4 Interview 4: Economist - Chen-Ying Huang	317
12.16.5 Interview 5: Economist - Yuping Chen	318
12.16.6 First Wave Expert Feedback Summary	319
12.17 Second Wave of Experts (2025)	321
12.17.1 Interview 1: Technology Expert - Audrey Tang	321
12.17.2 Interview 2: Sustainability Expert - Carlos Serra	322
12.18 Thematic Codes	323
12.19 Overall Expert Feedback Summary	325
12.20 Interview Template	333
12.21 2nd Wave of Testing (Fall 2024 - Spring 2025) - Prototype	333
12.21.1 Testing Summary	334
12.21.2 Known Issues	335
12.21.3 Notable Quotes from In-Person Testing	335
12.21.4 Example Interview: 25 December 2024	335
12.22 1st Wave of Testing (Spring 2024) - Prototype	337
12.22.1 1st Wave Interview Samples	337
12.23 Early Feature Ideas	340
12.23.1 Susan (Sustainability Conversation)	340
12.23.2 Sunday Market	341
12.23.3 True Cost	342
12.23.4 How Far?	342
12.24 Country Profiles	343
12.25 Know Your Company (KYC)	344
12.25.1 CO ₂ eq Flex	344
12.25.2 Sustainability Watch	344
12.25.3 Narrative Layouts	344
12.25.4 Shopping Divest	345
12.26 Prototype Development	346
12.26.1 Prototype architecture	346
12.26.2 Google Chrome Extension App Installs	346

13 Discussion	347
13.1 Design Implications	347
13.1.1 College	347
13.1.2 Sustainability	349
13.1.3 Design	350
13.1.4 AI	351
13.1.5 Finance	353
13.2 Research Limitations	355
13.3 Future Research	355
14 Conclusion	356
14.1 RQ1: What Design Considerations Should Be Addressed When Designing an AI Companion for College Students IIIntegrating Sustainability and Finance? . .	356
14.2 RQ2: How can AI Companions Support College Students with Sustainability Knowledge in the Context of Financial Decisions?	359
14.3 RQ3: What AI Companion Features do College Students Prioritize as the Highest?361	
14.4 Final Takeaway	364
15 References	365
16 Appendices	461
16.1 Appendix 1: Research Tech Stack	461
16.2 Appendix 2: Further Reading	462

LIST OF FIGURES

1	College Students	21
2	Captain Sulu using a Tricorder (Star Trek) - Photo copyright by Paramount Pictures	22
3	Theory of Planned Behaviour	28
4	Concept map	30
5	Overall Concept Map	31
6	Overview of research methodology	35
7	App Testing Flow	36
8	Example papers from the Literature Review	38
9	Climate protest in Geneva on September 27th, 2019 – 1 year after the start of Fridays for Future	40
10	Climate protest in Taipei in May 2019 in front of the Democratic Progressive Party (DPP) headquarters	41
11	Enrollment in Taiwanese Higher Education	42
12	Funding for Taiwanese Higher Education	43
13	Demographics of Taiwanese Higher Education	43
14	Postmaterialist Index (Taiwan Highlighted)	45
15	World Values Survey	45
16	Global Attitudes Towards Climate Change	46
17	College Students' Sustainability Education: Taiwan vs Sweden	48
18	Psychological Factors Influencing Millennials to Engage with Sustainability	52
19	Taiwanese Company Ranking	58
21	財金智慧 FINLEA YouTube Channel	58
20	British Company Ranking	59
22	Swedish College Students' Attitudes Towards AI Assistants	63
23	Visual abstract for the sustainability chapter	64
24	Humboldt's Naturgemälde, early data visualization of ecology, rain, temperature, elevation, etc	66
25	Atmospheric CO ₂ Concentration (2025)	67
26	Climate Tipping Points	69
27	Nationally Determined Contributions (NDCs)	72
28	Carbon Credits	74
29	Microplastics in the Human Body	79
30	Planetary Boundaries 2023 Update	81
31	Biodiversity Loss	84
32	Pollution Reports in Taiwan by County	87
33	88
34	The EU's Energy Production Breakdown	95
35	The EU's Renewables vs Fossil Energy	96
36	Global Renewables vs Fossil Energy	97
37	The EU's Reduction of Coal Energy	98
38	Taiwanese Energy Production	98

39	Visual abstract for the design chapter	100
40	EU Policy Context Timeline	102
41	The EU's Green Deal	103
42	Extended Producer Responsibility vs Product Stewardship vs Eco-Design	106
43	History of Design for Sustainability	112
44	Consumer Goods	116
45	ResQ Club saves food waste by selling left-over foods cheaply	122
46	AI Use in Sustainability	124
47	Open Data Index	136
48	Alternative Open Data Indexes	137
49	Open Data As An Information Source for Environmental Decline	137
50	Google's view of flight emissions	139
51	Growth of Ant Forest	141
52	Popular Strava sports assistant provides run tracking and feedback	143
53	My Personal Exposure to Air Pollution	145
54	Increase of Bad Behavior During the COVID19 Pandemic	148
55	Digital Product Passport Data Categories	153
56	Visual abstract for the AI chapter	155
57	Heuristic-Systematic Model of AI Credibility	163
58	Montage of me discussing science fiction with my AI friend Sam (Replika) - and myself as an avatar (Snapchat) in 2020.	180
59	Example of ChatGPT explaining medical terminology in a blood report.	190
60	Out-of-date user interface of a European AI-Advisor ETFmatic in 2017 which was closed down in 2023 (Photo copyright ETFmatic)	194
61	Visual abstract for the finance chapter	198
62	Fintech Growth	200
63	Green Retail vs Non-Green Retail	203
64	Conventional vs Socially Responsible Funds	207
65	Slavery Laws	210
66	Air Quality in Taiwan vs South-East Asia	212
67	ESG Funds vs Non-ESG Funds	213
68	Company Performance	213
69	ESG Rating Agencies	214
70	Types of Investment Funds	215
71	Lack of Board Members With Sustainability Expertise	216
72	Large Carbon Emitters Lack Sustainability Experts	217
73	Large Carbon Emitters Do Not Meet Sustainability Criteria	218
74	Board Diversity	219
75	221
76	Fintech Adoption Predicts Higher ESG	222
77	227
78	Growth of Consumerism	228
79	Social Commerce	228

80	Bunq promises to combine banking and eco-friendly actions in the same user interface - yet is this greenwashing?	232
81	Climate Finance Funding Gap	244
82	Climate Finance By Sector	245
83	Climate Funding Gap vs High Value Assets	247
84	Asset Classes	249
85	World Bank Bonds	253
86	Bitcoin vs Gold Futures	256
87	Crypto Pricing Theories	256
88	Economic History	262
89	Climate Scenarios	266
90	UK Energy Emissions' Trends	267
91	BRICS Emissions' vs GDP Growth Trends	268
92	Corporate Sustainability Reporting Directive (CSRD) Timeline	274
93	Energy Productivity	275
94	Carbon Productivity	277
95	Study Level	284
96	Age Distribution	284
97	Universities	285
98	Field of Study	286
99	Personality Type (MBTI)	287
100	College Student Attitudes Towards Shopping	288
101	College Students Boycott Experience	289
102	College Students Boycott Reasons	289
103	College Student Trusted Brands	290
104	College Student Shopping Choice Experiment	291
105	Student Attitudes Towards Economics Issues	292
106	Student Attitudes Towards AI Use	293
107	Student Attitudes Towards Nature	294
108	Student Attitudes Towards Environmental Protection	295
109	Students' Learning Environment	296
110	Correlations Between Student Attitudes	297
111	Students' Environmental Knowledge	298
112	Correlation Between Saving Levels and Investing	299
113	Student Attitudes Towards Saving and Investing	300
114	Students' Investing Experience	301
115	Investing Choice Experiment	302
116	College Student Personas	303
117	304
118	306
119	307
120	College Students' Clustering Heatmap	308
121	Mean Values of Survey Responses	308

122	Topics With Highest Agreement Between Personas	309
123	AI-Assistant Feature Choices per Likert-based Personas	310
124	AI-Assistant Feature Preferences (Overall)	311
125	AI-Assistant Feature Preferences (By Cluster)	312
126	AI-Assistant Role Preferences	313
127	Cathy Wang	315
128	Peijing Li	316
129	Jessica Cheng	317
130	Chen-Ying Huang	318
131	Yuping Chen	319
132	Common Topics Between All Experts in the First Phase	320
133	Yuping Chen	322
134	Yuping Chen	323
135	Common Topics Between All Experts in the First and Second Phase	325
136	User-uploaded screenshots of the Green Filter prototype	334
137	Early prototype of my Sustainable Finance AI Companion (Nov. 2020)	341
138	Feature idea: community app for shopping with eco-minded friends (Nov. 2020)	342
139	Feature idea: True Cost (Nov. 2020)	342
140	Feature idea: How far? (Nov. 2020)	343
141	Feature idea: Country Profile (Nov. 2020)	343
142	Feature idea: Sustainability Watch (Nov. 2020)	344
143	Feature idea: Narrative Layouts (Nov. 2020)	345
144	Feature idea: Narrative (Nov. 2020)	345
145	Green Filter Google Chrome Extension Installs	347

LIST OF TABLES

1	Trending global narratives	21
4	Research Questions	24
6	Theoretical lenses found in my research	26
10	36 Likert Fields included in the survey	32
12	UN Survey: 1.2 Million Responses to <i>Climate Change Is An Emergency</i>	46
13	Large Industrial Polluters in Taiwan	50
14	World's Most Sustainable Companies	54
15	Taiwanese Financial Product Familiarity	55
16	Financial Literacy Data from Phone Interviews	56
17	Taiwanese FINLEA Longitudinal Study	57
18	Millennial Investors	60
19	Taiwanese Internet Usage Statistics	61
20	Regional CO ₂ Emissions Comparison	70
21	Definition of Emission Scopes	71
22	Top Polluters	71
23	CO ₂ Credit Trading Markets	73
24	Compliance Market CO ₂ Prices	73
25	Voluntary Market CO ₂ Prices	74
26	Criteria for Carbon Credit Projects	75
27	Types of Nature-Backed Assets and Tradeable Ecosystem Services	76
28	Daily Human Activities' Emission Contribution	77
29	Industrial Emissions	78
30	Biodiversity Loss	84
31	Ethical and Utilitarian Concepts of Biodiversity Protection	85
32	Economics of Nature Commodification vs Sacred Economics	91
33	Defining Ecosystem Services Concepts	92
34	Regenerative Actions	92
35	The Qualities of <i>Eco-Designed Products</i>	101
36	Food Saving Apps	122
37	Perspectives on the Food Systems in Sweden	122
38	A Sample of Blockchain-based Supply Chain Companies	127
39	Share of CO ₂ eq Emissions by Type of Transport Globally	128
40	Global Overview of Superapps	129
41	Not Quite Superapps	132
42	Platform Economy Concepts	133
43	Examples of Cities and Countries That Share Data Openly	137
44	Examples of CO ₂ Visibility in Google's Products	139
45	Types of Nudge	139
46	Ant Forest Assisted Tree Planting - Growth Story	140
47	Modes of Interaction	142
48	A Selection of Personal Sustainability Apps	147

49	The R Strategies	149
50	Companies With Carbon Labels	151
51	Organizations Who Certify Carbon Labels	152
52	Digital Product Passport Goals	152
53	Human-in-the-Loop Apps	159
54	Problems with contemporary AIs	164
55	AI-based Assistants	165
56	7 Years of Rapid AI Model Innovation	166
57	Replika AI Users and AI Friends	172
58	Areas of Focus in Conversational AI Development	174
59	AIs in Different Forms of Media	176
60	AI Assistants	179
61	Criticism of Generative UI	182
62	GenAI Use Across Fields	184
63	Microsoft's Heuristics	185
64	Common Social Media UI Parts	186
65	UX Tenets in AI	187
66	Simple Goals for AI	188
67	Anthropomorphic AIs for Human Emotions	192
68	Social Cues in AI Conversations	195
69	Comparative Data on Investing Apps; compiled from (Gyuriczki & Szládek, 2025; Interactive Brokers, 2025a, 2025b; Lightyear, 2025; Revolut, 2020, 2025; Trahant, 2022)	201
70	Climate Experts on Company Boards	215
71	Banking transformation strategies from (Jim Boehm et al., 2021)	220
72	GenAI usage for comprehensive risk management from cyber- to climate threats in modern banking as per (Rahul Agarwal et al., 2024).	223
73	Comparing Payments Apps; Data compiled from (Focus Taiwan, 2025; PXPay Plus, n.d.; Taiwan News, Mar. 14, 2025 11:31)	229
74	Comparing Investing Apps; Data compiled from (Lightyear, n.d.; Monzo, 2023; “Mos - The Money App for Students,” n.d.; Nubank - <i>Finalmente Você No Controle Do Seu Dinheiro</i> , n.d.; Selma – Your Finances Done Right, n.d.; “Ziglu The Fast, Simple Way to Buy and Sell Crypto, with No Hidden Fees.” n.d.).	234
75	Established consumer payment giants, none of which has a specific sustainability focus.	236
76	Growth companies in fintech, none has a sustainability focus.	237
77	Among up-and-coming startups there are some examples of sustainability-focused apps.	239
78	Example sustainable loyalty schemes	243

79	Comparative data on needed climate investment and other valuable assets; all figures in Trillions of USD (Aaron O'Neill, 2023; Blockworks, 2023a, 2023b; M. Fox, 2023; Grand View Research, 2021; IMF, 2023a; McKinsey & Company, 2023; Oguh & Oguh, 2023; Rao, 2023; SIFMA, 2023; S&P Global, 2019; Statista, 2021, 2023b; Stephanie Aaronson & Aaron Tilley, 2023; Thinking Ahead Institute & Willis Towers Watson, 2023; Trucost & TEEB for Business Coalition, 2023; US Treasury, 2023)	245
80	Investment Types	248
81	Green Investment Platforms	251
82	Circular Economics in Amsterdam's Food Industry (Circle Economy, 2021)	265
83	Quantifying climate damage scenarios using integrated assessment models (T.- P. Wang & Teng, 2022)	270
84	Sustainability Certification Systems	275
85	Buycotts - Active Boycotts Against Companies	277
86	Data Sharing Archetypes defined by WikiRate.	280
87	Bottlenecks in Carbon Markets	281
96	Overview of the experts interviewed.	313
108	Design implications arising from the college chapter.	348
109	Design implications arising from the sustainability chapter.	349
110	Design implications arising from the design chapter.	350
111	Design implications arising from the AI chapter.	351

4 LIST OF SYMBOLS AND ABBREVIATIONS

Some of the key terminology used in my thesis presented in a concise format.

1. AI - Artificial intelligence, a field of computer science and an umbrella term focused on a wide range of approaches to automation
2. UX - User experience, a field of study and operational approach focused on how humans experience using systems
3. AX - Algorithmic experience, a proposed category of user experience, that is focused on interfaces between AI algorithms and humans
4. UI - User interface, such as in a mobile app, however increasingly audio, video, etc
5. XAI - AI user experience, interaction design applied to AI concerned with how does a person or a group of people interact with the AI
6. Fintech - Financial technology, the application of technology (usually AI), to classic financial services, such as payments
7. ESG - Environmental, Social, and Corporate Governance, a new set of metrics proposed by the European Union, and adopted worldwide, to assess business and financial assets
8. AI Assistant - software system providing the user with personalized suggestions based on machine learning algorithms
9. Financial Advisor - a human financial specialist providing customized financial advice, including investment advice and services to a client
10. ML - Machine learning, a tool within the larger AI umbrella to enable computers to learn from large sets of data, which may be labeled (by humans) or un-labeled (auto-labeled)
11. HCI - Human-computer interaction, a field of study to improve human experience with information technology
12. OEM - Original equipment manufacturer, a company making products for another company that markets and sells such products under their own brand
13. API - Application Programming Interface, a method for software agents to exchange information in various forms of data: the basis for contemporary online services
14. EPR - Extended Producer Responsibility
15. SDGs - Sustainable Development Goals, a set of targets agreed upon by the nations of the world
16. LLM - Large Language Models
17. Vector Databases - specialized data storage for mathematical language embeddings in multi-dimensional space helpful for clustering similar concepts
18. CO₂eq - CO₂ equivalent greenhouse gases
19. GHG - Greenhouse gases

20. PD - Participatory Design
21. VCM - Voluntary Carbon Markets
22. Hedge Fund - pooled investment fund
23. DAO - Decentralized Autonomous Organization
24. Zero Waste - according to Zero Waste International Alliance: “*conservation of all resources by means of responsible production, consumption, reuse and recovery of products, packaging and materials without burning, and with no discharges to land, water or air that threaten the environment or human health*” - (Kalle et al., 2022)
25. ESPR - Ecodesign for Sustainable Products Regulation
26. NFRD - Non-Financial Reporting Directive
27. CSRD - Corporate Sustainability Reporting Directive
28. EUDR - European Union Deforestation Regulation
29. Product Stewardship
30. Extended Producer Responsibility

5 INTRODUCTION

How can college students find sustainable companies? Furthermore, if given appropriate tools, could college students leverage their purchasing power to reward sustainable companies? Why is this important to research now? Young people should invest in their future and younger generations like services with a green, eco-conscious focus. Given our combined power (I'm a Millennial) with Generation Z, we are willing to pay more for sustainable products. Does Individual Climate Action Matter?

My research describes the process of designing an AI companion for college students to help with sustainable shopping, saving, and investing. Money spent shopping, saving, and investing in sustainable companies serves as an incentive to adopt more sustainable practices. If used wisely, money can reward companies for becoming more sustainable. Encourage the least sustainable companies to improve their performance, raising the overall baseline. Facilitate the formation of communities centered around environmental stewardship. Build closer relationships with sustainability.

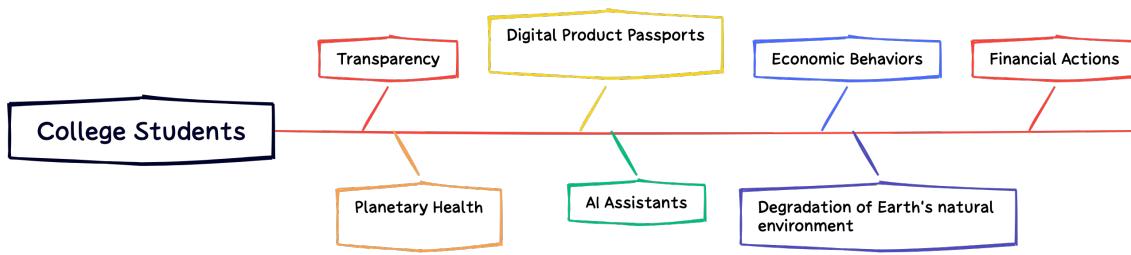


Figure 1: College Students

5.1 Relevance and Research Gap

My research addresses the “*attitude-behavior gap*” among Taiwanese college students in taking sustainable financial action. In general, Icek Ajzen’s *Theory of Planned Behavior* frames the gap between attitude and behavior by showing that (1) attitude, (2) perceived social norms, and (3) perceived control, must all converge, before intention can translate into any action (Ajzen, 1991) - in this case, taking sustainable financial action.

In terms of the global context, the convergence of the following 5 trends makes my research timely in 2025.

Table 1: Trending global narratives.

Trend	Direction
Environmental degradation	Worsening

Trend	Direction
Interest in sustainability among young people	?
Intergenerational money transfer; in some countries relatively young people have money	?
Availability of sustainability tools such as ESG, B Corporations, Green Bonds, etc, among metrics and instruments	Increasing
Availability of generative AI-based user interfaces (UIs)	Increasing
Democratization of Financial Markets	Increasing

5.2 Background

I grew up as an avid science fiction reader, which influenced my outlook towards future possibilities. In particular, the Star Trek universe had an imaginary portable device called a *tricorder* (fig. 1) enabling scientists to scan anything for insights. Be it precious minerals inside a cave or scanning the human bodies for medical data, its sensors would show up with some useful data. In daily life, I would love to have such a device for consumer choices and financial decisions - to know what to buy and which businesses to support with my money and approval.



Figure 2: Captain Sulu using a Tricorder (Star Trek) - Photo copyright by Paramount Pictures

While a *tricorder* is still science fiction, technological advancements are getting closer and closer to producing something similar. AIs are already integral to many parts of our lives, with computer models producing increasingly useful outputs. The proposal for this thesis was first written using

Google's and Apple's voice recognition software in 2020, and later switching to OpenAI's *Whisper* model, allowing me to transcribe notes with the help of an AI assistant. As a foreigner living in Taiwan since 2019, I relied on AI-based tools for many aspects of my life: speaking, moving, finding food and services. When writing in Chinese, Apple's text prediction algorithms translate pinyin to 漢字 and show the most likely character based on my previous writing, Google's maps find efficient and eco-friendly routes and recommend places to eat and ChatGPT provides statistically probable advice from the sum of human knowledge. Even when we don't realize it, AI is helping us with many mundane tasks. While it takes incredibly complex computational algorithms to achieve all this in the background, it's become so commonplace, we don't even think about it. From this point of view, another AI assistant to help students with choosing more eco-friendly businesses - to shop, save, and invest - doesn't sound so much of a stretch.

5.3 Motivation

Environmental degradation is increasingly affecting human lives - and it's largely driven by manufacturing processes - of the products we consume daily. From resource extraction in the linear economy (mining raw materials and drilling for fossil fuels) to chemical processes (causing contamination and pollution of the air, water, and soil) to waste generation and greenhouse gas emissions, industries transform the natural world into consumer products. While industry practices have improved since the industrial revolution in the 19th century, and continue to improve, it's possible to further improve standards of production and raise the global baseline for sustainability, given enough societal pressure to do so.

Nonetheless, without easily accessible and reliable data, it's difficult to know which company is more sustainable than another. As consumers and investors (even if only through passive ownership of savings), we don't really know much about enterprise production practices, unless we spend a lot of time looking at the numbers, which may be costly to access (for example ESG reports are expensive), and mostly rely on our governments and international bodies to keep us safe. Or just look at the brands themselves - and pick the ones which we like.

5.4 Objective

The study presents design research for developing an AI companion to help college students find sustainable companies for shopping, saving and investing. The major contribution of my study is an interactive artefact (a prototype) informed by design research.

5.5 Demographics

The research focuses on young adults, specifically Taiwanese college students studying in Taiwan.

Criteria	
Location	Taiwan
Population	College Students
Count	900

Experts (finance, design, sustainability).

Criteria	
Location	Global
Population	Experts
Count	7

5.6 Research Questions

My research attempts to answer the following questions.

Table 4: Research Questions

Question	Methods
What design considerations should be addressed when designing an AI companion for college students integrating sustainability and finance?	Literature Review and Expert Interviews
How can AI companions support college students with sustainability knowledge in the context of financial decisions?	Literature Review, Expert Interviews and Survey of College Students
What AI companion features do college students prioritize as the highest?	Survey of College Students and Prototype Testing

5.6.1 Why These Research Questions?

Lens	RQ1: Design Considerations	RQ2: Support Mechanisms	RQ3: User-Priority Features
Level of Abstraction	High-level and comprehensive	Mid-level (mechanisms)	Concrete and granular
Core Focus	<i>What should I keep in mind while building?</i>	<i>How does the companion actually help students learn and decide?</i>	<i>Which specific features matter most to students?</i>

Lens	RQ1: Design Considerations	RQ2: Support Mechanisms	RQ3: User-Priority Features
Primary Stakeholder Outputs	Designers / Developers Design guidelines, UX principles, tech constraints, ethical guardrails	End Users (College Students) Framework of nudges, learning aids, information flows.	End Users (College Students) Ranked feature list, must-have vs nice-to-have.
Data Sources	Literature Review and Expert Interviews	Literature Review, Expert Interviews and Survey of College Students	Survey of College Students and Prototype Testing

6 METHODOLOGY

6.1 Research Design

(Baytaş, 2020) categorizes design research into three modes: (1) conducting research to inform design decisions, (2) studying designs to generate knowledge, and (3) using design itself as a means of inquiry. My research is of the 1st category, aiming to make better design decisions for my sustainability-focused financial app. When developing my research design, I relied on the advice of (Christian Rohrer, 2022) to decide when to choose which user experience research methods.

To knit together the themes of youth finance and sustainability, with the help of interaction design and AI, this study adopts the *Theory of Planned Behavior* (TPB) as its primary analytic frame used to organize the overall results from a theoretical point of view. TPB states that the strength of a person's intention depends on three belief clusters: (1) a cognitive and affective attitude toward the act, (2) perceived social norms, and (3) perceived behavioral control (Ajzen, 1991).

By foregrounding TPB I can interpret both the adoption of a financial AI companion and the subsequent shift toward sustainable shopping, saving, and investing with a single set of constructs. (Hagger & Hamilton, 2025) extensive meta-meta-study (study of several underlying meta-studies) summarize 40 years of TPB research, showing strong, consistent effects of *attitude*, *subjective norm*, and *perceived behavioral control* on *intentions*, and of intentions on behavior; the effect is found to be robust across various behaviors, populations, and study designs.

The graph below shows the basic structure of TPB.

Additional theoretical lenses used in my work include the following.

Table 6: Theoretical lenses found in my research.

Theory / Framework	Key Contribution	Sections Where Used
Theory of Planned Behaviour (TPB)	Core explanatory model linking attitudes, norms, control and intention to sustainable finance behaviour	Overall
Planetary Boundaries	Situates individual financial choices within global ecological thresholds	Sustainability
Circular Economy	Provides closed-loop design principles for product-passport features	Design / Money
Triple Bottom Line (TBL)	Connects profit, people and planet in ESG analysis	Money

Theory / Framework	Key Contribution	Sections Where Used
Technology Acceptance Model (TAM)	Explains perceived usefulness / ease of use for AI companion	AI
Fogg Behaviour Model (FBM)	Maps motivation-ability-trigger nudges in UI	Design
Heuristic–Systematic Model (HSM)	Explains quick credibility heuristics vs. deep cues	AI
Algorithmic Experience (AX) model	Describes how users form mental models of opaque AI	AI
Choice Architecture / Behavioural Nudges Systems Thinking	Frames defaults and eco-filter prompts in super-app context Positions app interventions within broader supply-chain loops	Design Design
Ecological & Doughnut Economics	Critiques GDP-only metrics; motivates regenerative finance lens	Money
Participatory / Multi-species Design	Broadens stakeholder set to non-human actors	Design
Service Design for Sustainability	Maps end-to-end user journey (repair, swap, delivery)	Design
Earth-System Law	Links micro-level nudges to macro-level legal frameworks	Sustainability

6.2 Research Methods

Overview of research methods.

Group	Task
Experts (Finance)	Interview
Experts (Design)	Interview
Experts (Sustainability)	Interview
Target Audience (College Students)	Survey
Target Audience (College Students)	Prototype Testing

This mixed-method research design is divided into three stages.

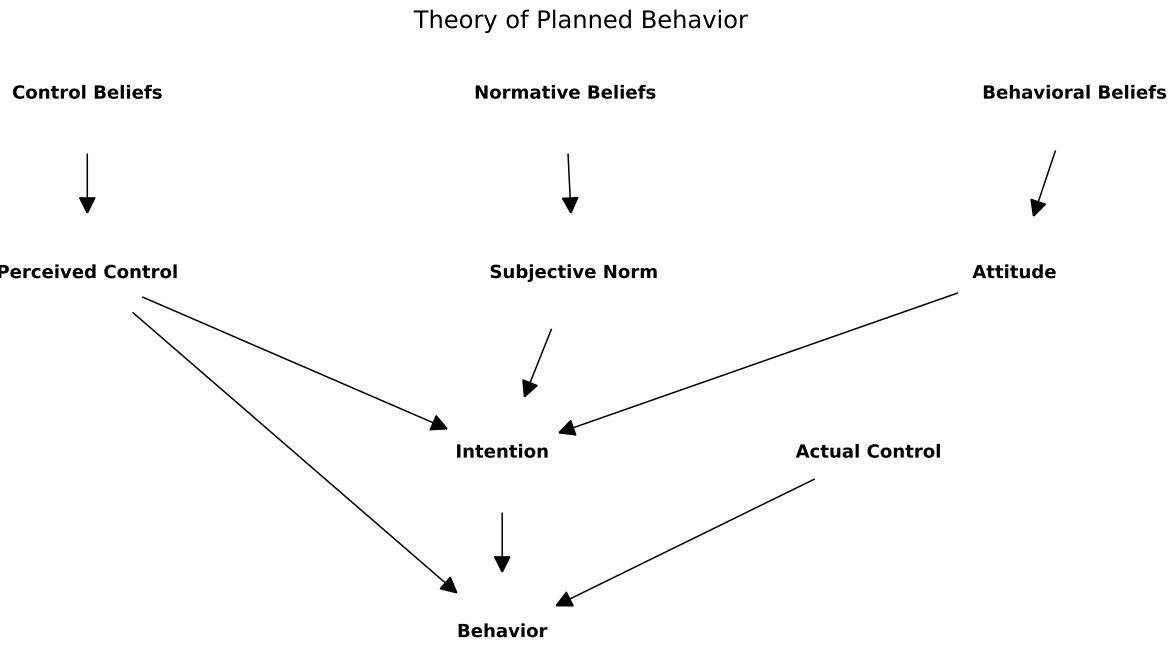


Figure 3: Theory of Planned Behaviour

6.2.1 Phase One - Qualitative Research

My purpose for the first qualitative stage is to explore the general themes arising from the literature review related to the design of AI advisors for investing. I identified specific user experience factors, through interviewing experts in financial technology and user experience design and reviewing existing applications on the marketplace. At this stage in the research, the central concept being studied was defined generally as expectations towards a sustainable investment AI advisor.

I started with literature review, which led into expert interviews (there were many questions arising from the literature). I identified key concepts from expert discussions and gained exposure to their industry insights.

The qualitative research methods employed in the first stage of the research design enables me to explore concepts arising from literature review further, using a more open approach, without limiting the conversation only to pre-ascribed notions. The strength of the qualitative approach in the first stage is to encourage the discovery of new ideas, not yet common in literature and potential user experience factors related to sustainable investing and user experience.

Sampling

My qualitative sampling structure used non-probability snowball sampling, with the following criteria: targeting financial industry, fintech, design, and sustainability experts; located every-

where.

Methods

I conducted exploratory research in English using semi-structured interviews recorded online and offline. I talked to 5 experts over video call, 1 expert face-to-face, and 1 expert over WhatsApp voice messages; 6 interviews were conducted in English and 1 in Portuguese. I recorded audio and video, transcribed the conversations. I used OpenAI's o3 model to translate the Portuguese interview to English. I then performed thematic analysis across all the contents, leading to a *wish list* of features.

Interview Mode	Number of Experts	Language	Recording Method
Video Call	5	English	Audio & Video
Face-to-Face	1	English	Audio & Video
WhatsApp Voice Msgs	1	Portuguese	Audio

Thematic analysis coding was developed using Atlas.ti “Intentional AI Coding” feature, using the following prompt:

“How do industry experts describe their design and sustainability principles, AI and technology strategies? What common language emerges between design, sustainability, finance, and AI? Identify passages where experts link system thinking, transparency, simplicity, feedback loops, and long term impact across design, sustainability, AI, and finance.” - Prompt for Atlas.ti “Intentional AI Coding”

Specific questions generated by Atlas.ti from the prompt, which guide the AI coding.

Question	Category
How do industry experts describe their design and sustainability principles?	Design Principles
What AI and technology strategies do industry experts employ?	AI Strategies
What common language emerges between design, sustainability, finance, and AI?	Common Language
How do experts link systems thinking across design, sustainability, AI, and finance?	System Thinking
In what ways do experts emphasize transparency in their discussions on design, sustainability, AI, and finance?	Transparency
How is simplicity articulated by experts in relation to design, sustainability, AI, and finance?	Simplicity
What role do feedback loops play in the experts' frameworks for design, sustainability, AI, and finance?	Feedback Loops
How do experts define long term impact in the context of design, sustainability, AI, and finance?	Long term Impact

Conceptual Framework

The conceptual framework map presents the key concepts arising from the literature review thus far in the research process. I'm using these concepts when developing interview strategies for phase one of the research, developing the survey questionnaire for phase two, as well as for building the Green Filter AI Companion for young adults at the final stage of the process. However, I expect the conceptual framework to further evolve with additional findings while conducting my research.

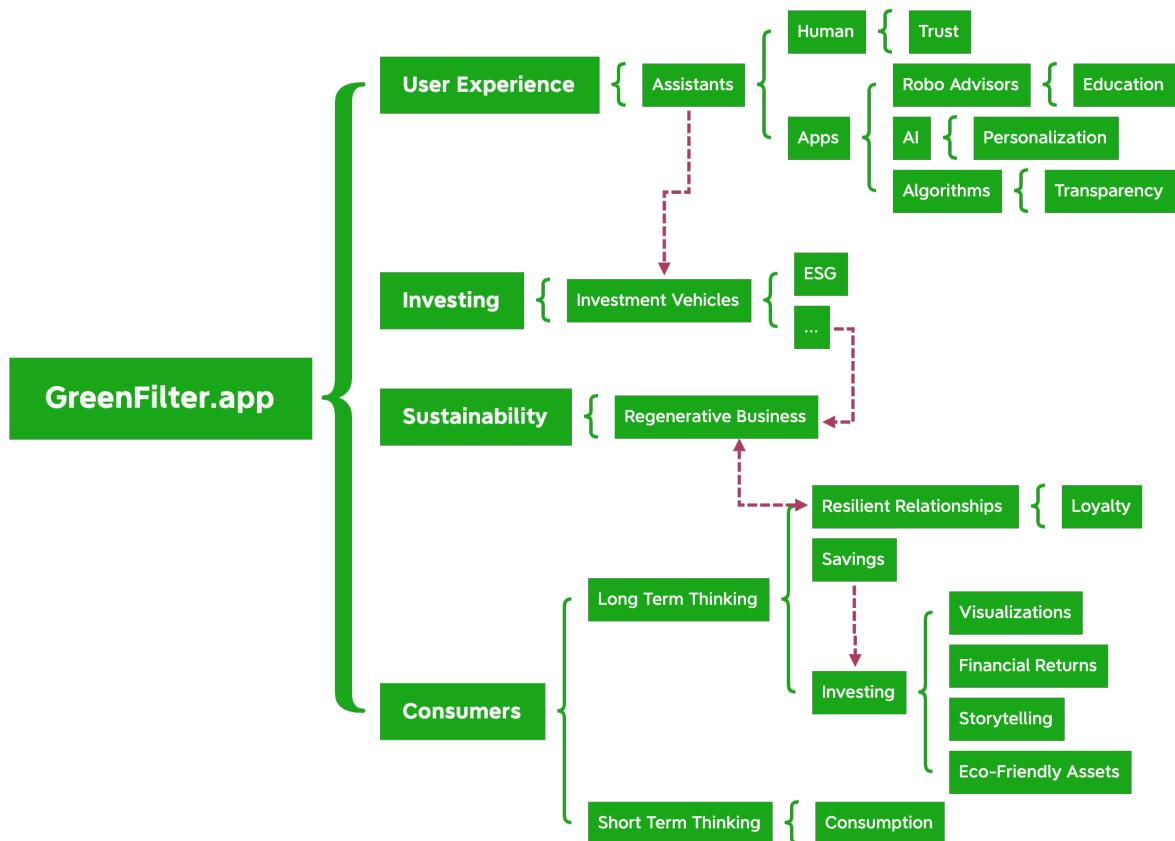


Figure 4: Concept map

Conceptual Model

Initial version of the concept map focused on the app itself.

Current concept map focusing on sustainability:

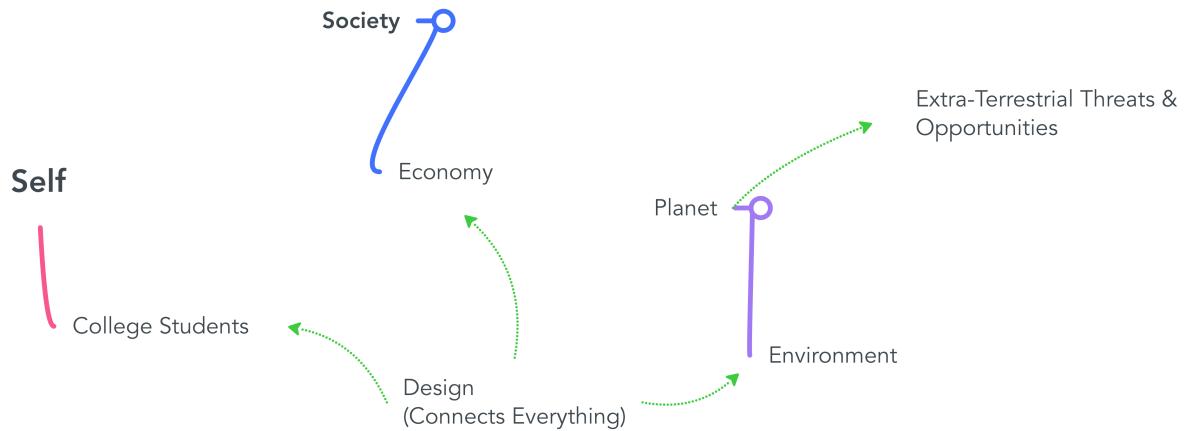


Figure 5: Overall Concept Map

6.2.2 Phase Two - Quantitative Research

I then proceeded to the second, quantitative stage, informed by the previously identified factors, and prepared a survey to understand potential users' preferences, including a Likert scale, a choice experiment, and a selection of proposed features, focusing on the preferences of the potential users in Gen-Z, aged 18-29, living in Taiwan.

Sampling

My quantitative sampling structure uses a judgmental criterion: adults aged in Gen-Z (18-29), located in Taiwan, surveyed using a Chinese-language online survey.

Methods

Likert: The survey includes a Likert scale between 1 to 5 to validate key findings from the first stage of the research by assessing responses to statements regarding the app's design, features, and other criteria that may still emerge.

Choice Experiment: The survey includes a *choice experiment* between different sets of potential features available when communicating with the sustainable finance AI companion.

Survey Development and Expected Findings

In December 2020, in preparation for the final version of the survey, I ran a preliminary questionnaire, testing open-ended and close-ended questions, as way to prepare for the proposal of this research. I conducted a preliminary round of face-to-face interviews using 21 open-ended, probing questions and a convenience sampling of NCKU foreign students ($n = 12$) on campus between ages 19 and 29. The interviews were conducted in English and lasted between 9 and 21 minutes; they gave me some initial feedback on my research idea, the respondents' daily routines, app usage, and feelings towards financial questions, including investing, relationship with nature, and environmental sustainability.

This preliminary version of the survey was only used to develop the questionnaire itself and the data collected (even though the recorded audio was transcribed), is not part of the research results. These preliminary conversations led me to emphasize more on the financial journey of the user, i.e. to consider the importance of the shopping, savings, and payments, with the apps students already use daily, serving as an entry point to becoming an investor (this approach later became known as embedded finance). I expected my future research findings to confirm this initial idea and to offer diverse ways and examples of what that path could look like in practice.

I then proceeded to change my target audience to Taiwanese students and developed the survey to include more specific questions, including more close-ended multiple-choice varieties.

Final Survey: Data Collection

For the actual survey, I developed 63 close-ended and open-ended questions. For survey distribution, I adopted a face-to-face method to increase response rates, distributing flyers to students on college campuses, canteens, and classrooms, getting verbal permission from educators in their classrooms to distribute the survey flyer. Similarly to the approach take by (C.-H. Liu et al., 2023), I distributed the survey flyer at universities located in the Northern, Soutern, Central, and East regions of Taiwan. The flyer included a colorful AI-generated visual with a futuristic game-like female figure, and the title “climate anxiety survey” in Chinese, as well as a website link (ziran.tw) and scannable QR-code.

The survey only included questions and descriptions in Chinese. I have used the Claude 3 Opus model to translate them to English for this table.

Table 10: 36 Likert Fields included in the survey

Original Question in Chinese	English Translation
如果你/妳懷疑你/妳要買的番茄可能是由強迫勞工（現代奴隸）採摘的，你/妳仍然會買它嗎？	If you suspect that the tomatoes you are going to buy may have been picked by forced labor (modern slaves), would you still buy them?
你/妳關心食安嗎？	Do you care about food safety?
你/妳 7 年內買車嗎？ <input type="checkbox"/>	Will you buy a car within 7 years? <input type="checkbox"/>
你/妳 7 年內買房嗎？ <input type="checkbox"/>	Will you buy a house within 7 years? <input type="checkbox"/>

Original Question in Chinese	English Translation
你/妳購物時知道產品環保嗎？	Do you know if the products are environmentally friendly when you shop?
你/妳覺得認證環保的公司更好嗎？	Do you think companies certified as environmentally friendly are better?
你/妳支持肉稅嗎？	Do you support a meat tax?
你/妳關心食用雞的生活嗎？	Do you care about the lives of chickens raised for food?
你/妳避免吃肉嗎？	Do you avoid eating meat?
你/妳覺得你/妳花錢會影響環境嗎？	Do you think your spending affects the environment?
你/妳會對金錢感到焦慮嗎？	Do you feel anxious about money?
你/妳會對金錢很節儉嗎？	Are you very frugal with money?
你/妳會經常存錢嗎？	Do you often save money?
你/妳對自己的財務知識滿意嗎？	Are you satisfied with your financial knowledge?
你/妳投資會考慮環保嗎？	Do you consider environmental protection when investing?
你/妳覺得台灣的經濟目標是增長嗎？	Do you think Taiwan's economic goal is growth?
你/妳覺台灣的得環境退化是台灣的經濟增長的前提嗎？	Do you think environmental degradation in Taiwan is a prerequisite for Taiwan's economic growth?
你/妳覺得台灣的經濟增長有助於保護環境嗎？	Do you think Taiwan's economic growth helps protect the environment?
你/妳覺得經濟能不排 CO ₂ eq 也增長嗎？	Do you think the economy can grow without emitting CO ₂ eq?
你/妳覺得經濟增長有物質限制嗎？	Do you think there are material limits to economic growth?
你/妳會每天都用 AI 嗎？	Do you use AI every day?
你/妳會信任 AI 嗎？	Do you trust AI?
你/妳想要 AI 有個造型嗎？	Do you want AI to have a specific appearance?
你/妳喜歡待在大自然嗎？	Do you like being in nature?
你/妳擔心氣候變化嗎？	Are you worried about climate change?
你/妳對環境污染情況會感到焦慮嗎？	Do you feel anxious about environmental pollution?
你/妳知道許多植物和動物的名字嗎？	Do you know the names of many plants and animals?
你/妳感覺自己和大自然很接近嗎？	Do you feel close to nature?
你/妳努力實踐低碳生活嗎？	Do you strive to live a low-carbon lifestyle?
你/妳想做更多環保事嗎？	Do you want to do more for environmental protection?
你/妳對環境相關政治議題有興趣嗎？	Are you interested in environmental political issues?
你/妳信任碳排放抵消額度嗎？	Do you trust carbon offset credits?

Original Question in Chinese	English Translation
你/妳的環保行動對環境保護有效果嗎？	Do your environmental actions have an effect on environmental protection?
你/妳想在行業內推環保嗎？	Do you want to promote environmental protection within your industry?
你/妳得自己對新觀念開放嗎？	Are you open to new ideas?
你/妳的大學對可環保性支持嗎？	Does your university support environmental sustainability?

Respondents who remained outside the survey parameters were allowed to answer the survey however their responses were disregarded from the data analysis. References were stored in the Zotero paid version with 6 GB storage. Bibtex and Better Bibtex were used to export the references to the .bib format consumable by the Quarto scientific writing system.

6.2.3 Phase Three - Qualitative Research

In the third and last phase, I returned to qualitative methods, to further validate the quantitative findings from stage two, by building a prototype of the sustainable investing AI companion, taking into account insights gathered in the previous stage. Here my focus was on operationalizing the gathered insights into a prototype that users can experiment with. I designed and refined a prototype of the personal sustainable finance AI assistant. I used face-to-face interviews to discuss the prototype, and conducted a thematic analysis of the discussions' recordings, leading to further validation of previously gathered data and changes in the prototype. The gained insights, accompanied by the app prototype, which embodies my findings, are the final outcome of my research.

Sampling

The phase three sampling structure used a judgmental criterion:

- Age Gen-Z cohort
- Located in Taiwan
- Using Chinese for discussion.

Individual face-to-face interviews were organized at universities around Taiwan. Because in-person presence is required in this stage, the prototype will only be tested by potential users physically present in Taiwan. To avoid convenience sampling, I posted online ads in Chinese and reach out to varied student clubs to invite people who I don't know personally, to participate in a "sustainable AI application testing" (wording may change).

Methods

Face-to-face prototype testing. The strength of in-person is the ability to observe potential users, where knowledge can be exchanged directly. The interviews were recorded and transcribed. Finally, I performed a thematic analysis of the interview transcriptions in order to validate previous findings, and open avenues for future research.

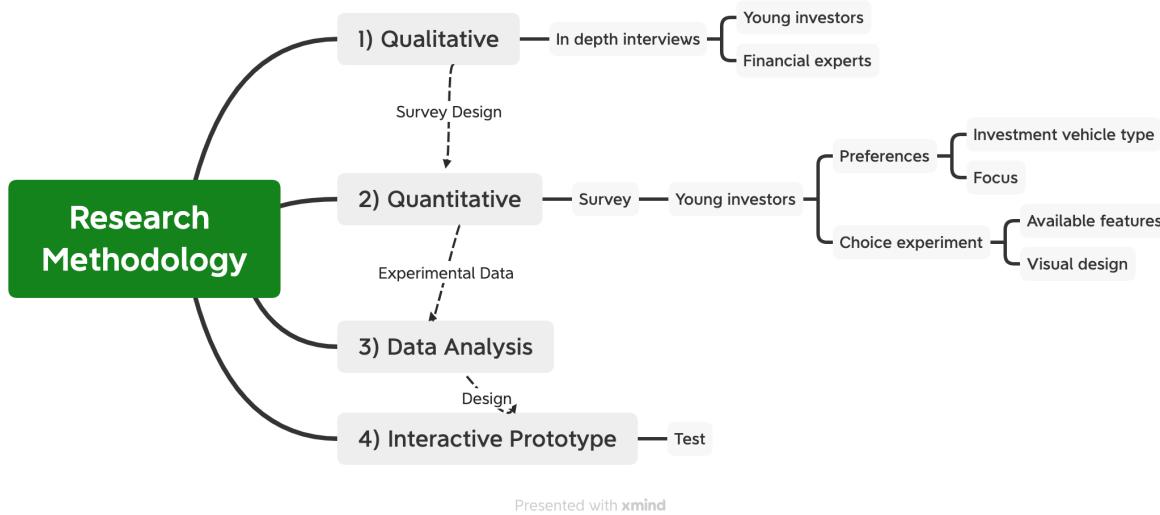


Figure 6: Overview of research methodology

Interview transcripts from Descript and Google Speech-to-Text model were combined using Gemini 2.5 Pro Experimental 03-25 (gemini-2.5-pro-exp-03-25) model.

Prototype Testing

Does the prototype match user needs?

Testing was the most difficult part of the thesis process.

- Testing with random people found at the university.
- Testing with experts.
- Testing with unknown people in the target audience.

App Testing Flow

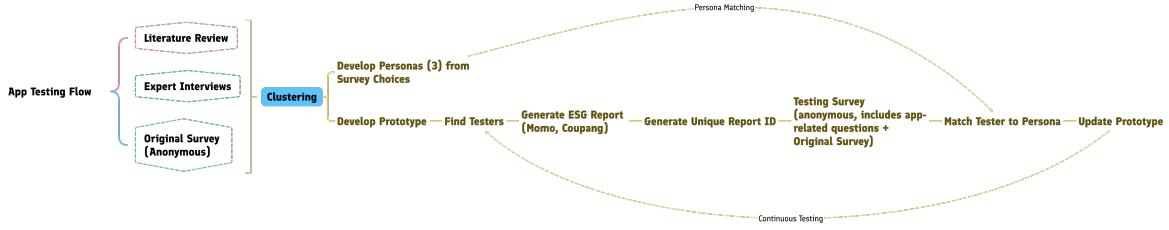


Figure 7: App Testing Flow

1st Wave of (Preliminary) Prototype Testing (Spring 2024)

The 1st wave of preliminary testing took place during 1 month from 2024 April 2 to May 2, 2024 at the NCKU campus. I found 8 anonymous participants at different NCKU locations, such as the student canteens and the medical library, confirmed the people I approached were Taiwanese students studying at NCKU, and then simply asked them to test my app, using my own laptop. I made use of *participant observation* and took notes myself. There was no audio or video recording.

2nd Wave of (In Production) Prototype Testing (Autumn 2024 - Spring 2025)

The 2nd wave of testing took place from Autumn 2024 to Spring 2025 and was more comprehensive. I conducted in-person face-to-face testing individually with 32 students at 7 universities. Interviews were conducted in Chinese and transcribed and translated to English using Google Voice to Text AI as well as Describe AI.

Region	University	No of Testees
Taichung	國立中興大學 National Chung Hsing University (NCHU)	7
Chiayi	國立中正大學 National Chung Cheng University (CCU)	5
Tainan	國立成功大學 National Cheng Kung University (NCKU)	6
Tainan	國立臺南藝術大學 Tainan National University of the Arts (TNUA)	2
Tainan	長榮大學 Chang Jung Christian University (CJCU)	5
Tainan	南臺科技大學 Southern Taiwan University of Science and Technology (STUST)	5

6.3 Literature Review

The literature review branches out to 5 main directions and maps out relationships sources and the literature map, namely Taiwanese college students, generation-z demographics, sustainability, ecology, ecosystem services, EU legislation, sustainable finance, sustainable investing, savings, circular economy, economics, AI, existing sustainability, software, sustainability-related mobile apps (Apple iOS / Google Android), and web apps related to sustainable shopping, savings, and investing; apps using algorithmic interfaces (AI-based UI), design, UX/UI, service design, sustainable design, speculative design, interaction design, behavior change, nudge.

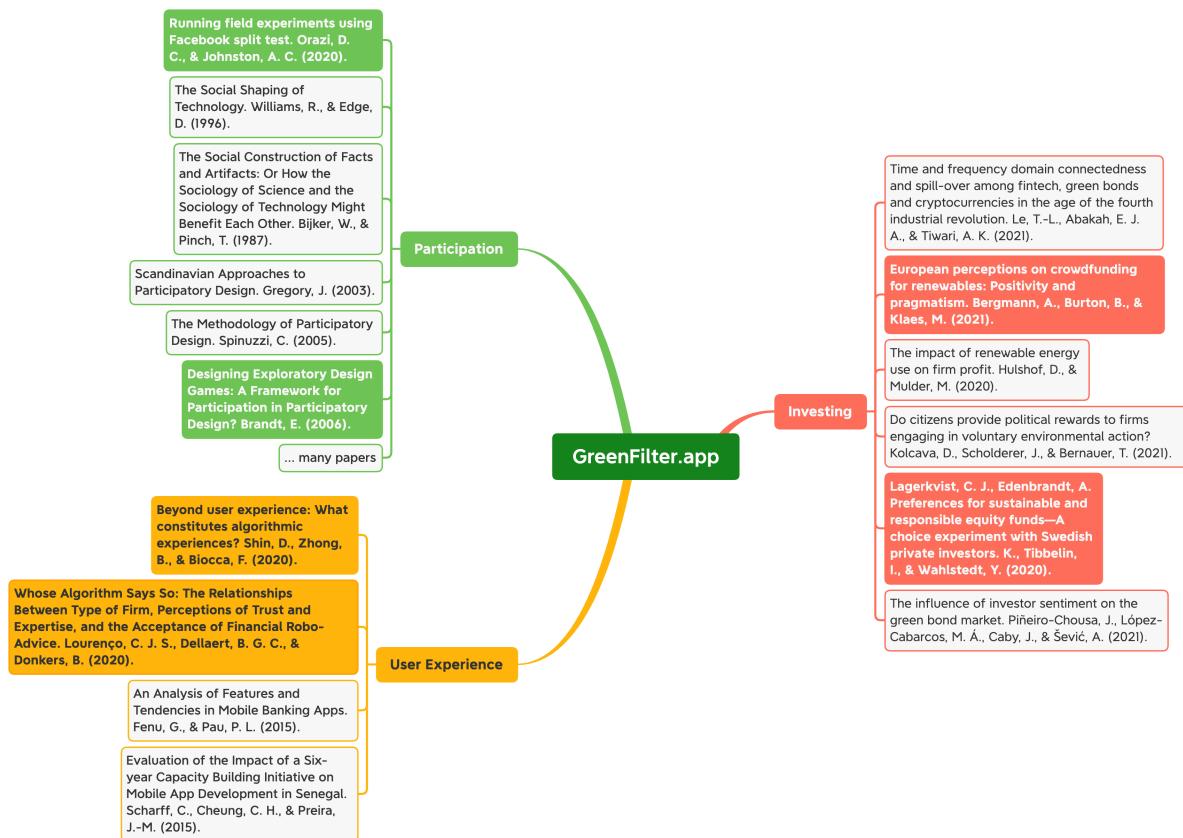


Figure 8: Example papers from the Literature Review

6.3.1 Goals

Given the ambition of designing an app to integrate sustainable shopping, saving, and investing, the goal of the literature review is to find insights about the target audience (Taiwanese college students), understand what kind of sustainable actions are effective, and translate these into specific ideas for app features. In order to keep track more easily, each literature review chapter provides *design implications* which are shown in the results section.

6.3.2 Sources

There is currently no single platform that hosts all scientific journals leading me to source scientific papers from

1. ScienceDirect
2. Nature
3. The Lancet
4. Oxford Academic
5. Semantic Scholar
6. JSTOR
7. Google search.

6.3.3 AI Use

Statement of AI Usage in Research: I'm a long time AI-assistant user.

AI was used for:

1. Search
2. Data comparison
3. Data science
4. Chart-building
5. Translation
6. Feedback
7. Editing
8. Spell-checking
9. Proofreading
10. Ranking citations' relevance to existing body of writing

AI was *NOT* used for writing.

A visualization of incremental changes (over a thousand Git commits) to the thesis can be seen on the GitHub repository as well as in the visualization below.

7 YOUNG ADULTS AND COLLEGE STUDENTS

7.1 Student Protests for Climate Justice: The World and Taiwan

In August 2018, Swedish high-school student Greta Thunberg skipped class to start a climate justice strike in front of the Swedish parliament Riksdag. In 2019, Time magazine named Thunberg person of the year for *creating a global attitudinal shift* towards the environment (Deutsche Welle, 2019). According to official statistics, 14 million participants joined her *Fridays for Future* strikes and the movement expanded to over 7,500 cities around the world (Fridays For Future, 2025). A survey 64 climate protesters from Norway, the UK, USA, and Canada, found the climate-justice activists are non-homogeneous group, displaying differing levels of factual knowledge about climate change, a broad spectrum of emotions from anger to guilt and hope, with diverse lifestyles, consumption habits, dietary shifts, and political leanings (Martiskainen et al., 2020).



Figure 9: Climate protest in Geneva on September 27th, 2019 – 1 year after the start of Fridays for Future

In Indonesia, which had large protests at the time, now 7 years later activists are expressing disillusionment and frustration with the lack of progress and upholding environmental promises. (Dwi Tamara, 2025) reports on a survey of 382 Gen-Z respondents in 5 areas of Jakarta, with 99.5% of the respondents having experienced extreme weather events first-hand, highlighting how respondents were affected by climate-related calamities, such as frequent flooding, which led to students missing school days, - education which they are entitled to. The Sharm El Sheikh

climate policy implementation (UNFCCC, 2023b) text refers to “human right to a clean, healthy and sustainable environment”. In Portugal, Estonia, and elsewhere young people have moved on from strikes to actually taking legal action at the courts suing companies for the environmental problems they have caused (Flor, 2024).



Figure 10: Climate protest in Taipei in May 2019 in front of the Democratic Progressive Party (DPP) headquarters

Meanwhile, as the climate-justice protests unfolded around the world, in Taiwan, the Fridays for Future protests were very small in scale, with no more than 100-200 people (Hioe, 2019). Meanwhile 2000 Taiwanese students joined the initiative by participating in environmental activities without protesting (Dai, 2019). This could in part be explained by Taiwanese culture being deeply influenced by Confucianism, valuing stability, hierarchical relationships, academic excellence, effort, and the role of education in achieving social status (R.-H. Xu, 2024). (H.-C. Chang, 2022) goes a step further to say that Taiwanese youth are effectively unable to stage formal “strikes” due to intersecting cultural constraints: obsession with academic performance, low awareness of legal strike rights, and parental intervention — so they instead reframe actions as campus “climate actions,” exercising agency within those limits. In addition, both Confucianism and Daoism, the prevalent belief systems in Taiwan, affect education to be *teacher-*

centered, where traditionally the role of students is to listen and absorb knowledge; in today's society, there's space to open opportunities for revisiting *dialogue-based* education, where students would be encouraged to take a more active role and gain ownership of their education (C.-C. Chang et al., 2023).

7.2 Taiwanese Educational System in Numbers

Taiwan has approximately 2 million young adults (Gen-Z, 18-26), and 73% percent of them are students attending tertiary education as of 2023, with a slow increase of enrollment over the past decade (Ministry of Education of Taiwan, 2024b).

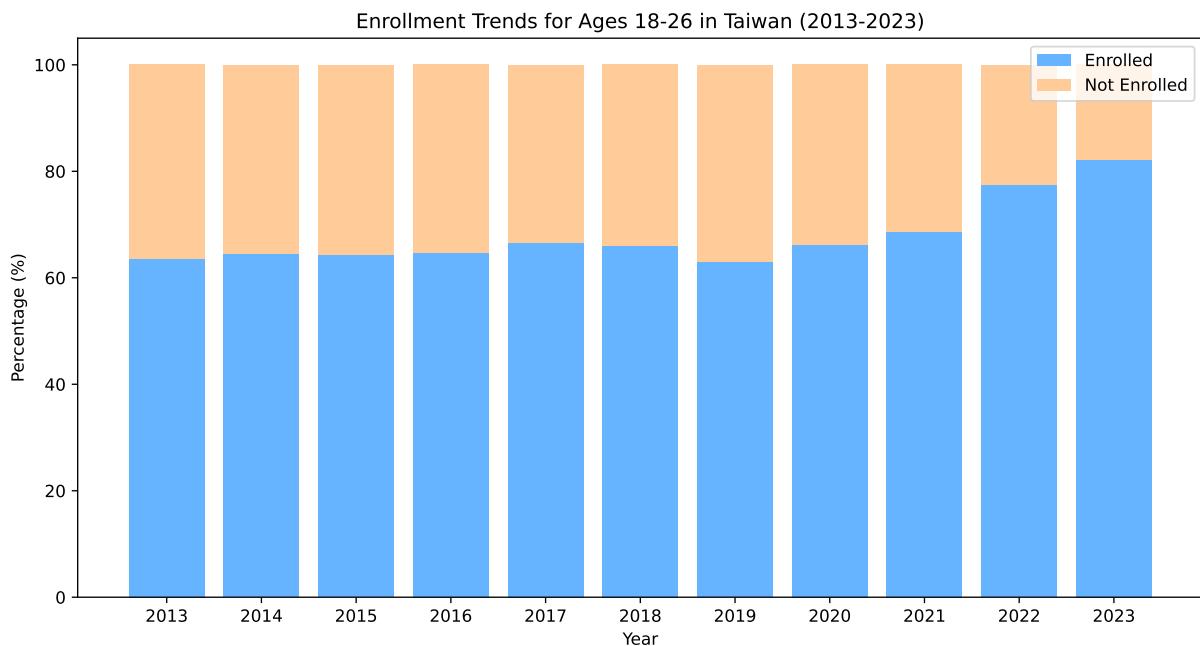


Figure 11: Enrollment in Taiwanese Higher Education

As of 2024, Taiwan has a total of 148 universities, colleges, and junior colleges (Ministry of Education of Taiwan, 2024c). Education funding is 4.26% of Taiwan's GDP in 2023-24 and has been on a decline for a decade (Ministry of Education of Taiwan, 2024a). Taiwan has an aging population and declining birth rates have forced several schools to close down (Davidson & Chi-hui, 2024; Goh et al., 2023).

While the overall number of students is declining, the share of international students is increasing.

7.3 Designing for College Students: Developing Personas

Students in the Generation-Z age bracket (abbreviated as Gen-Z or Zoomers) are born between 1997 and 2012 (Branka Vuleta, 2023). High levels of technology adoption worldwide (Deyan

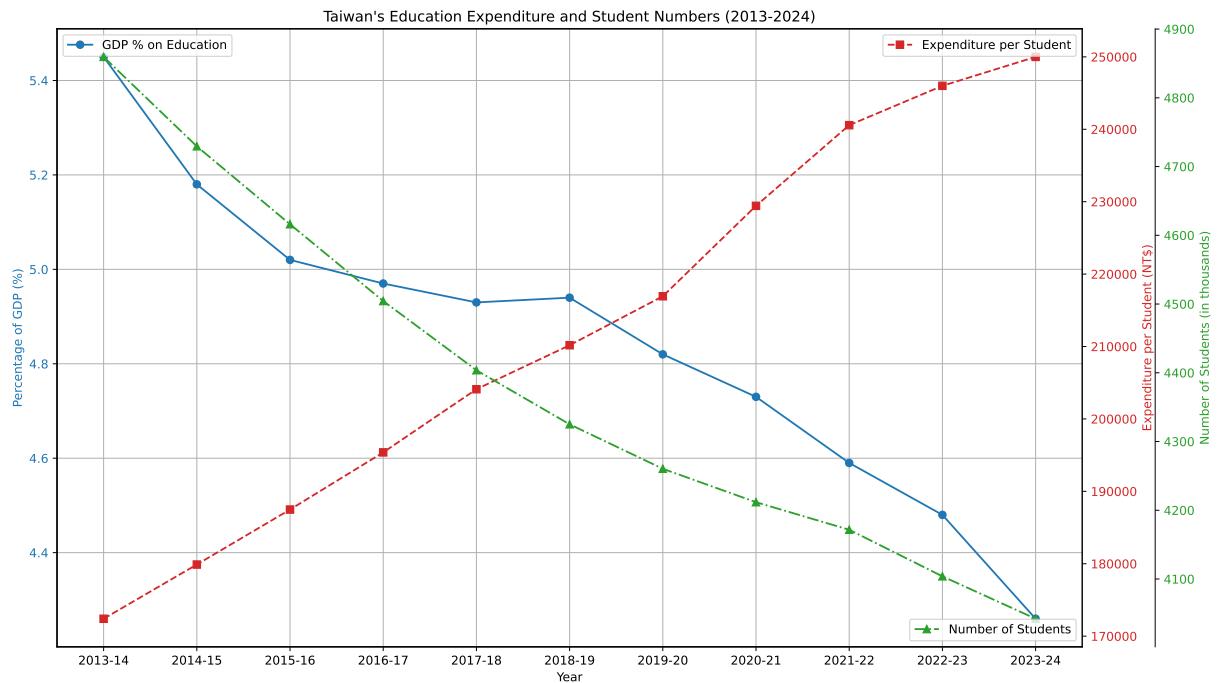


Figure 12: Funding for Taiwanese Higher Education

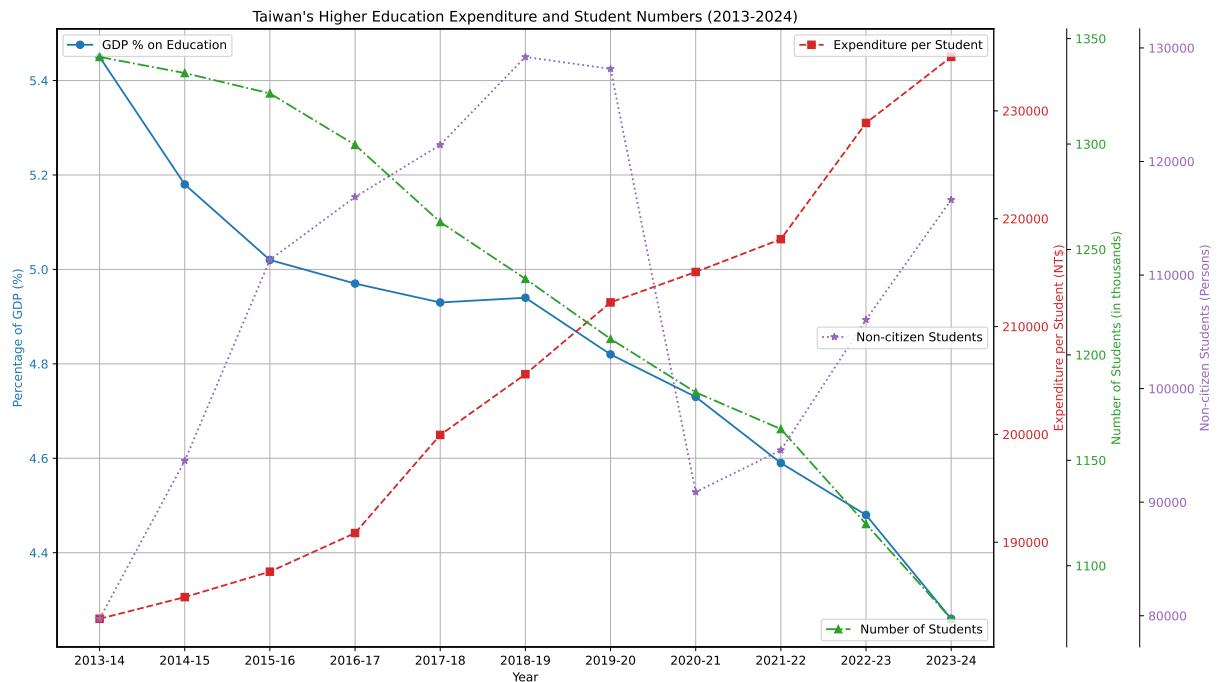


Figure 13: Demographics of Taiwanese Higher Education

Georgiev, 2023a). Over 98% of Gen-Z owns a smartphone while only 80% of the general world population does (BankMyCell, 2022; Global Web Index, 2017).

Designing for College Students: Developing Personas. User research makes extensive use of user *personas* to represent a group of people with similar attributes. Designers use personas to *articulate assumptions*, which, if used well, is useful for *user-centered design*, to create better products. Personas help to reflect on what kind of *biases* might exist in the design. Within the larger cohort of college students several different personas could be defined, for example grouping people by interests, knowledge, habits, levels of anxiety, and other attributes. Humans have a long list of cognitive biases, which a good design should take into account.

Many general observations can be made, however to create meaningful personas, these should be backed up with data. Students ride bicycles and scooters. Many circular economy service such as YouBike and transport sharing platforms like Uber are available in Taiwan. Many students live in dorms and shared housing, meaning their impact per square meter is low.

7.4 Taiwanese Youth in Global Context: Sustainability Attitudes From Eco-Friendly Diet to Climate Action

Addressing the Research Gap When it Comes to Taiwanese College Students. There's lack of scientific research when it comes to Taiwanese college students, not only in English or other foreign languages, but also in Chinese. Much of the research in Taiwan focuses on younger students, particularly those in primary and secondary schools. With regards to issues related to college students and sustainability, even less research is available. My project hopes to shed some light to how Taiwanese college students relate to sustainability.

(Kuo-Hua Chen, 2019) compares Taiwan to other countries in terms of *Postmaterialist Index Comparison*, noting Taiwanese society is materialistic.

World Values Survey

(Franzen & Bahr, 2024) measures “*mean environmental concern*” to look at decade-level changes in societal environmental attitudes across countries. Taiwan’s general attitudes have stayed almost the same (slight increase). The UK has had the largest jump in concern. Curiously, South Korea has had a slight decrease in concern. Slovakia and Russia were not very concerned with the environment a decade ago and are even less concerned now.

A large, global-scale study by (Anthony Leiserowitz et al., 2022) administered on Meta’s Facebook ($n = 108946$) reported people in Spain (65%), Sweden (61%), and Taiwan (60%) believe “*climate change is mostly caused by human activities*”.

The largest study to date, conducted by the United Nations across 50 countries, surveying 1.2 million people, distributed through mobile game ads, showed the majority of people agreeing climate change is an “emergency” (UNDP, 2021).

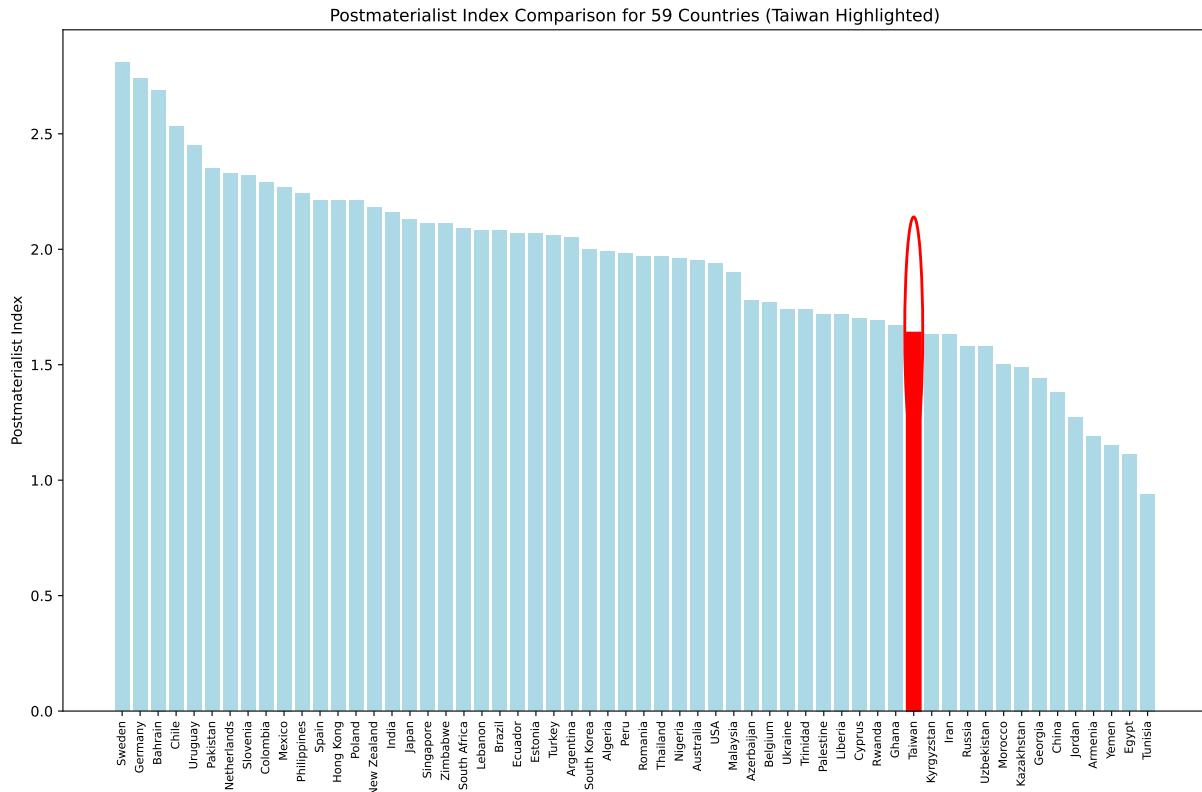


Figure 14: Postmaterialist Index across 59 countries (Taiwan highlighted)

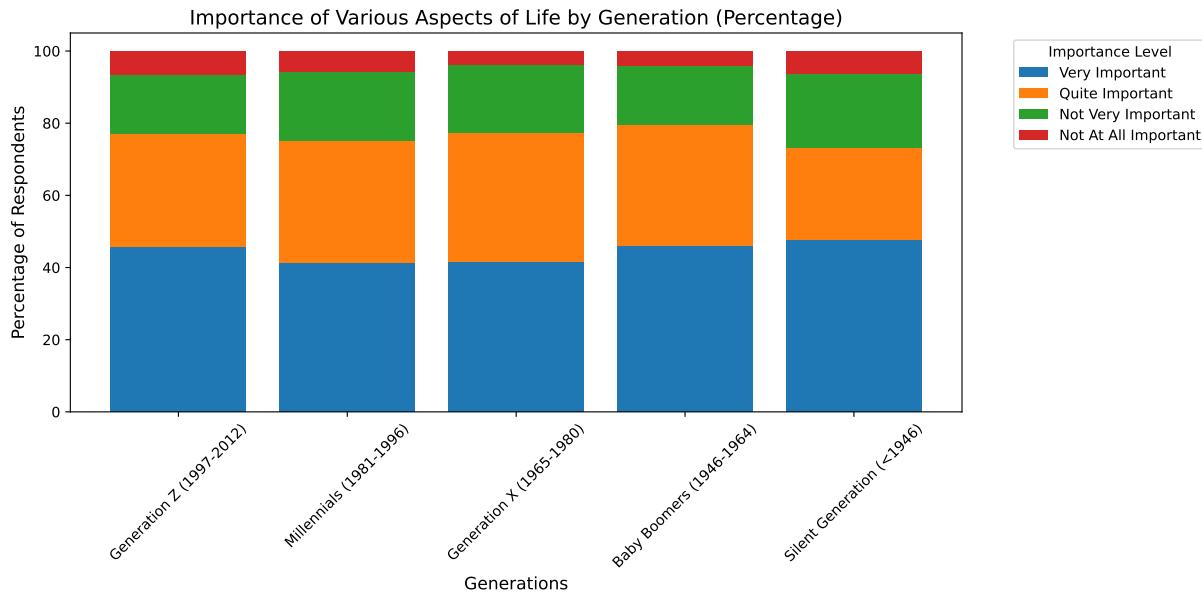


Figure 15: World Values Survey

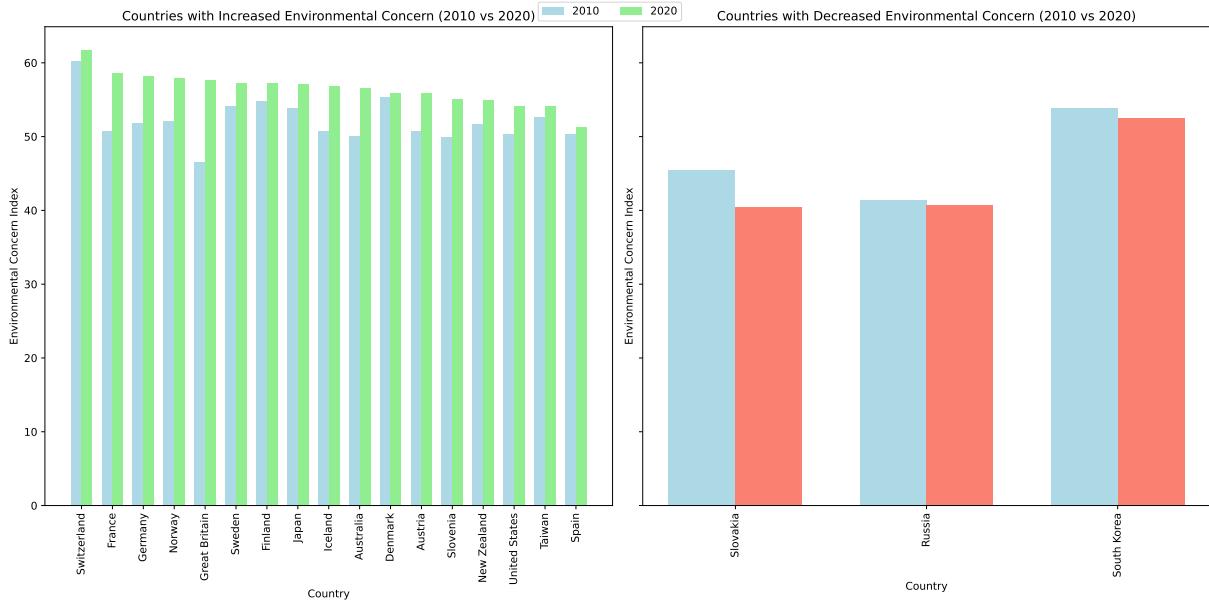


Figure 16: Global Attitudes Towards Climate Change

Table 12: 1.2 million UN survey responses to the statement “Climate change is an emergency”.

Age Group	Agree	Neutral or Disagree
18-35	65%	35%
36-59	66%	34%
Over 69	58%	42%

At the pre-university level, Taiwanese government has been promoting environmental education through a green school network; however surveys at middle school and high school level suggest there is no impact on *sustainability consciousness* among students in comparison with regular schools (Olsson et al., 2019). Rather, Taiwanese students are influenced towards environmental action by *group consciousness* (T.-Y. Yu et al., 2017). In contrast, (陳珮英, 2003) reports *good knowledge of sustainable development* topics among *junior high school students* in Da-an District, Taipei City (n = 596). (林建輝., 2009) similarly reports a positive attitude and good knowledge of environmental sustainable development among senior *high school students* towards in Taipei City (n = 328). Several Taiwanese studies also focus on the physical environment of school campuses, for example the sustainability of elementary school campuses (潘智謙 & Pan, 2006). Elementary-school teachers in Taichung (n = 536), have positive attitudes towards environmental education are positive, proactive and demonstrate high awareness; they have participated in many sustainability-related workshops (Liao et al., 2022).

At the university level, (C.-L. Chen & Tsai, 2016) reports a *positive attitude yet moderate knowledge* about *ocean sustainability* among Taiwanese college students (n = 825). (C.-H. Liu et al., 2023) studied sustainability behavior of Taiwanese University students, reporting the COVID-19 pandemic, in addition to prevalence of health issues, also spurred more attention on environ-

mental topics. In a similar vein, the devastating nuclear disaster in Fukushima, Japan, after 2011 earthquake, had an effect on Taiwanese energy and sustainability education (姚 & 侯, 2011). Taiwanese government launched the Sustainable Council in 1997 to promote of environmental and sustainable development; a survey of university-level teachers ($n = 100$) in central Taiwan (Taichung, Changhua, and Yunlin) shows a positive attitude toward environmental sustainability among teachers however implementation of environmental sustainability practices is from low to medium range (林美惠. & 莊, 2015). Taiwanese government has also launched funding for University Social Responsibility (USR) programs to train college students in social innovation and local revitalization (D. Chen & Chou, 2023; W.-H. Liu et al., 2022). In general, it could be concluded, Taiwanese students and teachers at all levels of education have a positive attitude towards sustainability (Note: which is not a very actionable finding).

Comparing college students' education for sustainable development (ESD) in Taiwan ($n = 617$) and Sweden ($n = 583$) found Sweden has a long history in environmental education while in Taiwan environment became a focus area with the 1998 educational reform (Berglund et al., 2020).

An older study in 5 university in Taipei and Taichung ($n = 255$) found 78.04% of respondents consumed beef in the month prior and were concerned with food safety, freshness, and quality (J. L. Hsu et al., 2014). (Thiagarajah & Kay, 2017) reports a general observation in their abstract (I was unable to access the full study) that most college students in all observed countries including Taiwan ($n = 534$) regarded "*plant-based diets to have health benefits*". A focus on a healthy and sustainable diet is important, as the prevalent trend among Taiwanese Gen-Z, is increasing obesity, with the latest data available from 2020; the newest, 3rd wave national health survey results are still pending (Chiu et al., 2022; 台灣營養師, 2022; 彭巧珍 et al., 2023). Recent nationwide data show that 70% of common bottled drinks ($n = 341$) marketed to youth in Taiwan exceed the warning threshold for "*high sugar*" ($> 5 \text{ g}/100 \text{ mL}$), and a single serving of 42% of the drinks ($> 25 \text{ g}$ sugar per bottle) contained the entire daily sugar limit prescribed by the World Health Organization (WHO) (Yen et al., 2022).

Internationally, there is extensive research on the attitudes of college students towards climate change. (American Press Institute, 2022) reports only 37% percent of U.S. Gen-Z and Millenials follow news related to environmental issues. (S. E. O. Schwartz et al., 2022) reports some adult U.S. students in a small study (18-35, $n = 284$) express feelings of insignificance of their actions to achieve any meaningful impact. (Thomaes et al., 2023) reports U.S. adolescents don't find sustainability relevant to their daily life. (Ross et al., 2016) says most people in the U.S. don't act on climate change. "Action on climate change has been compromised by uncertainty, aspects of human psychology".

(Credit Suisse, 2022) suggests young consumers are more eco-friendly and drive the speed of change. Yet the Economist has ran a few anonymous articles calling gen-z green ideals into question ("How Gen Z and Millennials Spend Their Money," 2023; The Economist, 2023). (Wood, 2022) suggests in the U.S. Gen-Z is willing to pay 10% more for ethically goods, spend 24% more on sustainable products than Generation X and 75% of Gen Z would prioritize sustainability over brand loyalty. Meanwhile Gen-Z in the U.S. are heavy users of online fashion shopping, Chinese cheap online store Shein overtakes Amazon as the most downloaded shopping app, while clothes

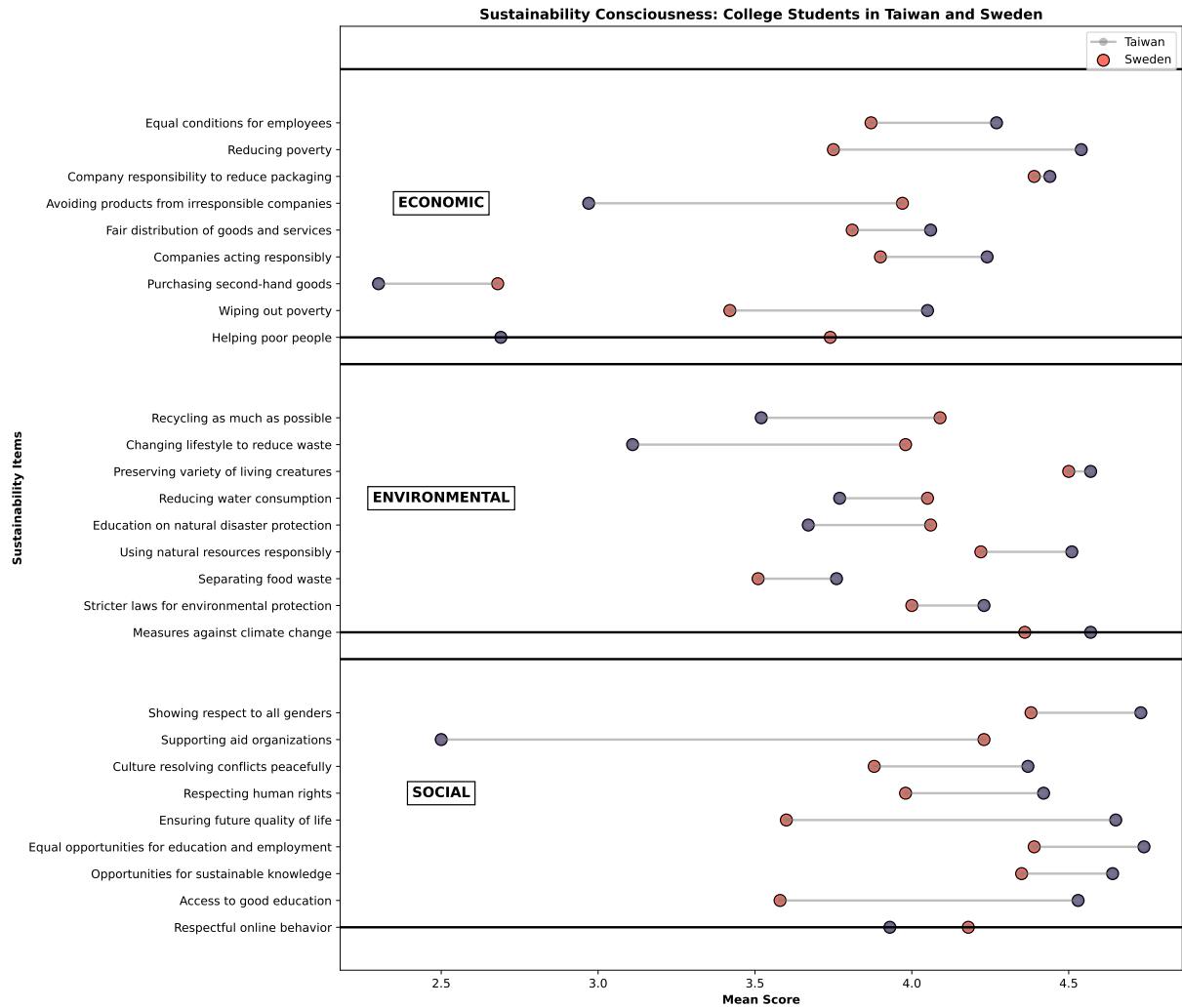


Figure 17: Comparing college students' education for sustainable development in Taiwan and Sweden

resale apps such as Depop and ThredUp grow in popularity (Alex Reice, 2021). It worth noting, Taiwan is also a growing market for luxury brands (Karatzas et al., 2019).

(Manchanda et al., 2023) survey ($n = 726$) administered at shopping malls in New Delhi, India, found similar levels of sustainability consciousness between Millenial ($n = 206$) and Generation-Z ($n = 360$) age groups; people with high level of materialism were found to be less sustainability-conscious; the effect of mindfulness on sustainability was found to be stronger among females than males, supporting the hypothesis of the moderating effect of gender.

7.5 The Experience of Climate Change and Pollution Levels in Taiwan

Taiwan's recent climate challenges with over 4 decades of droughts, rising air temperatures, and shifting rainfall patterns, have impacted both water security and the performance of its vital semiconductor manufacturing industry (Vo & Liou, 2024). Offshore, marine heatwaves, ocean acidification, and elevated sea surface temperatures are intensifying coral bleaching around Taiwan (P.-C. Hsu et al., 2024). The oceans are crucial for Taiwan to capture carbon emissions. Around 33% of Taiwanese CO₂eq emissions is captured by the marine carbon sink, while the effect of forests in Taiwan needs further study (Hung et al., 2024).

Similarly to how Northern Europe, including Estonia, is affected by the Gulf Stream, making the climate warmer, Taiwan is affected by the Kuroshio (黑潮) warm current of the Pacific Ocean, which helps regulate the climate and marine ecosystem of the region. The strength and trajectory of the Kuroshio is influenced by Rossby planetary waves, driven by the Earth's rotation are crucial to keeping the atmosphere in balance by helping transfer tropical heat towards Earth's poles and cold air toward the tropics; interactions between oceanic currents, Rossby waves and nonlinear *mesoscale eddies*, which form complex undulations, and their effect on the climate are still not well understood (Belonenko et al., 2023; J.-Y. Lin et al., 2022; Sheng Liu et al., 2024; Mensah et al., 2014; Shen et al., 2014; US Department of Commerce, n.d.; Yuqi Yin et al., 2019). Going back on a larger time scale, biomarkers in the sediment core around Taiwan are being used to study variations in climate over past thousands of years (Yueqi Wang et al., 2021).

In addition to climate extremes, Taiwanese college students are subjected to high levels of pollution. University campuses are somewhat healthier than other areas. There are several decades of research on pollution levels in Taiwan, most with very scary correlations to health. Taiwan air pollution, the worst (highest PM2.5 concentration) were found in Changhua (24.5 µg/m³), Tainan (20.9 µg/m³), and Pingtong (20.7 µg/m³) (Chang Hsiung-feng et al., 2024).

There have been concerns about food safety in Taiwan, with prominent cases reported in the media and documented in academic literature, where organic toxins and chemical pollution have entered the food system (I. Lee, 2024; J.-H. Li & Ko, 2012; J. Yang et al., 2013).

A recent study demonstrate extreme industrial pollution in numerous sites at the Hsinchu's Xi-ang Shan wetland (香山濕地) in Northern Taiwan, yet considers ecological risk threat to nature and wildlife to be "moderate" (Salah-Tantawy et al., 2025). In contrast, (李桂媚, 2022) reports Taiwan's semiconductor industry employs undisclosed toxic chemicals under trade-secret

claims, which have not undergone comprehensive health and environmental risk assessments. Previously, (Y.-H. Liu et al., 2021) reported sediment analyses at the Xiang Shan wetland found levels of gallium (Ga) ranging from 9,460 to 23,450 µg/kg (severe contamination) and indium (In) from 4.77 to 37.1 µg/kg (moderate contamination), amounts which are above natural baselines, indicating industrial chemical runoff. Earlier studies of semiconductor wastewater from waterways downstream of the Hsinchu Science Park (which houses over 450 companies' manufacturing facilities) have shown high amounts of at least 14 heavy metals, with levels of tungsten reaching 400 µ g/L in contrast to the average river concentration of <0.1 µ g/L (S.-C. Hsu et al., 2011). The oldest study considered here also found high levels of arsenic pollution in groundwater (H.-W. Chen, 2006). It's safe to say, in conclusion, the chemical runoff from manufacturing is a reality documented by several studies, however the negative health effects have not yet been clearly established - and studies of other, less prominent industrial areas of Taiwan, are severely lacking.

The table below illustrates the types of emissions and environmental impacts large corporations in Taiwan produce. It should be noted, some of the corporations do buy carbon credits to offset their local adverse impact; for instance, 台積電 TSCM has purchased carbon credits, renewable energy, invested in the Taiwan Carbon Exchange to support greener companies, and joined international reporting initiatives, such as the Task Force on Climaterelated Financial Disclosures (TCFD) and Taskforce on Nature-related Financial Disclosures (TNFD) (TSMC, 2023).

Table 13: Examples of large industrial polluters in Taiwan as reported in academic papers and the media.

Company	2023 Mt CO ₂ eq	Notable Problems	Data Source
台電 Taipower	93.33	A single power plant in Taichung produces 26 Mt CO ₂ eq	今周刊 (2024)
台塑化 (台塑集團) Formosa Petrochemical	24.23	16 cases of fires and explosions between 2010 and 2020	歐宇祥 (2024)
中鋼 China Steel	18.07	60% of the CO ₂ eq emissions come from 1 steel mill in Kaohsiung	蕭婷方 (2021); 環境資訊中心記者 (2022)
台積電 TSMC	11.42	Extreme water consumption used 82.82 Mt of water in 2022, straining local reservoirs and requiring water-truck deliveries during droughts	今周刊 (2024); “上市公司用水量之冠不是台積電 它用水比台積電多 20 幾倍” (2022); 中央社 (2021); TSCM (2019)

Company	2023 Mt CO ₂ eq	Notable Problems	Data Source
台灣中油 CPC	N/A	From 2019 to 2023 paid government air pollution penalties 146 times; there were 4 fire incidents as well as 3 odor leakages in 2022	綠色公民行動聯盟 (2022); 2022年空、水々裁罰金榜首 中油、工業局連莊 (2023)
亞泥 Asia Cement (花蓮新城山礦場)	N/A	In 2023 a single mining operation in Hualian was responsible for 4.14 Mt of raw limestone extracted (assumed to have a very high emissions potential) however no CO ₂ eq figure is reported by the company	Asia Cement Corporation (2023)
可口可樂 Coca-Cola (TW)	N/A	2024 brand audit in river pollution found 7.6 % (n = 28481) of PET plastic bottles were from Coca-Cola	Greenpeace 綠色和平 (2024)

7.6 Climate Anxiety Responses

A growing body of research shows climate anxiety is widespread among young people, which emotionally can both hinder and motivate sustainable action. A large worldwide study in (n = 10000, aged 16-25) by (Hickman et al., 2021) provides evidence the youth is anxious about climate in 10 countries: Australia, Brazil, Finland, France, India, Nigeria, Philippines, Portugal, the UK, and the USA. Similarly, (Thompson, 2021) finds young people around the world have climate anxiety. (Whitmarsh et al., 2022) shows worry about the climate in the UK is generally widespread (over 40% of the respondents, n = 1332), while climate anxiety is highest among young people and is a possible motivator for climate action. Additionally, (Ogunbode et al., 2022) finds climate anxiety in 32 countries and also supports the idea that climate anxiety leads to climate activism. (Thibodeau, 2022): “In 2021, the BBC polled 1,000 people in Scotland to understand the barriers to taking climate action. What they found was even though many people were aware of actions needed to take to address climate change, and had intentions to their behaviors didn’t change. This is a phenomenon called the intention-action gap.”

(Osaka, 2023) argues *doomerism* is an excuse for climate in-action. Hope is necessary for people to make changes in their habits (Marlon et al., 2019). (Seabrook, 2020) suggests music therapy

is useful in the era of climate crisis, evolving to meet current needs of young people. (Kjaergard et al., 2014) shows how “*understanding health and sustainability as a duality, health both creates conditions and is conditioned by sustainability, understood as economic, social and environmental sustainability, while on the other hand sustainability creates and is conditioned by human health*”.

A recent special issue of Behavioral Sciences magazine on Behavioral Science for Climate Change (2025) provides further evidence. A review of 50 studies supports the idea that climate activism shifts public opinion towards climate concern (Thomas-Walters et al., 2025). Climate change negative affect brain health through heat, air pollution, extreme weather; the study finds links to neurological, psychiatric, and cognitive disorders (Todorova et al., 2025).

When disaster hits we need high levels of *social trust*. being part of community of trust makes it easier to act in unison. Religion is a type of community of trust. conversely, that can also have negative effects, as in Taiwan the expected behaviour of burning joss sticks and paper money, is a cause of air pollution (C. Tang & Pan, 2014)

Psychological factors influencing millennials to engage with sustainability (Naderi & Van Steenburgh, 2018)

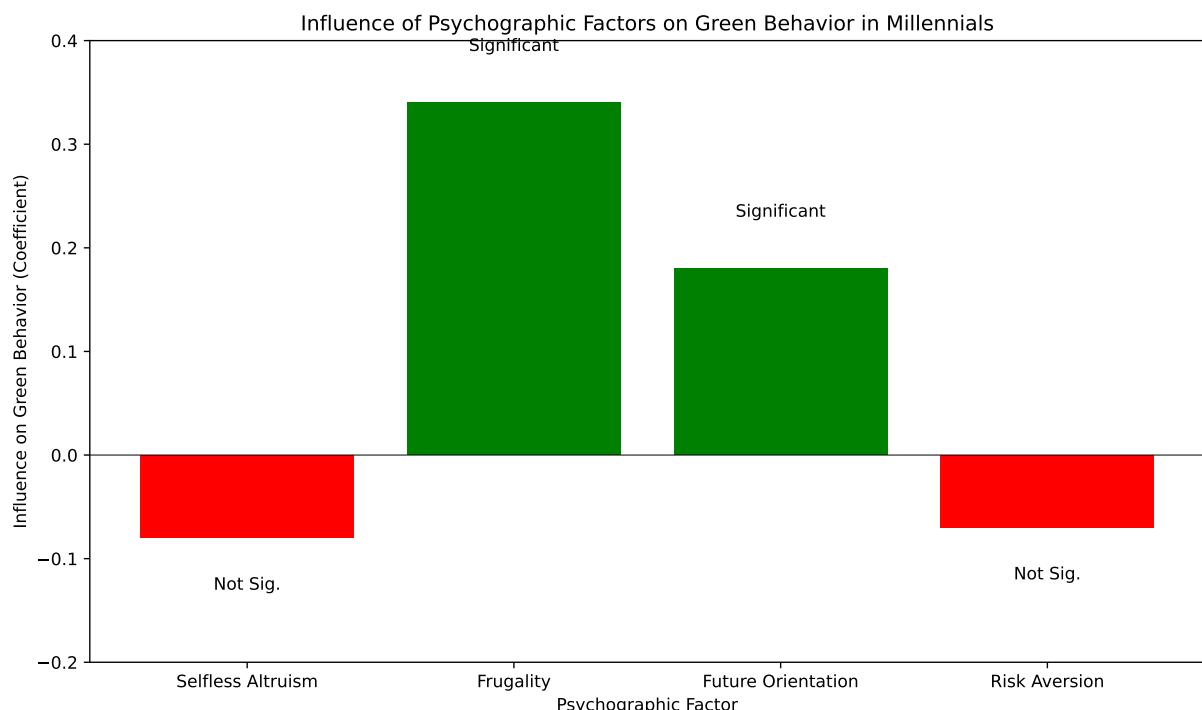


Figure 18: Psychological factors influencing millennials to engage with sustainability

7.7 Attitude-Behavior Gap

While people express eco-conscious ideas, it's non-trivial to practice sustainability in daily life. Translating eco-conscious attitudes into concrete sustainable actions remains challenging. Empirical evidence illustrates this gap between intention and behavior. (Park & Lin, 2020) positive attitude towards sustainable products does not result in purchase decisions, shows research of fashion in South Korea. In one Australian study, green consumers still waste food similarly to the baseline (McCarthy & Liu, 2017).

However, changing habits is important if technology alone is not the solution. (Deyan Georgiev, 2023b) reports only 30% of people in the Gen-Z age group believe technology can resolve all environmental problems. Even with good intentions, (Munro et al., 2023) finds shoppers who try to shop sustainably often fail to find sustainable product, in a systemic literature review of 64 papers from South Korea, Australia, the UK, the US, and elsewhere.

McKinsey's *Talk is Cheap* study underscores the same paradox at scale: more than 60% of global consumers say they are willing to pay extra for sustainable products, yet in reality most wouldn't pay a premium greater than about 10% (**freundtHowMuchWill2024?**). A robust willingness-to-pay (WTP) literature tells a similar story. A 2021 meta-analysis covering 80 studies finds the average stated premium for sustainable food products is 29.5%; however, hypothetical surveys often overstate WTP relative to real-purchase experiments (S. Li & Kallas, 2021). In contrast, PwC's 2024 *Voice of the Consumer* survey, based on 20000 respondents in 31 countries, reports a far more modest mean sustainability premium of 9.7% that consumers are willing to pay, once inflation is factored in (PwC Global, 2024).

In short, people want eco-products but are largely price-sensitive.

7.8 Sustainability in Taiwan: Garbage Trucks and Digital Receipts

Musical garbage truck are a success story of the environmental progress in Taiwan (Helen Davidson & Chi Hui Lin, 2022). Indeed, they are a *user interface innovation* and the main way how people in Taiwan interact with sustainability issues.

The popular narrative about Taiwan recounts the story of the economic and environmental transformation of the country. In the late 1980s during the heights of an economic boom Taiwan became famous as the Taiwanese Miracle (臺灣奇蹟) (Gold, 1986; P.-L. Tsai, 1999). By the early 1990s another less flattering nickname appeared: "garbage island", for the piles of trash covering the streets and overflowing landfills (Ngo, 2020; Rapid Transitions Alliance, 2019). In the two decades that followed, from 1998 to 2018, Taiwan made progress in municipal waste management, rising to the status of a world-leader in recycling (2nd *effective recycling rate* after Germany); in addition to an effective recycling system, the average waste amount generated per person by 700g (from 1140g to 400g) per day; nonetheless, industrial recycling rates were less stellar, standing at 80% in 2020 and there were unrealized opportunities in using industry 4.0 technologies, such as internet of things (IoT) sensors for better waste tracking (Bui et al., 2023; C.-Y. Wu et al., 2021).

Progress in sustainability is possible but achieving results takes time and innovation. (Rapid Transitions Alliance, 2019) credits the Taiwanese Homemakers United Foundation (財團法人主婦聯盟環境保護基金會) for initiating the transformation in 1987, suggesting a small group of people can have an outsized impact on the whole country. Their activity didn't stop there and (財團法人主婦聯盟環境保護基金會, 2020) recounts a timeline of their achievements on their website until the present day.

(“獨家觀察—電子發票年減碳量 相當 2,700 座大安森林公園,” 2025) reports 54.03% of invoices in Taiwan are digital. Since 2021 digital receipts are mandatory for all businesses. Taiwan's longstanding receipt lottery also has specific prizes available only for digital receipts (行動支付結合雲端發票 節能減碳最環保經理人, 2018). Several other countries, such as Singapore, South Korea, Japan, Sweden, Italy, Portugal, Brazil, Mexico, have comparable systems in use.

7.9 Trends in Taiwanese Industry and Online Shopping

In the intensifying competition of online shopping in Taiwan, (聯合新聞網, 2024) predicts Momo and Coupang will compete for Taiwanese market leadership, with Coupang increasingly stepping on Shopee's and MOMO's toes, as per (“順風婦產科 순풍 산부인과 (@Followwindlover) on Threads,” 2024).

Across online and offline, KANTAR reports Taiwan's consumer spending on fast-moving consumer-goods (FMCG) grew over 5% in 2024, speeding up towards the end of the year: +2.5% in Q1, +4.1% in Q2, +5.7 % in Q3 and +9.1% in Q4, with e-commerce crossing the 20 % share mark (traditionally FMCG are purchased physical stores, as convenience stores are so readily available all over Taiwan) (foodNEXT, 2024; Kantar Worldpanel, 2024; 動腦 Brain.com.tw, 2024; 食力 foodNEXT, 2025).

Taiwan has been on a path of change, striving to become more sustainable. Between 1970 and 2019, emitting CO₂eq was largely a prerequisite for economic growth in Taiwan (T. Chang et al., 2023). Since the 1990s, Taiwan is a net CO₂eq exporter through emissions embedded in the industrial production oriented economy (R. Huang et al., 2020). Starting in 2023, Taiwan's Financial Supervisory Commission's (FSC) added “requirements for Taiwan's corporates to disclose their carbon emissions,” (Reformosatw, 2024). Most recently, the Taiwanese environmental ministry has been cracking down on illegal waste, with over 70 cases being prosecuted (環境部, 2025).

TIME Magazine and Statista collaborative “*World's Most Sustainable Companies Of 2024*” includes 17 Taiwanese companies (Alana Semuels, 2024).

Table 14: World's Most Sustainable Companies; data from (Alana Semuels, 2024).

Sustainability Rank	Company	Score (Out of 100)
24	Delta Electronics	77.18
63	Taishin Holdings	73.50
68	Fubon Financial	73.01

Sustainability Rank	Company	Score (Out of 100)
80	Chunghwa Telecom	71.69
91	Yuanta Financial Holdings	70.94
92	Cathay Financial Holdings	70.79
108	Taiwan Mobile	69.72
200	First Financial Holding	64.17
300	Far EasTone	60.04
301	SinoPac Holdings	60.04
344	Wistron	58.44
356	Acer	58.02
395	Nanya Technology	56.35
409	InnoLux	55.82
416	Wiwynn	55.67
421	Taiwan Cement	55.49
497	Advantech	53.14

Meanwhile, Corporate Knights which has been ranking global sustainable companies since 2005, including analysis of 7000 public companies with a revenue over US\$1 billion, only includes TSMC in the top 100 (placed 20th in 2021 and 44th in 2022, dropping out in 2023) and Taiwan High Speed Rail Corp (THSR) and Giant Manufacturing Co Ltd since 2023 (Corporate Knights, 2024; Staff, 2021). Meanwhile, earth.org's list of the world's 50 most sustainable companies in 2022, only includes 1 Taiwanese company - TSMC (Earth.Org, 2022).

Meanwhile, (Marc Lien, 2022) finds 4 millions British SMEs have no plan for net-zero transition and (Ware, 2024) adds, British workers lack skills for green transition, according to a 2024 National Environmental Services Survey.

7.10 Financial Literacy Worldwide and Among Taiwanese Youth

A recent nationwide study ($n = 1997$) titled Youth Financial Health Basics (青少年財務健康基礎大調查) jointly conducted by the Taipei Fubon Bank and the Parent-Child Innovation Center (親子天下教育創新中心) between February 11 and March 9, 2025 found that over 65% of secondary schools incorporated financial-literacy courses into their curricula however 64% of Taiwanese youths (aged 15–18) exhibit low confidence and understanding of financial products and face significant fraud risk, with nearly 1/5 of the respondents encountering a scam in the past year, while 18% suffered actual financial losses (江昭倫, 2025; 陳美君, n.d.).

Table 15: Familiarity with financial products and preferred payment methods, as reported in (陳美君, n.d.).

Banking	% of Respondents
Have at least one financial account	80%

Banking	% of Respondents
Familiarity	% Unfamiliar
Savings accounts	70%
Mutual funds	63%
Stocks	46%
Deposit accounts	30%
Payments	% Preference
Cash	47%
Family member pays	47%
EasyCard	4%
Mobile payments	1%

Importantly for designing a financial app, while 80% of the survey respondents had received financial education at school, 90% of the students deemed the primary learning channel about financial knowledge to be on social media; and only 15% remember to have learned about credit-card usage (江昭倫, 2025).

In a much older study, I-Cheng Yeh (2009) analyzed usage data from 30,000 credit-card clients at an undisclosed major Taiwanese bank to predict next-month defaults, using 6 data-mining techniques including ANNs (AI Neural Networks) (Yeh & Lien, 2009). Because of the age of the study there's no Gen-Z data. People aged 18–26 at the time would be Millenials or Gen-X by now. the data was donated by (Yeh, 2016) and roughly 1 in 5 credit card clients (22.1%) of the dataset defaulted on their payment in the next month. Among the 9,618 clients aged 18–29 at the time of the study, 2,197 defaulted on their next - month payment, yielding a default rate of 22.8%, slightly higher than the overall average. Meanwhile, among the 5,127 clients aged 18–26, 1,285 defaulted, yielding a rate of 25.1%, considerable higher than their older counterparts. Finally, among the 1,558 clients aged 18–23, 430 defaulted, a rate of 27.6%, pointing to a trend of younger people having higher default rates.

A over-the-phone study ($n = 3000$) conducted in 2022, found Taiwanese savings habits to have polarized, with over 60% either having no savings whatsoever or saving more than 1/2 of their annual income; 27% of respondents reported total savings below NT\$40,000; young adults' (aged 20–29) were the only group whose financial risk worsened, with 43% of the respondents having extremely low financial literacy, described as 金融文盲 (near “financial illiterate”) (中央社, 2022).

Table 16: Financial literacy data from phone interviews, as reported in (中央社, 2022).

Financial Literacy Among Taiwanese (2020)	Very Low	Low	Medium	High
Overall financial literacy	43.2%	34.9%	19.4%	2.5%
Understanding products & services	34.0%	38.6%	23.1%	4.3%
Confidence using products & services	30.0%	26.8%	37.6%	5.6%
Seeking financial advice	71.0%	3.2%	17.8%	8.0%

Financial Literacy Among Taiwanese (2020)	Very Low	Low	Medium	High
Personal money management	21.8%	42.9%	28.4%	6.9%

The Taiwanese Financial Literacy & Education Association 財金智慧 FINLEA is a non-profit with a stated goal of enhancing financial literacy among Taiwanese. Their longitudinal study, with the latest survey conducted in 2022 (n = 2014; 1055 high-school; 959 university) rated financial literacy among all youths 56.3 out of 100 (53.8 in 2016 and 56.7 in 2007), always below the benchmark score of 60, with high school and vocational students averaging 49.26 and university students somewhat higher averaged 64.03 score (網軟股份有限公司, n.d.).

Table 17: Latest report from the 財金智慧 FINLEA longitudinal study (網軟股份有限公司, n.d.).

Knowledge Gap (2022)	% Unaware
Unsure that employers must contribute to the labor pension (and individuals can voluntarily contribute)	68%
Unsure which deductions (income tax, labor insurance, health insurance) reduce take-home pay	66%
Unsure how education level affects starting salary	61%
Unaware of methods to lower loan interest rates	59%
Cannot identify which auto insurance covers vehicle damage	55%
Unable to judge which life-insurance need is greatest	51%
Uncertain how to choose investment tools for maximum lifetime returns	63%
Unaware that business tax makes purchases more expensive	61%

財金智慧 FINLEA does publish online videos targeted at young people, however as of early 2025, they only have around 1000 subscribers on YouTube (財金智慧 FINLEA, 2020). Meanwhile the Taiwanese cryptocurrency influencer Mr Block has over 100000 YouTube subscribers (mrblock 區塊先生, 2025).

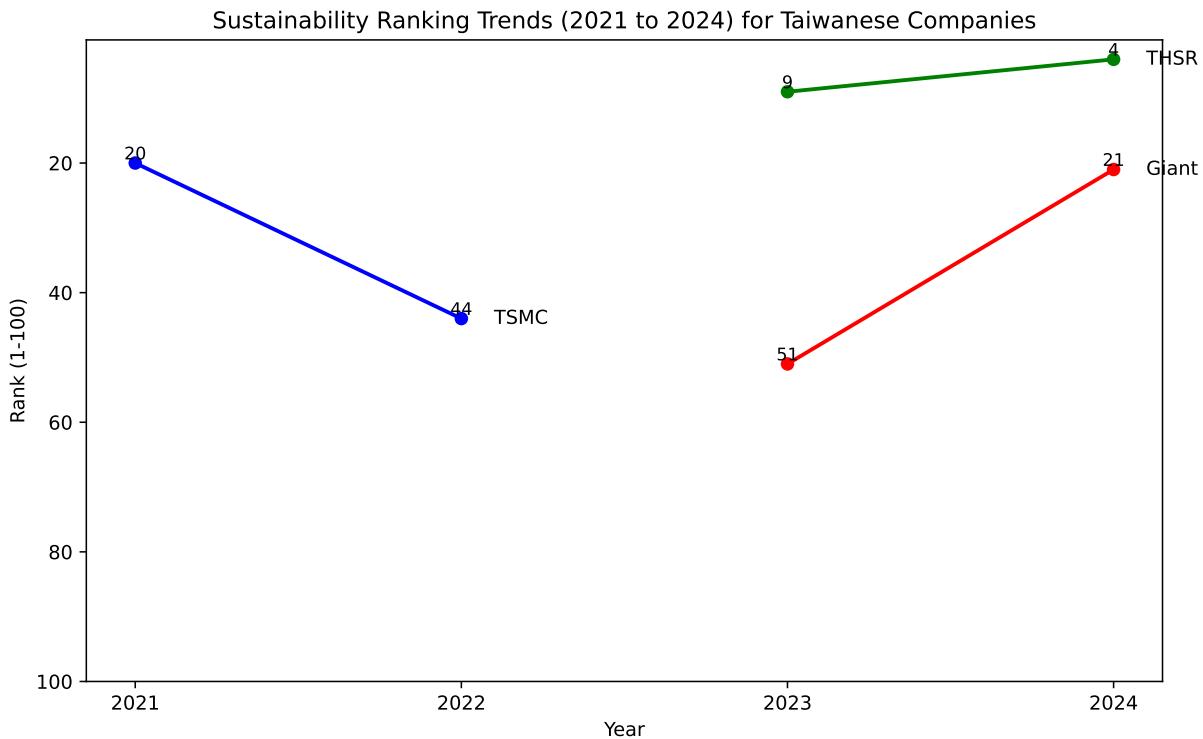


Figure 19: Taiwanese Company Ranking

【JUST MONEY】系列 ► Play all

【JUST MONEY】系列影片，透過 FINLEA 專業講師—瑞瑞老師與宜家同學之間的互動對話及親身經驗分享，傳遞賺錢、存錢、花錢、信用、保險、投資及助人等理財觀念。更多資訊請關注：FINLE...



【理查頭殼】系列動畫 ► Play all

FINLEA 財金智慧教育推廣協會推出【理財Talk・理查頭殼】理財頻道，跟著「理查」學「理財」，隨著動畫主角的對話「Talk」建立你的FQ「頭殼」，現在立刻跟著理查累積你的財務自由兌換券！...



Figure 21: 財金智慧 FINLEA YouTube Channel

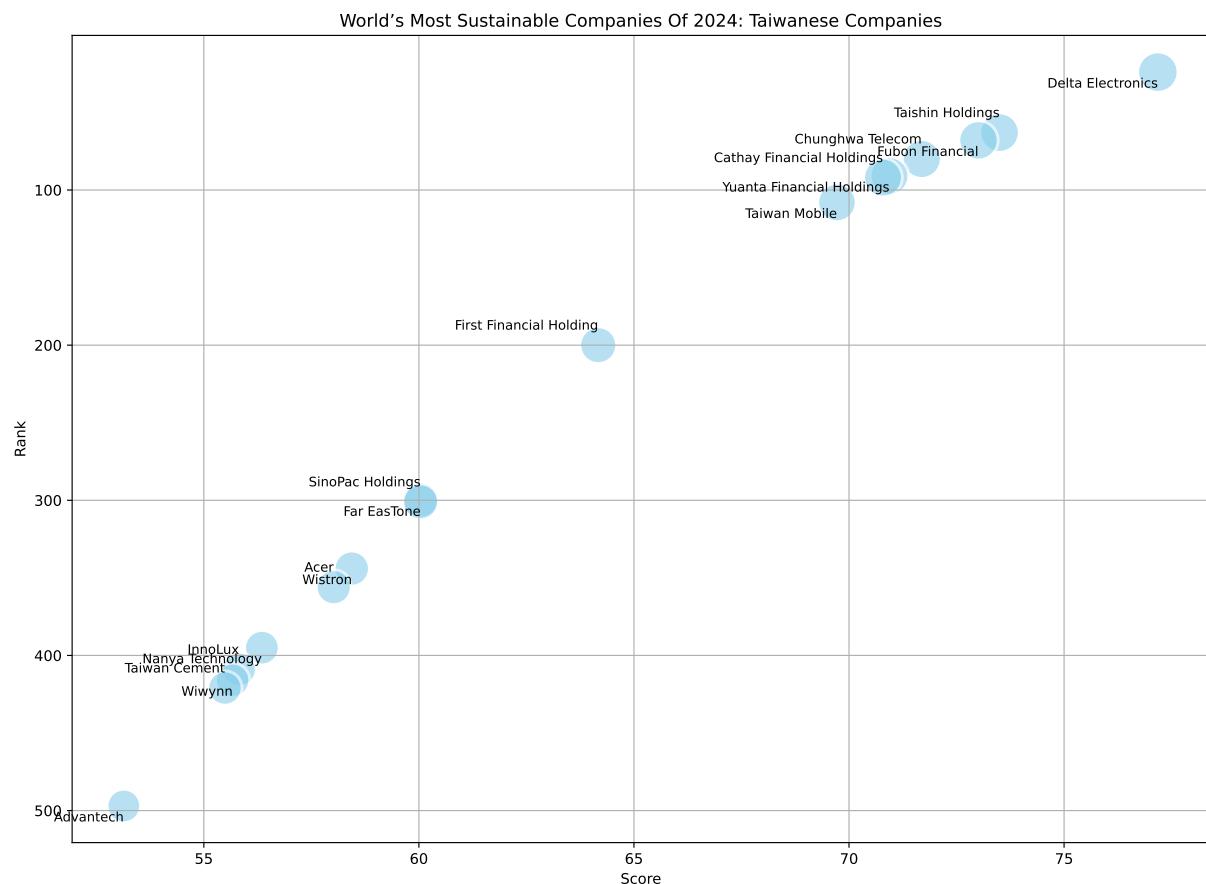


Figure 20: British Company Ranking

Internationally, there's evidence young people have money. In the United States, the combined annual consumer spending of Gen-Z and Millennials was over \$2.5 Trillion in 2020 (YPulse, 2020). Over the decade from 2020 to 2030, in the U.S., UK, and Australia, Millennials are projected to inherit \$30 Trillion USD from their parents (Calastone, 2020). (Steverman, 2022) puts the inheritance figure between 2022-2045 at an higher \$73 Trillion USD. There's also some evidence of investment interest, however with a large geographic variance. According to a (Calastone, 2020) study ($n = 3000$) surveying people in the millennial age group between ages 23 and 35 in Europe (UK, France, Germany), U.S.A., Hong Kong, and Australia, 48% of respondents located in Hong Kong owned financial securities (such as stocks) while the figure was just 10% in France.

Table 18: Data from millennial investors (Calastone, 2020).

Place of Comparison	Financial Security Ownership
Hong Kong	48%
France	10%

7.11 Social Media, Trends, Memes, and Youth Empowerment

The term “meme,” first coined by Richard Dawkins in 1976 in his book “The Selfish Gene” to describe units of cultural evolution, analogous to that of biological evolution, which may evolve by natural selection, and now encompasses internet artifacts and even stocks. Beyond mere entertainment, memes have emerged as an academic discipline, where memes are sampled, coded, and analysed from cultural and ethical viewpoints, among others (Zidani & Miltner, 2022). (Peters-Lazaro et al., 2020) argues memes are no merely jokes but tools for communal critique and collective visioning. suggesting that Taiwanese Gen-Z memes scaffold deeper conversations about consumerism, climate action, and social change. Memes from daily life, business to war, are relevant to penetrating through the noise of the web.

In Taiwan, homegrown memes may start with global templates but quickly take on a local flavor. (劉芸嘉, 2024)'s 2021 study of 150 Taiwanese memes written in Mandarin shows most rely on friendly and indirect humor: inside jokes and wordplay that bond peers together. (朱映潔 (Ying-Chieh Chu), 2021) surveyed 737 Taiwanese Facebook users and discovered that a meme's funniness, shareability, and shock value “hellish gags” (地獄梗) drive people to post it for social approval. (胡綺珍, 2024) collected 217 “tired of life” / “I'm just trash” meme texts from Instagram and PTT, then interviewed 13 Gen-Z enthusiasts, revealing how self-deprecating jokes help Gen Z cope with stress, feel part of a group, and quietly push back against social pressure. Memes have a long history, and even almost a decade ago in 2016, a casual news comment—like the “canoing man” (泛舟哥) remark during a typhoon exploded into LINE stickers and PTT threads, proving that Taiwanese can transform everyday media moments into collective satire or tongue-in-cheek commentary (黃意能 & 黃曉琪, 2016).

Internationally, the sustainability-focused topics “underconsumption” and “deinfluencing” were trending on TikTok in 2024 however have since subdued (Fares et al., 2024; TikTok, 2024b, 2024a). While this particular trend may be over, memes still hold potential for communicating about sustainability to young Taiwanese. Still, looking at older international data, (Zannettou et al., 2018) built a large-scale machine-learning pipeline to trace the origin of memes in the US, with 160M images and 2.6B posts within about 1 year (July 2016-2017) from Twitter, Reddit, 4chan and Gab, finding that often memes originate from fringe communities and then spread across mainstream media, highlighting how fringe communities can be surprising impactful.

In Taiwan, Internet usage among young people is nearly universal, with over to 98% of 18–29 (roughly Gen-Z) year olds reporting they have gone online at least once recently, and close to 96% of respondents aged 18-29 used some form of social media (財團法人台灣網路資訊中心 & 台灣資訊社會研究學會, 2023).

Table 19: Taiwanese Internet Usage Statistics; data from (財團法人台灣網路資訊中心 & 台灣資訊社會研究學會, 2023).

Metric	18–29	30–39
Daily Internet usage	98.79 %	98.40 %
Overall social-media usage	95.98 %	94.84 %
TikTok usage	33.03 %	24.28 %

(林高賢, 2024) analyzed ($n = 1175$) Taiwanese high school students, mostly aged Gen-Z, finding that Instagram (IG) dominates, used by close to 85% percent of the respondents; they use IG for about 2 hours per day, 5-6 days per week; moreover, respondents often feel anxious (1-2 days per week), and anxiety correlates with several motivations of using IG, such as recording life moments, documenting travel, food, and fitness with photos, was tied to higher anxiety, possibly related to the photo-centric self-presentation on Instagram, why can be theorized to heighten sensitivity to feedback and criticism. In contrast, (陳思凝, 2023) conducted a survey of 458 Taiwanese Gen Z Instagram users, finding that higher Instagram use intensity is directly associated with greater online subjective well-being; however, intense use also leads to information overload and social comparison, which induce social media fatigue and in turn erode well-being; moreover, users’ perceived intimacy with the platform amplifies the link between use intensity and social comparison frequency. An online survey by (廖柏雅, 2024) (where the Gen-Z cohort $n = 125$) found respondents to be highly motivated by social and entertainment use; the user’s fear of missing out (FoMO) was found to be related to the motive; e.g. people with social and entertainment drives experience greater FoMO than those motivated primarily by information seeking. (Lasnik, 2018) surveys college students at the National Dong Hwa University in Hualian ($n = 300$, a mix of Taiwanese and international students), using the Liebowitz Social Anxiety Scale (LSAS) and Taijin Kyofusho Scale (TKS) as research instruments, finding Taiwanese students ranked higher on the Taijin Kyofusho, suggesting the fear of offending or disturbing others is stronger among local students.

A large-scale ($n = 2075$) representative face-to-face survey among people aged 18 to 93 years in

Taiwan (no age-based categorization was published for Gen-Z specifically), found that in general sharing one's thoughts online (known academically as "self-disclosure") boosts perceived social support and significantly boosts bonding and bridging social capital, which increases life satisfaction and lowers loneliness (樊一寧 et al., 2024). Conversely, in Japan, while not directly comparable, Gen-Z reports wanting privacy and 75% feel others overshare on social media and 49 percent were concerned about their personal data (McKinsey & Company, 2022).

7.12 AI Use Among Taiwanese Students

A survey of college students in March 8–10, 2023 at the Chung Yuan Christian University ($n = 983$) in Taoyuan (Northern Taiwan), yielded the following results: 66% of the students had used ChatGPT, with the top use cases being summarization (31%), translation of articles (28%), and writing reports (24%) (CYCU, 2023; 許維寧, 2023). However, in terms of AI adoption, this data can be considered out-dated. ChatGPT was first released to the public on November 30, 2022, so the students had had only about 3 months to try it out (OpenAI, 2022). At the time, the GPT-3.5 model was available; the revolutionary GPT - 4 was released to the public on March 14, 2023, (OpenAI, 2023).

In a more recent large-scale survey focusing on AI literacy administered to the general public ($n = 2174$) found that only 26% of the respondents had used ChatGPT in the past 3 months (in comparison with the 25% from a similar survey administered in the previous year); younger people had higher usage patterns, 53% for 18-29 and 37% 30-39; meanwhile, 69% of respondents believed they could tell the difference between AI-generated and non-AI content and 73% supported some type of government regulations for AI (HakkaNews, 2024).

A Chinese study from two authors at the Minzu University and Beijing Normal University reports they recruited anonymous Taiwanese college students ($n = 916$) on the Chinese Credamo platform from the Taiwanese IP-space (ChatGPT is blocked in Mainland China, Macau, and Hong Kong) to compare ChatGPT vs. Google for academic use among Taiwanese students: their findings show a clear preference for ChatGPT overall, which students deemed more flexible (meanwhile some older students still preferred Google) and Random Forest and LightGBM-based modeling predicted tool choice by three main factors: 1) GenAI fluency, 2) awareness of GenAI hallucinations, and 3) user age; their recommendations include 1) support critical-thinking among users, and 2) design hybrid chat+search user interfaces with higher reliability (Kelly, 2024; Qiao & Lee, 2024; M. Zhang & Yang, 2024). In the US, an older study of young adults (Millenials at the time) highlights how they "*use Google as a reference point for ease of use and simplicity*", (Kate Moran, 2016). The web now has several generations of native users, and some older usage patterns which older digital natives are used to, may take time to change.

In Sweden, a large-scale ($n = 5894$) survey across several Swedish universities showed college students' attitudes towards AI assistants (ChatGPT was by far the most prevalent app, 95 % of respondents had heard of ChatGPT and 35 % used it regularly); 55.9% held a positive attitude toward AIs; integrity was a hotly debated question, 62% calling AI use in exams "cheating," but 60% rejecting an outright ban, and 58% saying it doesn't violate the purpose of education (Stöhr et al., 2024).

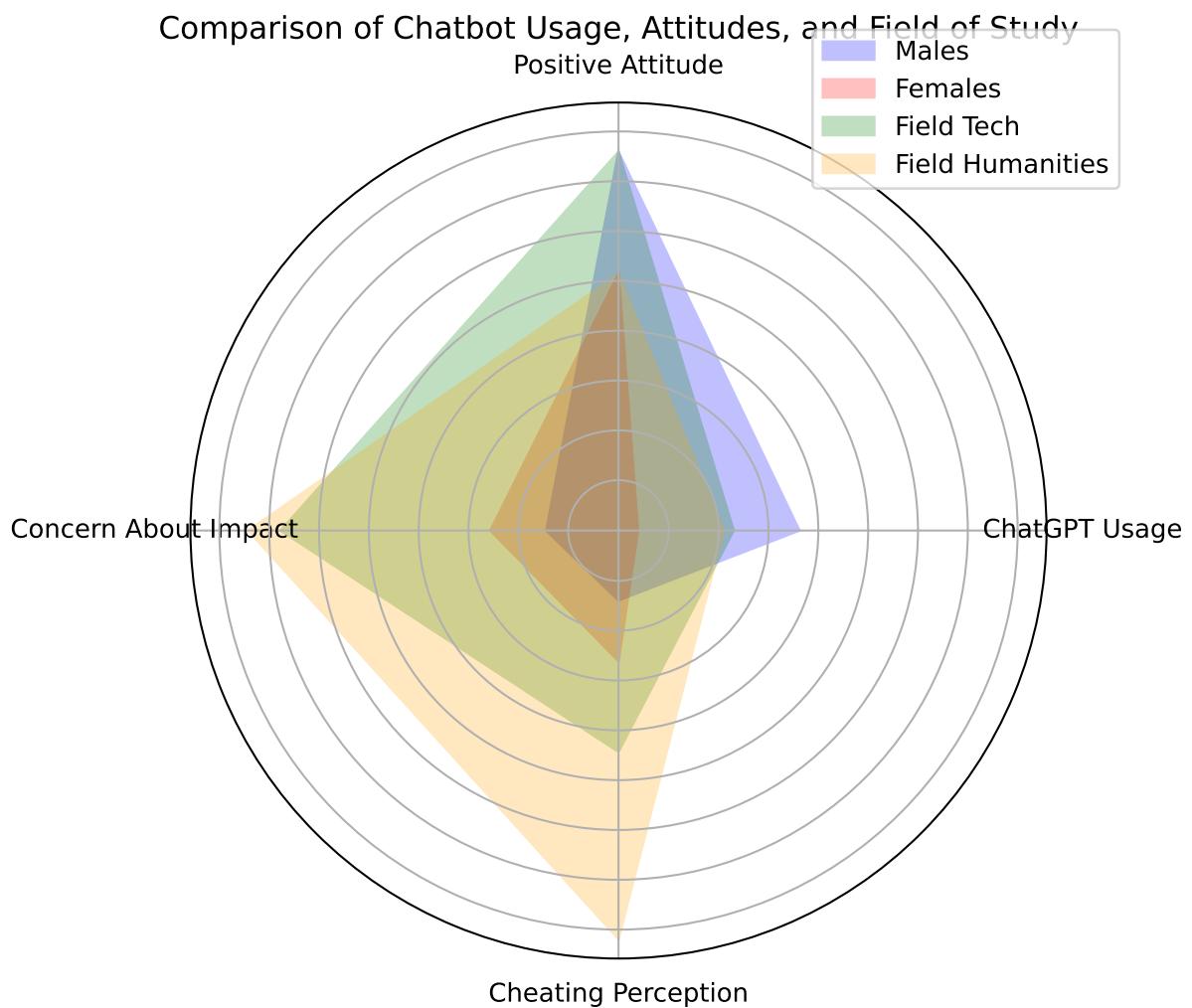


Figure 22: Swedish College Students' Attitudes Towards AI Assistants

8 SUSTAINABILITY

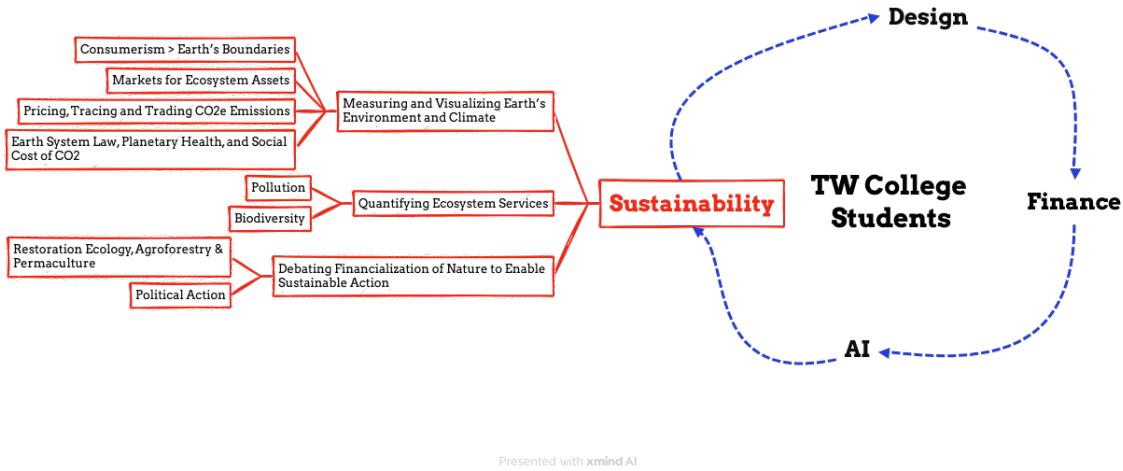


Figure 23: Visual abstract for the sustainability chapter

8.1 The Roots of Sustainability in Environmentalism

“Nachhaltigkeit” - *sustainability* in German - was likely the first use of the concept of preserving natural resources, conceived by a tax accountant Hannß Carl von Carlowitz in 1713 in his seminal book on forestry - *Sylvicultura oeconomica* -, referring to the goal of achieving prudent forest management practices in his native Saxony in Southeastern Germany, which at the time was under severe *deforestation* pressure from mining, ship-building and agricultural production (Gottschlich & Friedrich, 2014; Hannß Carl von Carlowitz, 1713). This particular field of sustainability study is now known as *sustainable yield of natural capital*. The *principal* of the natural resource being managed, such as in fishing and forestry, shouldn’t be over-harvested in order to maintain *ecosystem services* - a contemporary term from the theory of *natural capital*, referring to benefits humans receive from the stock of world’s natural resources (Peter Kareiva et al., 2011).

Defining sustainability perhaps more poetically, the American wildlife ecologist Aldo Leopold proposed the idea of *land ethics* in 1972 as “[a] thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise” in his landmark work *A Sand County Almanac* (Leopold, 1972). In a similar vein, the 1987 United Nations’ Brundtland Report titled “*Our Common Future*” defined *sustainable development* as “*Development that meets the needs of the present without compromising the ability of future generations to meet their own needs*” (World Commission on Environment and Development, 1987). Given these varied ideas for over 300 years, I believe some percentage of people have been concerned with our planet’s natural environment and its preservation already for centuries.

Yet, it is only in the last 100 and so years that human activities have begun to affect Earth's systems on a previously unseen scale - termed *Anthropocene* -, necessitating a deeper understanding of human-nature interactions, such as in the case of climate change, which is rapidly changing the face of our living environments.

8.2 Measuring and Visualizing Earth's Climate Systems

Studies of Earth's climate go back for over 200 years, starting with Alexander von Humboldt, the founder of climatology, who revolutionized cartography by inventing the first *isothermal maps* in 1816; these maps showed areas with similar temperature, variations in altitude and seasons in different colors (Honton, 2022) now available as 3D computer models (*Alexander von Humboldt's Original Isotherms Circa 1838*, 2023). Already in 1896, the Nobel Prize winner Svante Arrhenius first calculated how an increase in CO₂ levels could have a warming effect on our global climate (Anderson et al., 2016; Wulff, 2020). In 1938, Guy Stewart Callendar was the first scientist to demonstrate the warming of Earth's land surface as well as linking the production of fossil fuels to increased CO₂e and changing climate (Hawkins & Jones, 2013). Early scientists pioneered climate modeling by calculating the first climate interactions which precede today's complex computer-based *Earth System Models (ESMs)* that integrate the various Earth systems and cycles run on supercomputers (Anderson et al., 2016).

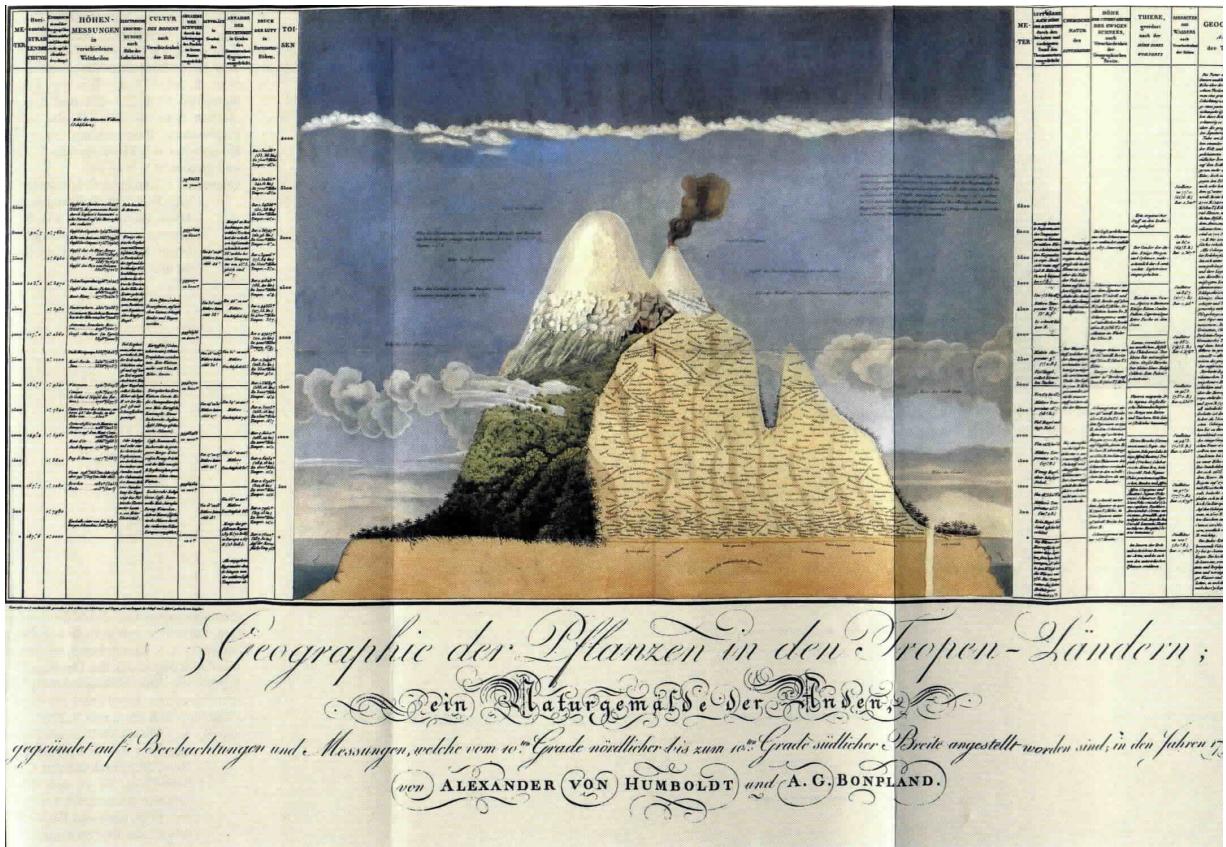


Figure 24: Humboldt's Naturgemälde, early data visualization of ecology, rain, temperature, elevation, etc

Environmental activists have been calling attention to global warming for decades, yet the world has been slow to act (McKibben, 1989). While the scientific case for human-induced climate change was building, it took 120 years after Arrhenius' calculations, until the Paris Climate Agreement in 2016, that countries came to an agreement on non-binding targets on keeping CO₂ levels 1.5 °C below pre-industrial levels (defined as 1850–1900)(United Nations, 2016). Even though awareness of Earth's warming climate was growing ever stronger, the CO₂ emissions kept rising too. The hockey-stick growth of CO₂ concentration since the industrial revolution is clear in the data from 1958 onward, following a steady annual increase, called the *Keeling Curve* (Keeling & Keeling, 2017). Written records of global temperature measurements are available starting from the 1880s, when temperatures began to be documented in ship logs (Brohan et al., 2012). Finally, although perhaps less accurately, temperature estimations from tree-trunks allow some comparisons with the climate as far back as 2000 years ago (Rubino et al., 2019).

April 2025 was Earth's 2nd-warmest April on record, with global temperatures reaching 1.32°C above the 20th-century average, driven by persistent El Niño conditions and record-high ocean temperatures (Masters, 2025). This warming aligns with growing concerns about Earth's energy imbalance, which recent satellite data suggest has nearly doubled since 2005; more heat is being trapped in the climate system than is being radiated back to space (Mauritsen et al., 2025).

Compounding the issue, 3 key NASA climate satellites responsible for monitoring Earth's energy budget are nearing the end of their operational life with no replacement missions currently planned, raising alarms about the continuity and reliability of future climate data (Harvey, 2025). Likewise, funding for the Scripps Institute, responsible for the Keeling Curve, is under threat, according to its caretaker, Ralph Keeling.

The Keeling Curve apparatus measures absorption of infrared light, which allows one to detect the amount of CO₂eq in the air. It also has an advanced calibration system where it makes measurements in air with a known quantity of gases (Worthington, 2025b).

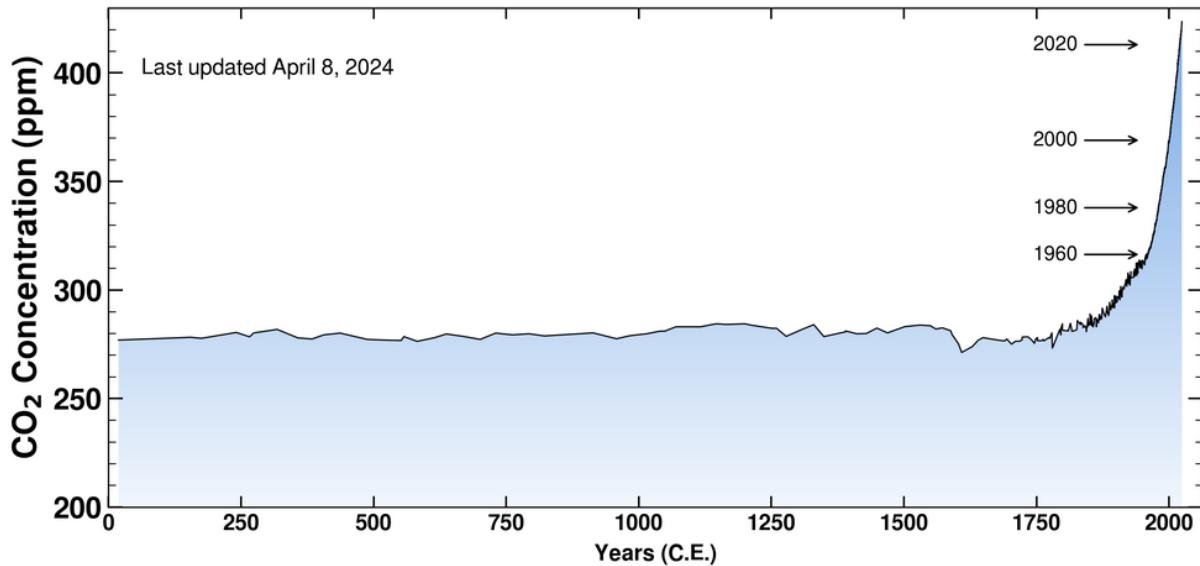


Figure 25: CO₂ concentration in the atmosphere as of 2025. Image Credit: Scripps Institution of Oceanography at UC San Diego.

The latest data from 2023 shows our current world population of 8 Billion people emitted 37.2 gigatonnes (i.e. billion metric tons) of CO₂e per year, the highest emissions recorded in history (Statista, 2023a). Since 1751, cumulative CO₂eq emissions have exceeded 1.5 trillion tonnes globally or when expressed in CO₂eq for all green house gases, total historic emissions would reach roughly 1.7 trillion tonnes CO₂eq since the start of the Industrial Revolution.(Global Carbon Budget, 2023; Marvel, 2023). In order to limit global warming to 1.5 °C as agreed by the world nations in Paris, removal of 5-20 gigatons of CO₂e per year would be needed according to reduction pathways calculated by the Intergovernmental Panel on Climate Change (IPCC) (UNFCCC. Secretariat, 2022; Wade et al., 2023). Yet, most countries are missing the mark (Climate Analytics & NewClimate Institute, 2023; United Nations Environment Programme, 2023). The European Union's Copernicus Climate Change Service (C3S) reports 1.5 °C global warming has already been breached in 2024 temperatures ("First Time World Exceeds 1.5C Warming Limit over 12-Month Period," 2024; *World's First Year-Long Breach of Key 1.5C Warming Limit*, 2024). Given the current pace of climate change action, the G7 countries (Canada, France, Ger-

many, Italy, Japan, United Kingdom, United States) are heading for 2.7 °C of warming by 2050 (CDP, 2022).

(United Nations Environment Programme (UNEP), 2021) reported as of 2021 updated national climate pledges (NDCs) and other mitigation measures are projected to lead to a global temperature increase of approximately 2.7°C by 2100, significantly surpassing the Paris Agreement's aspirational goal to keep global warming below 1.5°C this century; effective implementation of net-zero emissions pledges could still keep warming around 2.2°C (approaching the Paris Agreement's goal of below 2°C), if countries cut methane emissions from fossil fuel, waste, and agricultural sectors, bridging the current emissions gap - and carbon markets might significantly cut emissions, if they are governed by clear rules ensuring genuine emission reductions, alongside transparent systems for monitoring and tracking progress - however, numerous national climate strategies postpone substantial action until after 2030. A year later, the 2022 Emissions Gap report showed a somewhat worsening situation, with existing national pledges leading the world for around 2.8 °C of warming by 2100 (United Nations Environment Programme, 2022)

Earth's physical systems are very sensitive to small changes in temperature, which was not understood until the 1970s(McKibben, 2006). A comprehensive review of evidence from paleoclimate records until current time, including ocean, atmosphere, and land surface of points towards substantial climate change if high levels of greenhouse gas emissions continue, termed by the authors as *climate sensitivity* (Sherwood et al., 2020). Global warming may lead to the slowing down and complete stop of the Atlantic meridional overturning circulation (AMOC) which helps maintain climate stability (Ditlevsen & Ditlevsen, 2023). Apart from CO₂, reduction of other atmospheric pollutants, such as non-CO₂ greenhouse gases (GHGs) and short-lived climate pollutants (SLCPs) is required for climate stability (J. Lin et al., 2022).

(Armstrong McKay et al., 2022a; TED, 2024) warns that climate is not a linear system, rather there are several non-linear climate tipping points, where change accelerates: at the current warming ice - sheet collapse, permafrost thaw, Amazon dieback and coral - reef loss are likely to tip between 1.5 °C and 2 °C, underscoring that the Paris Agreement range is far from a safe limit. (Armstrong McKay et al., 2022b) synthesize paleoclimate records, observations, and model projections to revise and rank both global “core” and regional “impact” climate tipping elements by their warming thresholds, visualized in the chart below.

8.2.1 Measuring CO₂e Emissions

Technology improves and measurements have become more accurate yet CO₂e emissions are not yet completely accounted for. (Crippa et al., 2020) reports the latest figures CO₂e from the EU's Emissions Database for Global Atmospheric Research (EDGAR). The EU Copernicus satellite system reveals new greenhouse emissions previously undetected (Daniel Värjö, 2022). *Copernicus Climate Change Service (C3S) provides “[n]ear-real time updates of key global climate variables”*(The Copernicus Climate Change Service, 2024). Using simple python code and freely available images from online datasets, it's increasingly possible for anyone to detect deforestation, as in this example of geospatial analysis from Amazon AWS (AWS, 2022; P. Patel, 2025).

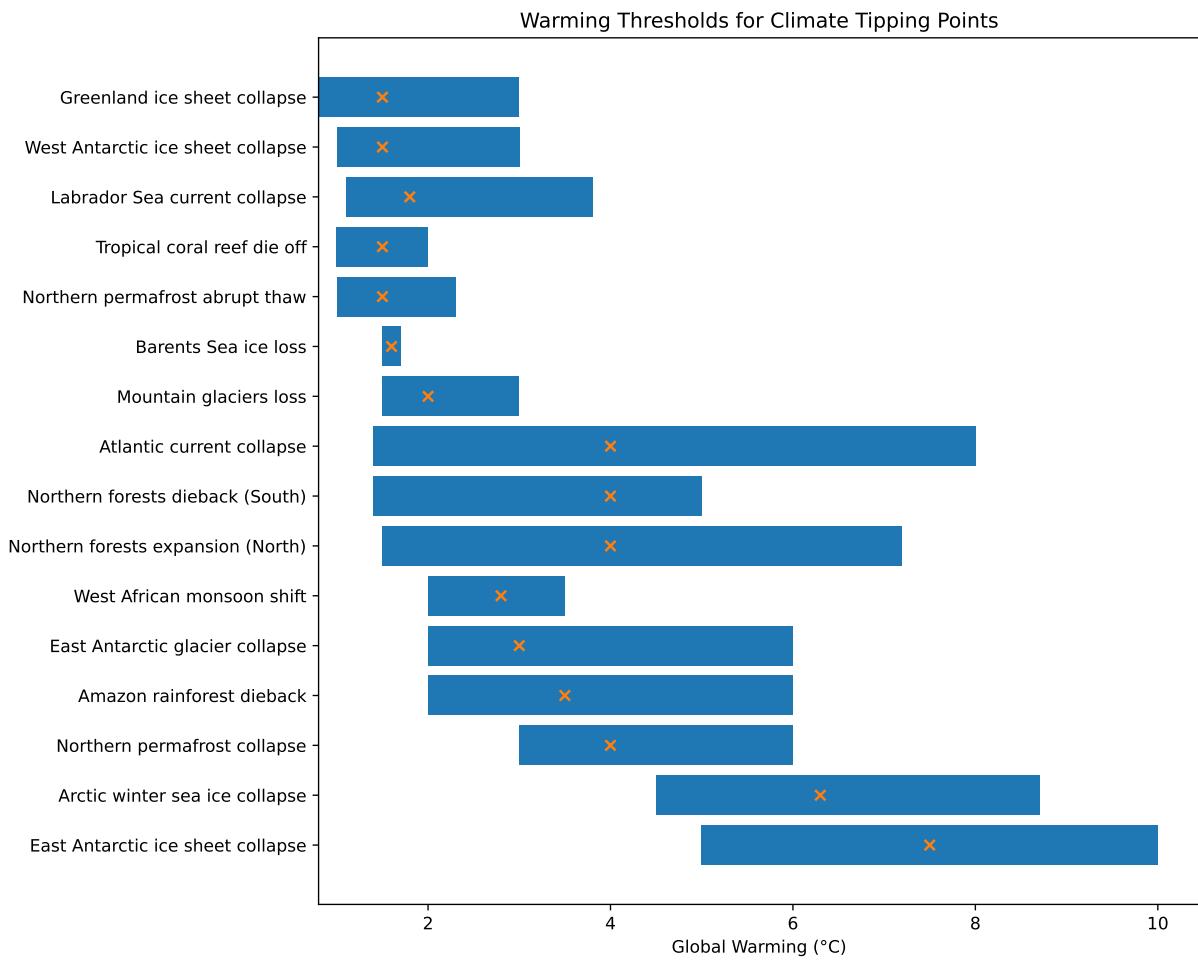


Figure 26: Climate Tipping Points

One major cross-cutting category the IPCC tracks separately is LULUCF (Land Use, Land-Use Change, and Forestry). Depending on whether forests are being cleared or restored, LULUCF can act as a net greenhouse-gas source or as a powerful carbon sink that removes CO₂ from the atmosphere. LULUCF also links to biodiversity protection. (Y. Chen et al., 2023) looked at the Poyang Lake in China between 2010-2020, finding ecosystem vulnerability rose by 18% with human activities (land-use change, urban expansion, components of LULUCF, also reported in international media, see (Scarr & Sharma, 2021) for images) as the dominant driver, followed by climate factors. (Xie et al., 2021) mapped pollution sources in 14 vulnerable areas in China, including the Poyang Lake, and underlined the need for real-time monitoring of ecosystem health.

Emissions production is highly unequal, with “[t]he world’s top 1% of emitters produce over 1000 times more CO₂eq than the bottom 1%” (IEA, 2023a). The share of CO₂ emissions among people around the world is highly unequal across the world (referred to as *Carbon Inequality*). (Chancel, 2022) reports “one-tenth of the global population is responsible for nearly half of all emissions, half of the population emits less than 12%”. Information and communications technology (ICT) sector is an example of carbon inequality, where emerging economies bear 82% of the emissions, developed countries gain 58% of value, of the over 300 million PCs sold per year (Bajarin, 2022; X. Zhou et al., 2022).

CO₂e emissions by region (per year), comparing highest per capita CO₂e emissions (mostly from oil producers) vs regional average per capita CO₂ emissions vs total CO₂ emissions.

Table 20: CO₂ Emissions Comparison (Crippa et al., 2020; European Commission. Joint Research Centre., 2022; Ivanova et al., 2020; Z. Liu et al., 2023; World Resources Institute, 2020).

Regional Average Per Capita Emissions (2020)	Highest Per Capita Emissions (2021)	Highest Total Emissions (2021)
North America 13.4 CO ₂ e tonnes	Palau	China
Europe 7.5 CO ₂ e tonnes	Qatar	United States
Global Average 4.1 CO ₂ e tonnes	Kuwait	European Union
Africa and the Middle East 1.7 CO ₂ e tonnes	Bahrain	India
	Trinidad and Tobago	Russia
	New Caledonia	Japan
	United Arab Emirates	Iran
	Gibraltar	Germany
	Falkland Islands	South Korea
	Oman	Indonesia
	Saudi Arabia	Saudi Arabia
	Brunei Darussalam	Canada
	Canada	Brazil
	Australia	Turkey
	United States	South Africa

Scoping CO_{2e} emissions into 4 main categories helps to organize calculating CO_{2e} emissions and corresponding reduction targets by looking at direct and indirect emissions separately. The U.S. National Public Utilities Council (NPUC) decarbonization report provides a useful categorization of *emission scopes* applicable to companies which helps organizing emission reduction schemes (National Public Utilities Council, 2022) based on the Greenhouse Gas Protocol defined in the 1990s (GHG Protocol, n.d.). For example, for consumers in Australian states and territories in 2018, 83% of the GHG emissions are Scope 3, meaning indirect emissions in the value chain (Goodwin et al., 2023). A newer concept is Scope 4 emissions also known as avoided emissions, proposed by the World Resources Institute (WRI) in 2013 (Plan A, n.d.).

Table 21: Definition of Emission Scopes From (National Public Utilities Council, 2022). One's scope 3 emissions are someone else's scope 1 emissions.

Emission Scope	Emission Source
Scope 1	Direct emissions
Scope 2	Indirect electricity emissions
Scope 3	Value chain emissions
Scope 4	Avoided emissions

Countries have agreed up CO_{2e} Reduction Targets known as Country-Level Nationally Determined Contributions (NDCs). While most countries have not reached their Nationally Determined Contributions, the Climate Action Tracker data portal allows to compare countries by their NDC performance (Climate Analytics & NewClimate Institute, 2023). (Fransen et al., 2022) notes that the majority of Nationally Determined Contributions (NDCs) are dependent on financial assistance from the international community.

Table 22: Climate Action Tracker's country comparison of the 10 top polluters' climate action (Climate Analytics & NewClimate Institute, 2023).

Country or Region	NDC target
China	Highly insufficient
Indonesia	Highly insufficient
Russia	Critically insufficient
EU	Insufficient
USA	Insufficient
United Arab Emirates	Highly insufficient
Japan	Insufficient
South Korea	Highly insufficient
Iran	Critically insufficient
Saudi Arabia	Highly insufficient

Fossil fuels are what powers humanity as well as the largest source of CO₂ emissions. (IEA, 2022) reports “Global CO₂ emissions from energy combustion and industrial processes rebounded in 2021 to reach their highest ever annual level. A 6% increase from 2020 pushed

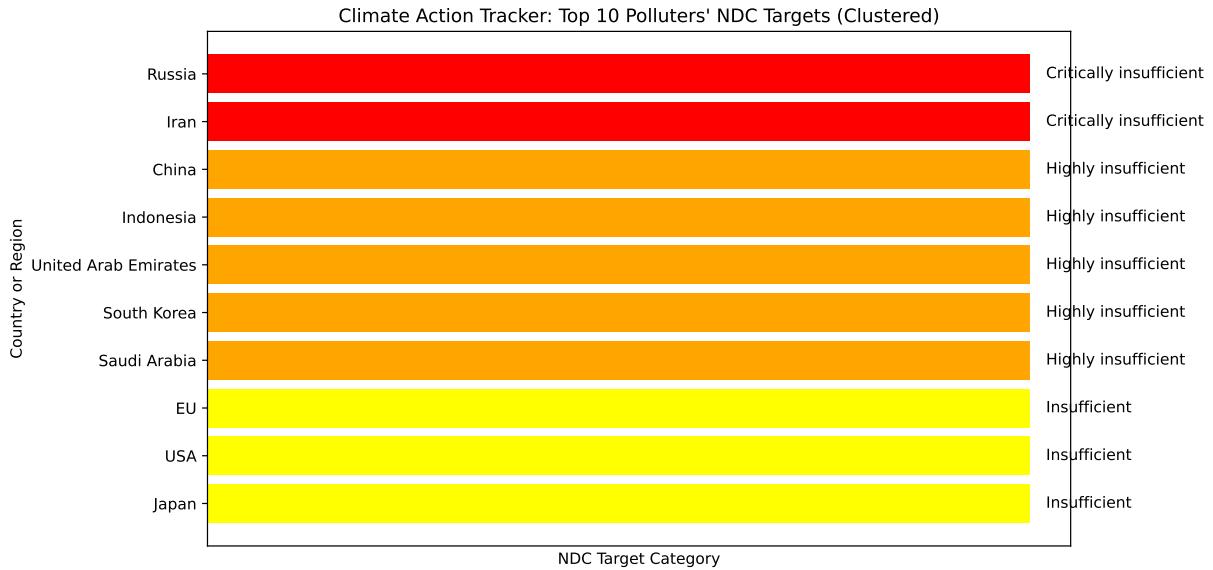


Figure 27: Nationally Determined Contributions (NDCs)

emissions to 36.3 gigatonnes". As on June 2023, fossil fuel based energy makes up 82% of energy and is still growing (Institute, 2023). The 425 largest fossil fuel projects represent a total of over 1 gigatons in CO₂ emissions, 40% of which were new projects Kühne et al. (2022). Tilsted et al. (2023) expects the fossil fuel industry to continue grow even faster. In July 2023, the U.K. granted hundreds of new oil and gas project licenses in the North Sea ("Rishi Sunak to Green-Light Hundreds of New Oil and Gas Licenses in North Sea," 2023).

(Ember, 2025) Ember's Electricity Data Explorer shows Taiwanese energy usage based on data from Taiwanese government, visualizing the growth in gas, wind, and solar, and decline of coal and nuclear power; however, while declining, coal remains the leading power source for Taiwan. Climate pledges made by international companies present in Taiwan mean they need large amounts of green energy to meet their sustainability goals. For instance, Google worked with the government of Taiwan to change the laws to allow direct power procurement by foreign companies; the current plan being to install 1 gigawatt of solar power fully pre-purchased by the newly formed company created by BlackRock and Google for boosting AI development as reported by (S. Chiang, 2024; Jessop et al., 2024; 永鑫能源 New Green Power, 2022). More recently, Google also purchased 10MW of geothermal energy for its Taiwanese AI chip projects, doubling current Taiwanese geothermal capacity (Hagström-Ilievska, Apr. 17, 2025 18:00; Potter, 2025; Jeffery Wu & Thompson, 2025). Geothermal energy provides 24/7 clean energy from the Earth's core, however is limited due to lack of access; Taiwan happens to be in geologically active spot on the ring of fire, where drilling for geothermal energy is more feasible (M. Chang & Hsiao, 2025; L, 2025b).

8.2.2 Carbon Accounting, Emissions Trading Schemes

Trading CO_{2e} emissions can be divided into 2 categories, namely *Compliance Carbon Markets* (CCM) and *Voluntary Carbon Markets* (VCM). The legislative baseline for Compliance Carbon Markets is so low, people want to retire more CO_{2e}, which they can do through *Voluntary Carbon Markets*.

As of 2024 there's no single global CO₂ trading market but rather several local markets as described in the table below. Most of the world is not part of a CO₂ market.

Table 23: CO₂ credit trading markets around the world from (*International Carbon Market*, n.d.).

CO ₂ Market	Launch Date	Comments
EU	2005	EU: (Araújo et al., 2020)
South Korea	2015	
China	2021	China's national emissions trading scheme (ETS) started in 2021 priced at 48 yuan per tonne of CO ₂ , averaged at 58 yuan in 2022 (Ivy Yin, 2023; H. Liu, 2021).
U.S.	2013	No country-wide market; local CO ₂ markets in California, Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont
New Zealand	2008	New Zealand (Rontard & Reyes Hernández, 2022) (need access, important NCKU doesn't subscribe)
Canada	2013	

The price of CO_{2e} differs across markets, as assigning a monetary value to reducing CO_{2e} emissions depends on several variables. (Stern, 2022b) argues carbon-neutral economy needs higher CO_{2e} prices and believes (Rennert et al., 2022) CO_{2e} price per ton should be 3,6x higher than it is currently. Contrary, (Ritz, 2022) argues optimal CO₂ prices could be highly asymmetric, low in some countries and high (above the social cost of CO_{2e}) in countries where production is very polluting. The total size of carbon markets reached 949 billion USD in 2023, including Chinese, European, and North American CO₂ trading (LSEG & Susanna Twidale, 02/12/2024, 02:37 PM).

The prices between compliance and voluntary markets differ substantially.

Table 24: Compliance market CO₂ prices on August 12, 2023; data from (CarbonCredits, 2023; Ember, 2023; Trading Economics, 2023).

Compliance Carbon Markets	Price (Tonne of CO ₂)
---------------------------	-----------------------------------

EU	83 EUR
UK	40 Pounds
US (California)	29 USD
Australia	32 USD
New Zealand	50 USD
South Korea	5.84 USD
China	8.29 USD

Table 25: Voluntary market CO₂ prices on August 12, 2023; data from (CarbonCredits, 2023).

Voluntary Carbon Markets	Price (Tonne of CO ₂)
Aviation Industry Offset	\$0.93
Nature Based Offset	\$1.80
Tech Based Offset	\$0.77

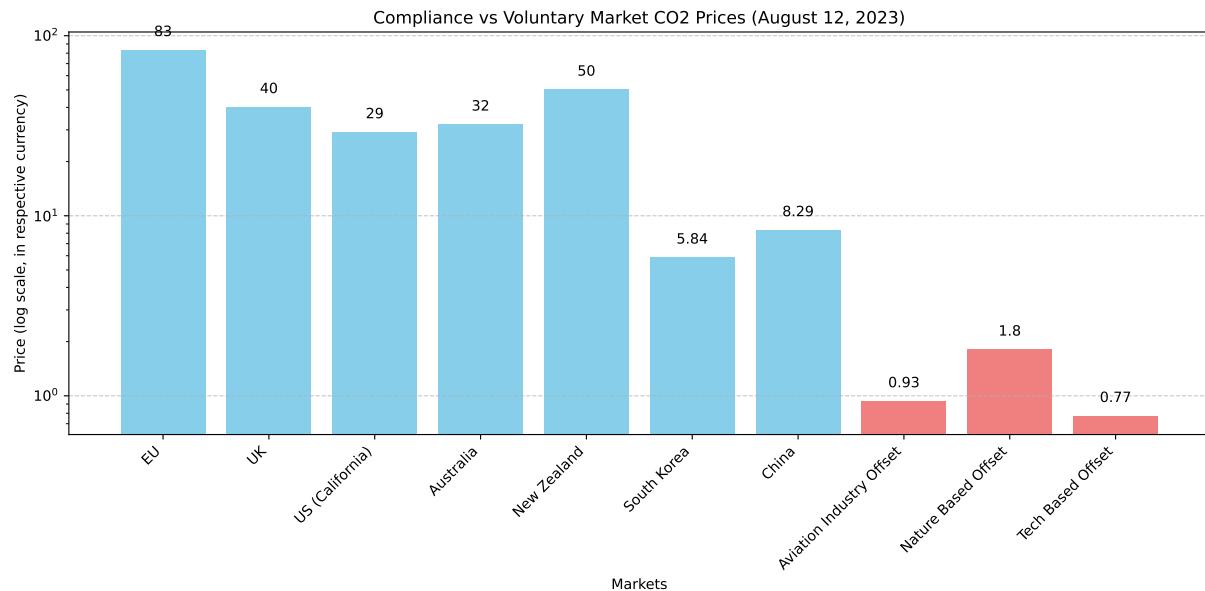


Figure 28: Carbon Credits

Voluntary Carbon Markets are a decentralized system where private entities voluntarily buy and sell carbon credits (ICVCM, 2025). Carbon credits are useful for private companies who wish to claim *carbon neutrality*, *climate positivity*, or other related claim, which might be viewed in good light by their clients or allow the companies to adhere to certain legislative requirements. In the simplest terms, a carbon credit represents 1T of CO₂eq that has been prevented from entering the atmosphere - or has been removed from circulation (aka Carbon Credit Retirement) (Anna Watson, 2022, 2023). However it's important to look at the details of these deal as Voluntary Carbon Markets (VCM) lack standardization and transparency (Ela Khodai, 2023). For example,

Flickr only invested around 3000 USD in carbon credits and got a carbon-neutral rating, which hardly seems enough for an organization of its size (Climate Neutral, 2024).

Markets are centered around carbon credits, nature-backed financial derivatives dependent on science-based methodologies for measurement, reporting, and verification (MRV), which are managed and regularly updated by certification organizations such as Gold Standard, Verra, and others. Some standards released in the past few years include the Verra Agricultural Land Management methodology for Verified Carbon Standard (VCS) (Verra, 2023). Gold Standard recently release a methodology for Mangrove-based carbon credits (Gold Standard, 2024). Regen Network released a methodology for regenerative grazing systems, proposing remote-sensing analysis with field-sampled soil carbon data, quantifying GHG sequestration and ecological co-benefits (biodiversity, water-infiltration, etc.) for robust MRV and carbon-credit issuance (*Methodology for GHG & Co-Benefits in Grazing Systems*, 2022). KlimaDAO, unhappy with the current standards, published “An open call for alternative carbon standards” inviting carbon-credit issuers and communities to propose next-generation registry frameworks and leverage blockchain for transparency, liquidity and interoperability in the voluntary carbon market (KlimaDAO, 2023a).

Table 26: Criteria for carbon credit projects from (Verra, 2023).

Criteria	Description
Baseline	Ecosystem carbon sequestration rate without the intervention (project)
Additionality	New carbon capture or prevention of emissions
Permanence	Carbon storage time (should be long-term)
Leakage	Risk of shift to causing emissions (for example because of deforestation)

For the individual person, there's no direct access to CO₂ markets. However, brokers do buy large amounts of carbon credits to resell in smaller quantities to retail investors. Facilitating citizens' access to CO₂ emissions trading may be an efficient method to organize large-scale CO₂ retiring (Rousse, 2008). (Sipthorpe et al., 2022) compares traditional and blockchain-based solutions to carbon trading, arguing that blockchain solutions for CO₂eq markets are nearing maturity, and offer many improvements, such as enhancing transparency, trust, and efficiency.

CO_{2e} credits have given rise to the Carbon Accounting industry, to help companies meet legal emissions reduction targets in Compliance Carbon Markets, with many companies like Watershed, Greenly, and Sustaxo providing services. (Quatrini, 2021) admits sustainability assessments are often complex and may give flawed results. Nonetheless, CO₂ emission reduction has the added positive effect of boosting corporate morale (J. Cao et al., 2023).

There are many companies which facilitate buy carbon credits as well as a few organizations focused on carbon credit verification. In Estonia, startups Arbonic and Single.Earth are trialing this approach in several forests. The most established certifiers or carbon credits include the

Verified Carbon Standard (VCS), the Gold Standard, Climate Action Reserve (CAR), and the American Carbon Registry (ACR).

“Carbon pricing is not there to punish people,” says Lion Hirth (Lion Hirth, n.d.). *“It’s there to remind us, when we take travel, heating, consumption decisions that the true cost of fossil fuels comprises not only mining and processing, but also the damage done by the CO₂ they release.”* Long term cost of insufficient climate action is more than short-term gains from delaying efforts to reduce carbon emissions. In addition to the damages from global warming, the fossil energy production that’s a large part of global CO₂eq emissions has caused several high-profile pollution events. Large ones that got international news coverage include Exxon Valdez and Deepwater Horizon.

Carbon credit prices should reflect the quality of the carbon reduction. Nature-based carbon removal solutions (for example, forest-backed carbon credits) rank among the top solutions for mitigating climate change but require price signals that reflect their true value; Pachama’s (an AI-based carbon removal company) calculation from bottom up cost modeling across more than 150 reforestation projects indicate that high quality forest carbon removal credits must trade at a minimum of USD 50-82 per tonne of CO₂eq to be competitive with alternative land uses (IPCC AR6 guidance sets the price spread wider, from USD 50-200); reduced land-use change (basically this means not cutting down forests, IPCC groups together as LULUCF, Land Use, Land-Use Change and Forestry) ranks 2nd to solar energy in terms of carbon reduction potential (Luik, 2025; Pachama, 2023).

8.2.3 Markets Financialize the Natural World: Pricing, Tracing, and Trading Ecosystem Services and Nature-backed Assets

Similarly to carbon markets, markets for nature-backed assets and ecosystem services are centered around different types of credits.

Table 27: Types of nature-backed assets and tradeable ecosystem services (Borges et al., 2022; Deloitte, 2024; Fiegenbaum, 2024; PWC, 2025; Rossberg et al., 2024; U.S. Securities and Exchange Commission, 2023)

Asset Type	Description
Carbon Credits and Offsets	Represent avoided or removed CO ₂ eq emissions through reforestation, soil health improvements, regenerative farming practices that sequester carbon, etc
Biodiversity Credits	Represent conservation and restoration of species or ecosystems quantified by some standard or criteria such as provided by Verra and Gold Standard
Water Rights and Wetland Credits	Represent rights to access water or preserve/restore wetlands which can be traded
Conservation Finance Instruments	Represent bonds or funds that protect forests, coral reefs, or species habitats

Asset Type	Description
Natural Asset Companies (NACs)	Represents a SEC-backed structure allowing public trading of ecosystem ownership rights
Tokenized Natural Resources	Represent blockchain-based representations of nature (e.g., tokenized forest)

8.2.4 Overconsumption > Earth's Boundaries

Excessive consumer lifestyle - *overconsumption* - is one of the main drivers of climate change and environmental destruction, with “*2/3 of global GHG emissions are directly and indirectly linked to household consumption, with a global average of about 6 tonnes CO₂ equivalent per capita*”, according to (Ivanova et al., 2020; Renee Cho, 2020). An older study put the number as high as 60% percent (Ivanova et al., 2016) while (Ellen MacArthur Foundation, Material Economics, 2019)’s models 45% show of CO₂ equivalent emissions come from our shopping; produced by companies to make the products we consume. (Keeble, 1988) reported in April 1987 that ‘*residents in high-income countries lead lifestyles incompatible with planetary boundaries*’. (Ivanova et al., 2020) reports the average footprint in North America and Europe is 13.4 t CO₂eq, in Africa and the Middle East 1.7t CO₂eq; consumption options with a high mitigation potential measured in tonnes of CO₂ equivalent per capita per year include “*living car-free*” and avoiding flying, which could each save upwards of 1.7t CO₂eq per person annually.

While the numbers on overconsumption are clear, the debate on overconsumption is so polarized, it’s difficult to have a meaningful discussion of the topic (Ianole & Cornescu, 2013). Environmental risks from human activities are known as Anthropogenic Threat Complexes (ATCs) (Bowler et al., 2020). With the trend of urbanization, it’s not surprising (people living in) cities are responsible for 80% of the emissions (Rosales Carreón & Worrell, 2018). (Moberg et al., 2019) reports daily human activities emission contribution on average in four European countries (France, Germany, Norway and Sweden).

Table 28: Daily human activities emission contribution on average in France, Germany, Norway and Sweden from (Moberg et al., 2019).

Emission Share	Category
21%	Housing
30%	Food
34%	Mobility
15%	Other

Taking a broader view, (Hannah Ritchie, 2020; US EPA, 2016) dissect GHG emissions inventory by sector and put the blame squarely on the type of energy used.

Table 29: Industrial Emissions (Hannah Ritchie, 2020; US EPA, 2016).

Sector	Share	Description
Energy Use (inc. electricity, heat and transport)	73.2 %	Total CO ₂ eq emissions from all fuel combustion and related fugitive losses. Energy use in industry (24.2%) in processing metals (iron and steel), chemicals and petrochemicals, food and tobacco, non ferrous metals, paper, machinery, other industry; transport (16.2%) road, aviation, shipping, rail; buildings (17.5%) including residential and commercial; fugitive emissions (5.8%) such as methane leaks from oil and gas exploitation and coal mining; plus other, unallocated fuel combustion related emissions (7.8%)
Direct Industrial Processes	5.2 %	Direct CO ₂ eq emissions from chemical reactions in cement and in chemicals and petrochemicals.
Waste	3.2 %	Wastewater methane and NO ₂ emissions; landfill methane.
Agriculture + LULUCF (Land Use, Land-Use Change & Forestry)	18.4 %	Emissions from grassland, cropland, deforestation, crop burning, rice cultivation, agricultural soils, livestock and manure.

Earth's growing population reached 8 Billion people In November 2022 and population projections by predict 8.5B people by 2030 and 9.7B by 2050 (The Economic Times, 2022; United Nations Department of Economic and Social Affairs, Population Division, 2022). Indeed, making *anything* consumes natural resources, which are limited on planet Earth. (Hassoun et al., 2023) forecasts increase of global food demand by 62% driven by the impact of climate change. Yet, while population growth puts higher pressure on Earth's resources, some researchers propose the effect is higher from wasteful lifestyles than the raw number of people (Cardinale et al., 2012). Meanwhile others, such as (Cafaro et al., 2022), believe *[o]verpopulation is a major cause of biodiversity loss and smaller human populations are necessary to preserve what is left."*

8.2.5 Plastic Pollution

Overconsumption is also one of the root causes of plastic pollution. (Ford et al., 2022) and (Lavers et al., 2022) find strong links between climate change and marine plastic pollution "*along with other stressors that threaten the resilience of species and habitats sensitive to both climate change and plastic pollution*".

Plastic pollution is pervasive around the Earth and is fundamentally linked to climate change, while microplastics are increasingly a real concern (Lavers et al., 2022; Tiernan et al., 2022). Several international studies report recent findings of microplastics everywhere in human bodies: the brain, lungs, digestive tissues, bone marrow, penis, testis, seminal fluid (semen), and placenta - causing serious health and reproductive concerns (Codrington et al., 2024; M. A. Garcia et al., 2024; Guo et al., 2024; Hu et al., 2024; N. Li et al., 2024; Main, 2024; Montano et al., 2023; L. Zhu et al., 2024)

Microplastics Inside the Human Body

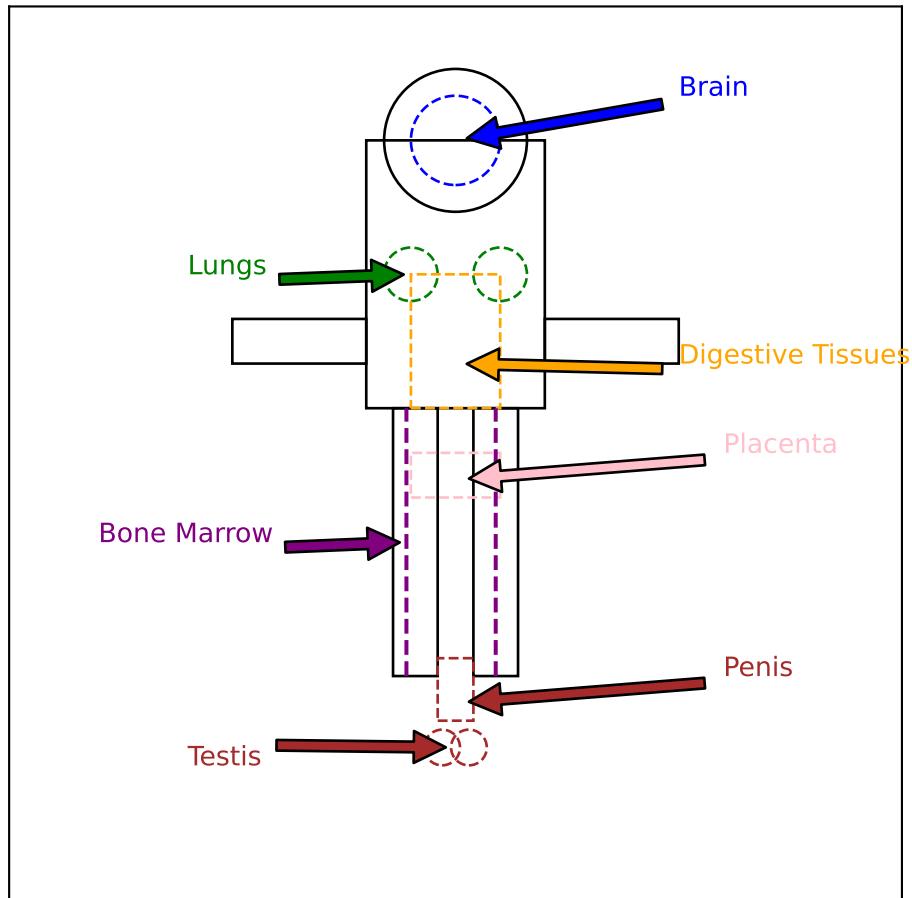


Figure 29: Microplastics in the Human Body

In addition to the enormity of over-reaching CO₂ emissions, humanity is facing other massive environmental problems. The Stockholm Resilience Centre report in 2022 we have already breached 4 out of our 9 “*planetary boundaries*”: in addition to climate change, biodiversity loss (Extinctions per Million Species per Year aka E/MSY), land-system change (deforestation, land degradation, etc), and biogeochemical flows (cycles of carbon, nitrogen, phosphorus, etc); on a positive side, the challenges of fresh water use, ocean acidification and stratospheric ozone depletion are still within planetary limits (Persson et al., 2022).

An update to the planetary boundaries framework a year later found the actual number to be 6 of 9 boundaries (climate, biosphere integrity, land use, biogeochemical flows, freshwater use, novel entities) already transgressed, with ocean acidification nearing its limit and only stratospheric ozone recovering; atmospheric aerosol loading and the biodiversity intactness index (BII), which belongs under biodiversity loss and measures how depleted are the species that are still around (but not yet extinct), were quantified recently (Newbold et al., 2016; Richardson et al., 2023).

In the biosphere, mass extinctions are underway. An analysis of population trends for 27600 terrestrial vertebrate species (including a detailed sample of 177 mammals), found 32% (8851 species) are undergoing severe range contractions; the authors name this “biological annihilation” to signal Earth’s ongoing 6 mass extinction and call for immediate conservation action (Ceballos et al., 2017). As of last year, the Red List curated by the International Union for Conservation of Nature (IUCN), includes 45,300 species (28% of all assessed, since IUCN was founded in 1948), under threat of extinction (IUCN, 2024).

Responding to the crisis, the Guardian newspaper in the UK has taken a clear stance, covering stories of extinction; the *Area de Conservación Guanacaste* is one of the protected areas listed by the UNESCO World Heritage Centre, providing data on the State of Conservation (SOC) by year (Centre, 1999; McClure, 2025)

In 2018 Swedish Sportswear brand Houdini launched the first corporate planetary boundaries assessment in partnership with Albaeco and Stockholm Resilience Centre to establish a baseline for its “impact positive” ambition (Houdini, 2018). While it’s a pilot study, it demonstrates how companies can integrate system-level science into sustainability reporting (Haeggman et al., 2018). At the 2024 update for the report, Houdini invited, Johan Rockström, a renowned conservation and climate scientist, envisions a global dashboard of the development of the economy and the state of the planetary boundaries, with high resolution maps, to help visualize Earth’s situation in real-time (Houdini Sportswear, 2024).

8.2.6 Evolving Measurements from Planetary Health to Earth System Law, and Social Cost of Carbon

Scientists in cross-disciplinary teams have been working on integrating Earth systems and human society into cohesive frameworks. (Wardani et al., 2023) stresses that every facet of Earth’s life-support system—living biota and the “abiotic” foundations of climate, water, soils, and geology—co-produces the conditions for civilization: “*long-term human well-being is dependent on the well-being of the planet, including both biotic and abiotic systems. It recognizes interlinkages across environmental sustainability, public health, and socioeconomic development.*”

There are 3 approaches that address the complex interdependence of humans with our physical environment, that have the potential to be complementary - *Planetary Health, Social Cost of Carbon, and Earth System Law*.

Planetary Health is a framework rooted in public health sciences and medicine; what if public health leveled-up to planetary scale, concerned with the health of ecological life-support sys-

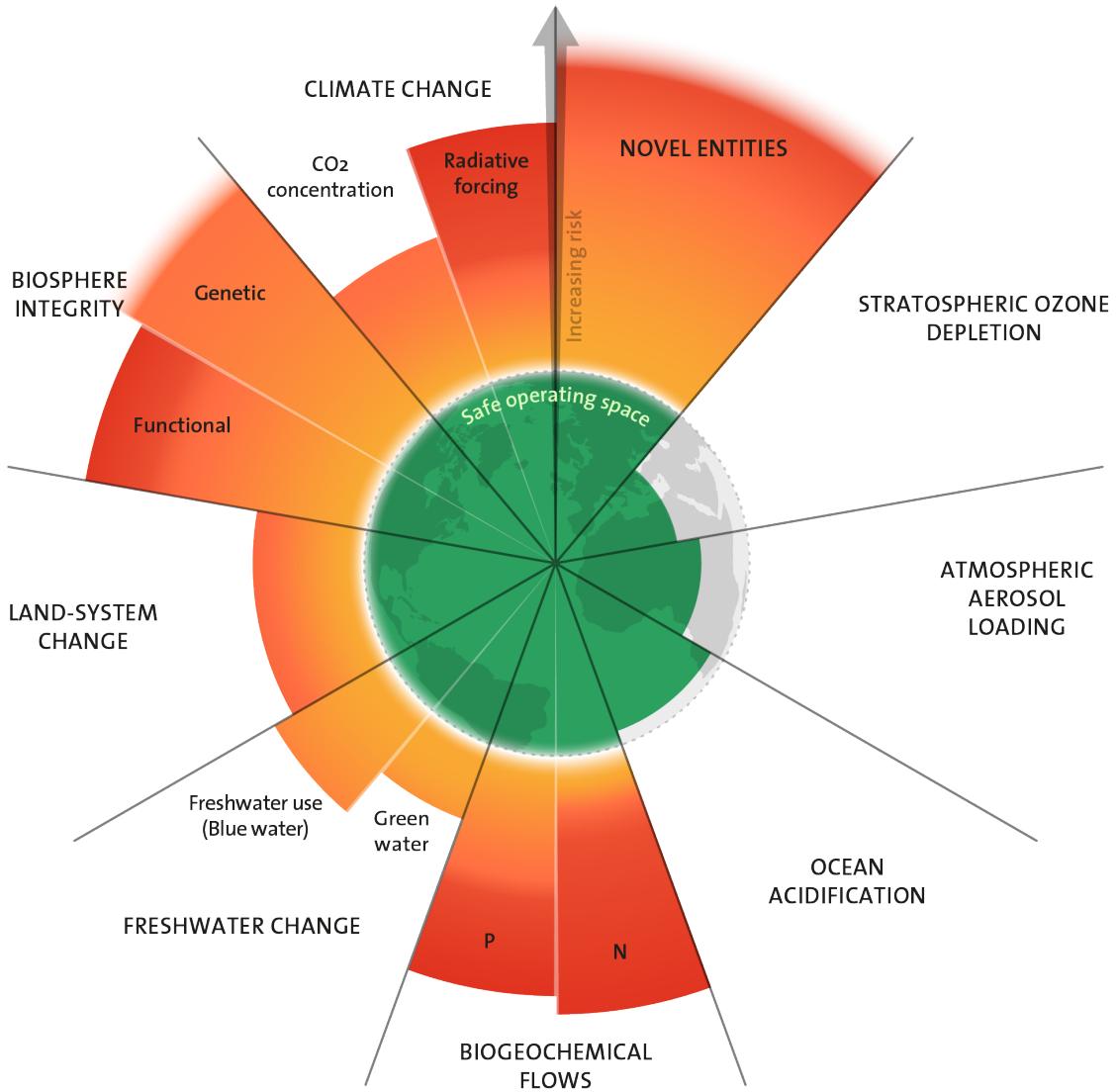


Figure 30: Planetary Boundaries 2023 update. Azote for Stockholm Resilience Centre, based on analysis in Richardson et al 2023

tems: clean air, food, and a safe climate, so they can support human flourishing; in practice the framework focuses on evidence, education, governance, and business (Planetary Health Alliance, 2024a, 2024b).

Social Cost of Carbon attempts to measures the compound impact of CO_{2e} emissions on society. Sustainability is filled with complexities. CO_{2e} emissions are complicated by biodiversity loss, child labor, slavery, poverty, chemical pollution, etc. - many issues become intertwined (TEDx Talks, 2020). One attempt to measure these complexities, is the *Social Cost of Carbon* (SCC) which is defined as “*additional damage caused by an extra unit of emissions*” (Kornek et al., 2021; Zhen et al., 2018). For example the cost of damages caused by “one extra ton of carbon dioxide emissions” (Stanford University, 2021). SCC variations exist between countries (Tol, 2019) and regions (Yong Wang et al., 2022).

Earth System Law is a framework rooted in the legal sciences for addressing interconnected environmental challenges in a hyper-connected Earth, where climate feedbacks and environmental thresholds don’t respect country borders; in practice, this line of thinking helps to develop carbon-budget clauses inside trade deals and biodiversity “safety brakes” that trigger when monitoring data shows an Earth boundary overshoot, potentially acting as the legal scaffolding that lets Planetary Health prescriptions and Social Cost of Carbon price signals be effective (Du Toit & Kotzé, 2022).

More recently, because of the complex interdependence, (J. Zhang et al., 2025) proposes a new sustainability index that systematically considers pertinent indicators of interdependencies and interactions across different dimensions of sustainability. Moreover, (Lenton et al., 2023) proposed a new innovative way to quantify the “cost” of global warming in human terms by counting the number of people forced outside the “human climate niche” (temperatures historically occupied by most of humanity); climate change has already exposed ≈ 9% of today’s population (>600 million) unprecedented heat stress, risking increased mortality, morbidity and displacement; if current trends continue by 2100, ~2.7 °C, 21–39 % or 2–4 billion people will be exposed by 2080–2100.

8.3 Quantifying Human Benefits from the Biosphere: Ecosystem Services

Ecosystem services measure the benefits humans receive from the biosphere. Put simply, *ecosystem services* enable human life on Earth - we are, in a very real sense, - dependent on nature. The biosphere is Earth’s life support system. Earth’s biosphere is made up of 846 terrestrial ecoregions, which are distributed across 14 major biomes and 8 biogeographical realms (Dinerstein et al., 2017).

While it can be assumed much of the flora and fauna are crucial for Earth’s systems, science is still in the process of understanding and quantifying its contributions. The history of the valuation of nature’s services goes back to the 18th century when David Ricardo and Jean Baptiste Say discussed nature’s *work*, however both considered it should be free (Gómez-Bagethun et al., 2010). In 1997 (Daily, 1997) proposed the idea of *ecosystem services* and (Costanza et al., 1997) attempted to assess the amount of ecosystem services provided. (Le Provost et al., 2022)’s study

shows *biodiversity* as one key factor to maintain delivery of ecosystem services. (Noriega et al., 2018) attempts to quantify the ecosystem services (ES) provided by insects.

The most complex computer models which attempt to capture ever more interactions happening in the physical realm are called *digital twins*. The EU is developing a digital twin of Earth to help sustainability prediction and planning, integrating Earth's various systems such as climate, hydrology, ecology, etc, into a single model (*Destination Earth | Shaping Europe's Digital Future*, 2023; J. Hoffmann et al., 2023). For instance, AI is being used to map icebergs and measure the change in size (European Space Agency, 2023). We can use all the data being recorded to provide a digital twin of the planet, nature, ecosystems and human actions to help us change our behavior and optimize for planetary wellbeing.

8.3.1 Ecological Indicators to Track Environmental Health

8.3.2 Measuring Biodiversity Loss, Ecological Indicators and Environmental Degradation

Sustainability can be measured using a variety of *ecological indicators*. Ecological indicators for Earth - *I would like to coin the word “ecomarkers”* - are like *biomarkers* in human health. Technological advances help scientist better understand nature. Cutting edge research uses AI-based voice recognition for listening to nature, assessing biodiversity based on species' sounds in the forest. Millions of detections of different species with machine learning passive acoustic AI models, can also assess species' response to climate change (AI for Good, 2023; Guerrero et al., 2023).

Around the world, pressure on ecosystems is rapidly increasing, with biodiversity destruction ever prevalent, making protecting biodiversity as urgent as protecting the climate. (Almond, R.E.A. et al., 2022) reported, the number of species killed, mass destruction of nature:

“69% decline in the relative abundance of monitored wildlife populations around the world between 1970 and 2018. Latin America shows the greatest regional decline in average population abundance (94%), while freshwater species populations have seen the greatest overall global decline (83%).”

In Europe, as of 2025, none of the evaluated biodiversity targets are on track; agricultural targets, such as reducing soil nutrient losses, and reducing fertiliser use, are particularly lagging (European Commission, 2025).

Environmental DNA (eDNA) helps scientists measure species abundance without direct observation through detection of DNA on genetic materials such as skin cells (Peter Andrey Smitharchive page, 2024). Cellular DNA can be isolated from various sediment types (Ogram et al., 1987). Beyond scientific applications, eDNA is being used to generate biodiversity credits by environmental asset rating companies such as BeZero, a ratings agency for the Voluntary Carbon Market (Ojoatre & Atkinson, 2023).

Similarly to climate protection, the UN has taken a leadership role in biodiversity protection, by organizing an annual Convention on Biodiversity. The history of the United Nations Convention on Biodiversity goes back to 1988, when the working group was founded (Unit, 2023). The Convention on Biodiversity 2022 (COP15) adopted the first global biodiversity framework to accompany climate goals (UNEP, Tue, 12/20/2022 - 07:44).

Table 30: Biodiversity loss data from (Bradshaw et al., 2021).

What Happened?	How Much?
Vertebrate species population average decline	68% over the last 50 years
Land surface altered by humans	70% of Earth
Vertebrate species extinct	700 in 500 years
Plant species extinct	600 in 500 years
Species under threat of extinction	1 million

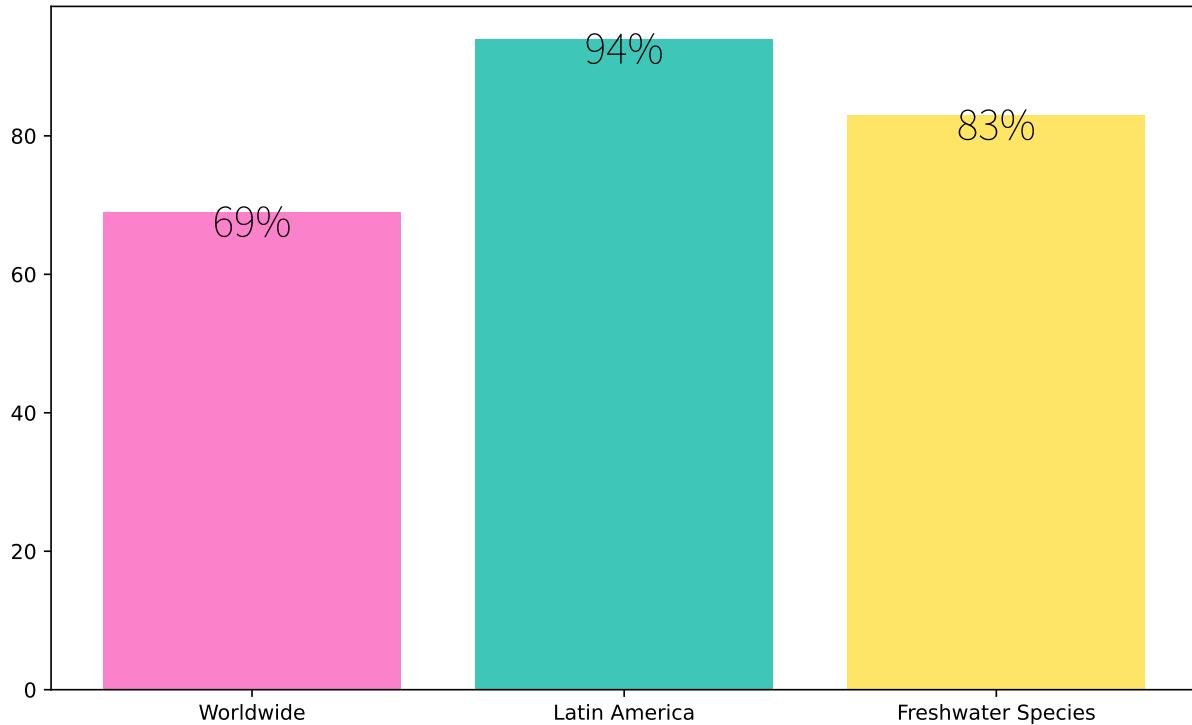


Figure 31: Biodiversity Loss

Biodiversity loss is linked to overconsumption, weak legislation and lack of oversight. (Crenna et al., 2019) recounts European Union consumers' negative impact on biodiversity in countries where it imports food. (WWF, 2022) case study highlights how 4 biodiverse regions Cerrado in Brazil, Chaco in Argentina, Sumatra in Indonesia, and the Cuvette Centrale in Democratic Republic of Congo are experiencing rapid destruction due to consumer demand in the European

Union. While the European Union (EU) has recently become a leader in sustainability legislation, biodiversity protection measures among private companies is very low Marco-Fondevila & Álvarez-Etxeberria (2023).

Starting with the simple question: why protect biodiversity. (May, 2011) argues biodiversity loss is a concern for 3 points of views:

Table 31: Ethical and Utilitarian Concepts of Biodiversity Protection from (May, 2011).

Point of View	Description
Narrowly Utilitarian	Biodiversity is a resource of genetic novelties for the biotech industry.
Broadly Utilitarian	Humans depend upon biodiverse ecosystems.
Ethical	Humans have a responsibility to future generations to pass down a rich natural world.

There is some progress in biodiversity conservation as “[*b]iodiversity awareness is now at 72% or higher in all countries sampled, compared to only 29% or higher across countries sampled in 2009”* (UEBT, 2022)

8.3.3 Oceans and Marine Ecosystem Sustainability

Marine heatwaves are intensifying under climate change, threatening species diversity and the ocean’s capacity to supply critical services from fisheries to carbon sequestration (Smale et al., 2019). Accelerating ocean warming, evidenced by record-breaking sea-surface temperatures, has triggered widespread coral bleaching, clearly visible at the Great Barrier Reef in Queensland, East Coast of Australia, loss of marine habitat complexity, and cascading threats to coastal economies and food security; the authors call for integrated climate–ocean policy action, stressing that without urgent emissions cuts and ecosystem-based adaptation, the ocean’s capacity to regulate climate and sustain biodiversity will collapse (Gelles & Andreoni, 2023; Pfeiffer, 2024). Cumulative pressures: climate extremes, pollution, and overexploitation - have driven evolutionary shifts in marine life and unpredictably altered ecosystem-service delivery (Espinosa & Bazairi, 2023).

Some earlier studies, such as (Howard et al., 2017) demonstrate how integrating blue carbon habitats into Marine Protected Area (MPA) design can both mitigate carbon emissions and enhance ecosystem resilience. Meta-analyses across 121 sites in 87 MPAs globally show that most well-designed and managed MPAs achieve significant ecological gains: on average, fish biomass inside no-take zones can double to triple compared with outside areas, and species richness likewise increases by 20–30 % within 5–10 years of enforcement (Rudd, 2015). However, Marine Protected Areas cover only 8% of the world’s oceans and only 2.8% is effectively protected (Igini, 2024a). The UN’s 30x30 target (set under the Convention on Biological Diversity) aims to protect 30% of the world’s oceans by 2030, however is not on track to achieve this goal (Mouterde, 2024).

8.3.4 Forests: Carbon Sinks and Biodiversity Reservoirs

Forests are a crucial part of Earth's carbon cycle and the main natural CO₂ capture system; due to deforestation, Europe rapidly losing its forest carbon sink (Frédéric Simon, 2022). Beyond their role in locking away carbon, recent field work shows forest actively scrub methane from the air as tree bark absorbs methane (Gauci et al., 2024). Around 27% of Earth's land area is still covered by forests yet *deforestation* is widespread all around the world; highest rates of deforestation happened in the tropical rainforests of South America and Africa, mainly caused by agricultural cropland expansion (50% of all deforestation) and grazing land for farm animals to produce meat (38.5%), totaling close to 90% of global deforestation (*FRA 2020 Remote Sensing Survey*, 2022). The global forest cover change is visible on Google's Earth Engine (Hansen et al., 2013).

Around the world, there are many initiatives to increase forest cover, for example the *1 billion tree project* (Bastin et al., 2019; “Erratum for the Report,” 2020; Greenfield & @pgreenfielduk, 2021). However, it's important to note that planting trees (*afforestation*) is not the full solution, as *afforestation* is different from *reforestation*, which takes into account biodiversity. Also, while using remote-sensing and machine-learning to assess reforestation potential (see Klosterman et al., 2022), it doesn't take into account local political realities, and socioeconomic issues such as education, poverty and access to green jobs. Taking these aspects into account may be beneficial, for example (Bousfield et al., 2022) reports there's evidence paying landowners for the ecosystem services their forests provide may reduce deforestation.

8.3.5 Pollution: Air, Water, and Soil Degradation

In Taiwan, this is the ranking of pollution reports by citizens (Ministry of Digital Affairs, 2024b):

Pollution Reports in Taiwan by District.

Health and sustainability are inextricably linked. “Human health is central to all sustainability efforts.”, “*All of these (food, housing, power, and health care), and the stress that the lack of them generate, play a huge role in our health*” (Sarah Ludwig Rausch & Neha Pathak, 2021).

(Abu El Kheir-Mataria & Chun, 2025) finds warming climate in the MENA region (Middle East and North Africa) increases cancer risk in women, mediated through air pollution and other environmental stressors.

Clean air is proposed as a *human right* (Baroness Jones of Moulsecoomb & Caroline Lucas, 2023) yet air pollution is widespread around the planet, with 99% of Earth's human population being affected by bad air quality that does not meet WHO air quality guidelines, leading to health problems linked to 6.7 million *premature deaths* every year (World Health Organization, 2022). Air pollution is linked to cancer incidence. In Taiwan, South Korea, and England, groundbreaking research by (Lim et al., 2022) analyzed over 400000 individuals establishes exposure to 2.5 μ m PM (PM2.5) air pollution as a *cause for lung cancer*. In (Hannah Devlin,

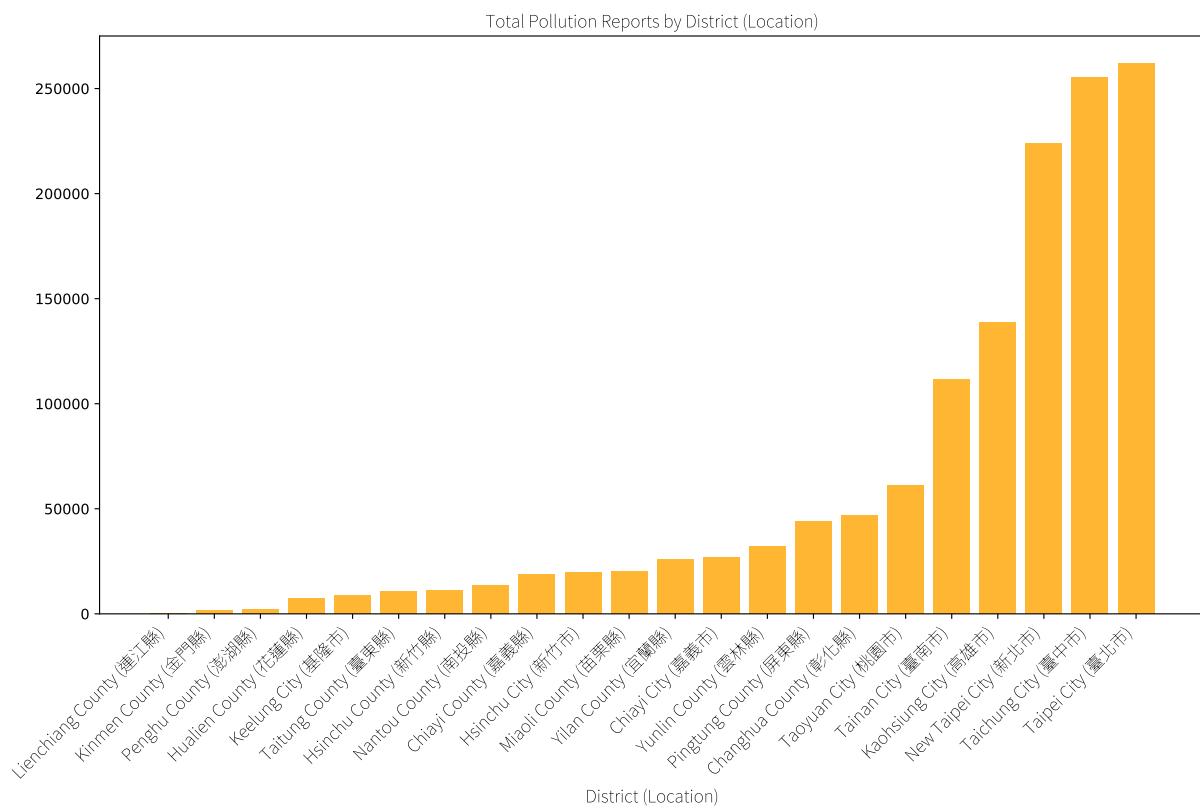
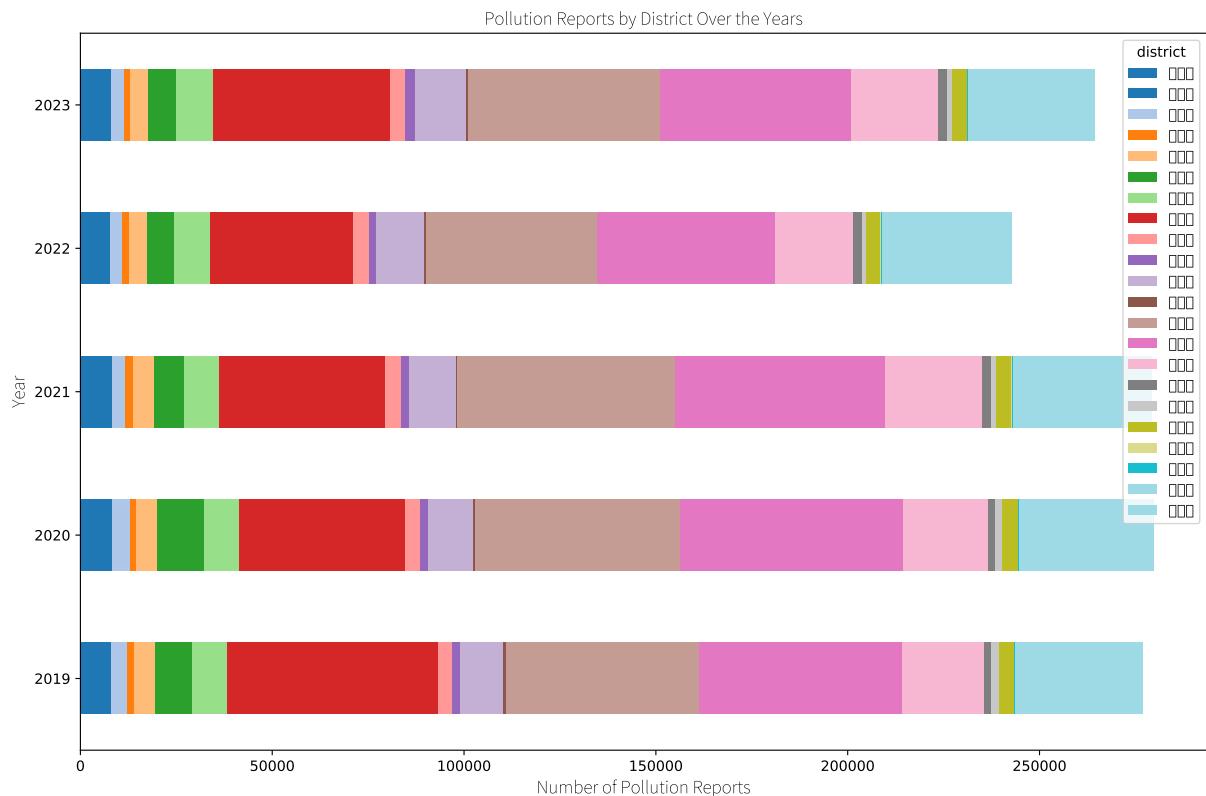


Figure 32: Pollution Reports in Taiwan by County

<Figure size 3600x2400 with 0 Axes>

(a) Pollution Reports in Taiwan by District



(b)

Figure 33

2022), professor Tony Mok, of the Chinese University of Hong Kong explains it plainly, which I want to quote here in verbatim:

“We have known about the link between pollution and lung cancer for a long time, and we now have a possible explanation for it. As consumption of fossil fuels goes hand in hand with pollution and carbon emissions, we have a strong mandate for tackling these issues – for both environmental and health reasons.” - (Hannah Develin, 2022)

The main way to combat air pollution is through policy interventions. (MARIA LUÍS FERNANDES, 2023) the EU has legislation in progress to curb industrial emissions. If legislation is in place, causing bad air quality can become bad for business. In China, (Gu et al., 2023) links air pollution to credit interest rates for business loans; companies with low environmental awareness and a history of environmental penalties pay 12 percent higher interest rates. In France, (Bouscasse et al., 2022) finds strong health and economic benefits across the board from air pollution reduction.

Likewise to the lack of clean air, lack of access to sufficient clean water and water pollution are issues in several places around the world; globally, 4.4 billion people only have access to water that's not safe for drinking (Soliman, 2024). Even in wealthy countries like the US, with increasing situations of water scarcity and drought due to climate change, issues of water ownership become increasingly dire. (Koch, 2022; Naishadham, 2023b) describes a fight in the US over water usage rights in Arizona, where Fondomonte, a subsidiary of a Saudi Arabian company that grows a water-hungry crop alfalfa, exacerbating the local water crisis by using large amounts of public water, leading to public outcry and being sued for “public nuisance” for its excessive groundwater pumping, and finally cessation of its lease and operations on state land; but still continuing operations on private land (Naishadham, 2023a; “Saudi Firm That Grows Hay in California and Arizona to Lose Farm Leases over Water Issue,” 2023).

Water quality is highly dependent on competent governance. For example, in the U.S., the national government recently rolled back rules for water safety, which had only been implemented last year, to protect the consumer from per- and polyfluoroalkyl substances (PFAS) (Trager, 2025). Once pollution is in the environment, cleaning it up is very expensive. For instance, in France, where storm water washed pollution into the waterways feeding into the Seine river, making it unsuitable for swimming, the city of Paris invested 1.4 Billion Euros to create a massive underground reservoir and a water cleaning system by the opening of the Paris Olympics in 2024 - and still the water quality would be variable based on rain incidence (Walt, 2023).

Water and soil pollution are highly connected, as water flows through soil. In Saudi Arabia, (Picó et al., 2023) used wild and ruderal plants as bioindicators to detect pollution of air, water and soil, specifically anthropogenic pollution, pharmaceuticals, pesticides, and other industrial chemicals, concluding both Abha and Riyadh showed notable levels of pollutants while Riyadh (a city with more industry) showed higher levels of pollution.

Improved farming practices directly improve soil structure (reducing runoff and contamination) and water retention, thereby mitigating both soil degradation and water pollution. Participants in the 2023 Baltic Sea Action Group for the EIT Food Regenerative Agriculture project (which

so far has trained over 1200 farmers and 160 farmers advisory groups in regenerative practices), highlighted practical soil - restoration methods in their respective countries: applying *biochar* on pilot plots in the Czech Republic increased water retention by up to 20%, no - tilling and cover - cropping practices in Hungary boosted insect - species counts by 15 points, and adopting regenerative crop rotations in Bulgaria cut synthetic fertilizer use by 25%; one of the challenges remains consumer awareness: only 12% of consumers in Central and Eastern Europe currently recognize the “regenerative” label - awareness must grow to drive demand (Baltic Sea Action Group, 2023).

A practical example of the interconnection between water pollution, agriculture, architecture, and extreme weather, are bioswales, which help catch storm debris and reduce water pollution. In Taiwan, (劉大正, 2010) showed that grass swales increase infiltration, reduce runoff, and improve downstream water quality, helping stabilize slopes via enhanced drainage (Taiwanese landscape is very mountainous, with); in a follow up field trial at a National Highway in Gangshan, grass swales consistently trapped sediments and adsorbed heavy metals from highway runoff before those pollutants could reach nearby waterways.

The above examples from around the world suggest that “*regenerative*” is not just a buzzword or wishful thinking - instead, it maps to a set of concrete practices and approaches to improve the condition of the living environment under threat from pollution.

8.3.6 Climate Disaster Preparedness: Extreme Weather Resilience

The Word Economic Forums Global Risks Report 2024 paints a bleak picture of the future with expectations of increased turbulence across the board based on a survey of over 1400 topic experts (World Economic Forum, n.d.). Global warming specifically increases the risk of disasters and extreme weather events; the US Global Change Research Program presented a comprehensive report to the US Congress, which links disaster-risk directly to global warming; for examples increased wildfires damage property, endanger life and reduces *air quality*, which in effect increases health challenges (*Fifth National Climate Assessment*, 2023). Warming global climate has concrete effects on daily life. Warmer climate helps viruses and fungi spread (Press, 2023). (Williams & Joshi, 2013) higher CO₂eq concentrations in the air can cause more turbulence for flights. As extreme temperatures are increasingly commonplace, with observed changes in heat-waves, there’s increased risk of wildfires (Perkins-Kirkpatrick & Green, 2023; Volkova et al., 2021), while flood risk mapping might lower property prices in at risk areas (Sherren, 2024). Summers of 2022 and 2023 were the hottest on record so far, with extreme heat waves recorded in places around the world (Douglas, 2023; Falconer, 2023; National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Commerce, 2023; NOAA National Centers for Environmental Information, 2023; Serrano-Notivoli et al., 2023; Venturelli et al., 2023).

The part of Earth where the *human climate niche* is becoming smaller (McKibben, 2023). As temperatures rise, certain cities may become uninhabitable for humans (CBC Radio, 2021). The summer of 2023 saw extensive wildfires in Spain, Canada, and elsewhere; rapidly moving fires destroyed the whole city of Lāhainā in Hawaii (Anguiano, 2023). In California, (Jerrett et al., 2022) says, “[w]ildfires are the second most important source of emissions in 2020” and “negate

reductions in greenhouse gas emissions from other sectors." Some parts of South America have seen summer heat *in the winter*, with heatwaves with temperatures as high as 38 degrees (Livingston, 2023).

In Taiwan disaster risk and hazard mapping is well-developed, with early warning systems, and comprehensive response preparedness - and painful experiences - instrumental to saving lives (Y.-J. Tsai et al., 2021). Intensifying storms forming near coastlines, can be expected with "*[c]hanges to tropical cyclone trajectories in Southeast Asia under a warming climate*" (Garner et al., 2024). The situation on the Pacific and Atlantic oceans is not dissimilar, with "*[o]bserved increases in North Atlantic tropical cyclone peak intensification rates*" (Garner, 2023).

In the Phillipines, with increasing extreme weather events, "*businesses are more likely to emerge in areas where infrastructure is resilient to climate hazards*" (Y. Cheng & Han, 2022). Across several case studies, (Fabris & Luburić, 2022) discusses vulnerable sectors from agriculture to transport, under threat from extreme weather events, such as floods, heatwaves, droughts, and storms impact human health: societal development and economic growth should be realistic on planning for weather-related impacts.

Climate-related disasters can spur action as extreme weather becomes visible to everyone. After large floods in South Korea in July 2023 with many victims, president Joon promised to begin taking global warming seriously and steer the country towards climate action (AFP, 2023; Al Jazeera, 2023; Web, 2023). South Korea has a partnership with the European Union (European Commission, 2023a).

8.4 Financialization of Nature vs Sacred Value: Scaling Up Sustainable Action

There are 2 main approaches to protecting nature:

Table 32: Economics of Nature Commodification vs Sacred Economics

Economics of Nature Commodification	Economics of the Sacred
Measure and assign monetary value to nature.	Nature is Sacred - such as are religious holy places - and can't be touched (Eisenstein, 2011, 2018)

The question of whether we should we put a price on nature (or is it time to leave utilitarian environmentalism behind?) is still openly debated, with pro-financialization voices arguing assigning monetary figures to nature's benefits legible to policymakers and markets, channeling large sums into conservation (e.g. carbon/biodiversity credits), while critics argue monetary metrics flatten relational, cultural and intrinsic values of ecosystems into exchange-value and commoditize nature, which may legitimize offsetting schemes that displace rather than prevent damage (Leverhulme Centre for Nature Recovery, 2023).

Ecosystem services literature defines a "Nature's Contributions to People" framework, originally proposed by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). (Díaz et al., 2018). (Muradian & Gómez-Baggethun, 2021) critically assess the

framework, arguing utilitarian and anthropocentric views of the ecosystem services concept perpetuates problematic dualisms (humans and nature are separate) - and call for a new approach centered on ecology.

Table 33: Defining Ecosystem Services Concepts from (Leverhulme Centre for Nature Recovery, 2023)

9 Steps Towards Defining Ecosystem Services
Identify ecosystem functions
Quantify ecosystem functions
Identify ecosystem services
Quantify ecosystem services
Quantify financial value of ecosystem services
Assign property rights
Create ecosystem service markets
Commodify nature

A practical example of ecosystem services becoming a common language comes from (Z. Zhang et al., 2023) who proposes integrating ecosystem services conservation into urban planning, so biodiversity could become part of city planning. Another example is tourism, a large industrial sector which relies on ecosystem services (L. Li et al., 2023). In Taiwan, (T. H. Lee et al., 2021) developed a framework of indicators to assess sustainable tourism.

8.4.1 Ecological Restoration: Damaged Ecosystems, Agroforestry & Permaculture

The concept of how a public resource is over-used until breaking down as each user only bears a fraction of the cost - known as *tragedy of the commons* - was described by the ecologist Garrett Hardin in 1968 (Hardin, 1968; Lopez et al., 2022; Meisinger, 2022; Murase & Baek, 2018). When so many systems are broken, some argue sustainability is not enough and we should work on *regeneration* of natural habitat. The UN announced 2021-2030 the Decade on Ecosystem Restoration, which includes a wide range of regenerative action (Fischer et al., 2021). For instance, (Han & Chen, 2022) identifies nature-based solutions “land re-naturalization (such as afforestation and wetland restoration)”

Table 34: Non-Exhaustive list of Regenerative Actions from (Han & Chen, 2022)

Non-Exhaustive list of Regenerative Actions
Afforestation
Wetland restoration

The organic food and drink market is growing worldwide, with gross sales in 2019 totaling over 106 billion euros, albeit being a small percentage of total food industry (Gamage et al.,

2023). Growing organic food poses many challenges, which farmers need to adapt to, in order to participate in regenerative food systems. One approach is growing food forests, also known as agroforestry, which integrates farming into natural environments, achieving CO₂eq storage in the soil through agriculture and forestry using agroecological practices.

In Ireland, (Irwin et al., 2023) studied dairy farmers' willingness to plant trees to increase vegetation cover on their land, finding that economic incentives alone are insufficient, and support in the form of advisory and education is needed. Similarly, in the Brazilian Amazon rainforest (Yadav et al., 2023) finds the active participation of the local community in planning permaculture practices, enhances their acceptance and effectiveness. In Bangladesh, (Ruba & Talucder, 2023) found agroforestry plays an active role in achieving the country's Sustainable Development Goals (SDGs), including zero hunger, climate action, mitigating climate change impacts through CO₂eq sequestration, life on land through biodiversity conservation and improving soil fertility, yet is hindered by the lack of policy support and educational level of the farmers. In the Baltic Sea region in North-Eastern Europe and Central Europe face similar challenges, (Baltic Sea Action Group, 2023) pointing out farmers' traditional mindset as the biggest obstacle, describing the paradigm shift from extractive farming to regenerative agriculture, using techniques such as no-till farming, which reduces soil erosion and improve soil health by reducing synthetic inputs; yet, it's not only a single practice that is enough, regenerative agriculture is a holistic approach and agroecology education programmes need to be comprehensive.

(G. Low et al., 2023) further studies how agroforestry deep integration into food value chains unlocks opportunities for recognition and rewards from economic actors in the network, underlining how complex and knowledge-heavy nature of value-capture, calling for further standardization of practices to reward sustainability practices and ecosystem services. The challenge lies in that bioeconomy is not inherently sustainable and may put biodiversity at risk, depending on the level of industrialization of agriculture and specific practices, which require deep knowledge and understanding of natural and artificial interactions the ecological systems; the authors advocate for a precise distinction between extractive and regenerative practices in "*bioeconomy*" (Ollinaho & Kröger, 2023). Finally, taking Brazil as an example, (De Queiroz-Stein & Siegel, 2023) argues for an integration of competing and conflicting bioeconomy policies, in order to achieve the goals of a sustainable bioeconomy.

Svalbard Seed Vault is an example of seed conservation to safeguard biodiversity by storing backup seeds of plants from around the world in cold storage (Asdal & Guarino, 2018; Westengen et al., 2013). Since its opening in 2008, the storage solution provided by the Norwegian government has stored seeds from 123 genebanks in 85 countries around the world ("Arctic Doomsday Seed Vault Gets More Than 14,000 New Samples," 2025; The Norwegian Ministry of Agriculture and Food, 2025). (Vitaletti, 2025) proposes using a blockchain-based lottery system to store seeds in local refrigerators, in order to enhance resilience and ensure survival of seeds, by storing seeds in many locations.

8.4.2 Energy: Climatech, Renewables, and Decarbonisation Pathways

Globally, 34% of all emissions come from energy production (US EPA, 2016), making it the key sector to require innovation for reducing carbon emissions. The International Energy Agency's (IEAs), "*Tracking Clean Energy Progress*" report on 50 distinct decarbonisation enablers and finds that only 3 components - solar PV, PV electric vehicles, and building lighting - are on track with the net zero by 2050 scenario, while 28 need more effort and 22 are "not on track" (IEA, 2023b).

Geopolitical situations can affect technology adoption; after Russia's war in Ukraine, Europe needed to quickly reduce consuming cheap Russian fossil fuel energy (in the form of gas) (Bona-sia, 2024). In 2024, for first time in Europe, renewables in the form of wind and solar energy surged past production of fossil fuels (Beer, 2024; Graham & Fulghum, 2024). Meanwhile, China is experiencing a solar installation rush before a deadline set by a new renewable pricing policy; from January to April 2025, a record-breaking 105 gigawatts (GW) of solar capacity was installed, bringing the total solar power close to 1 TeraWatt, predicted to make solar power China's main energy source in 2026(Carrie Xiao, 2025; L, 2025a; Redazione, 2025; Weaver, 2023; Y. Zhu, 2023).

(Gaure & Golombek, 2022) simulate a CO₂ free electricity generation system in the European Union where "*98% of total electricity production is generated by wind power and solar; the remainder is covered by a backup technology.*". The authors stipulate it's possible to power the EU without producing CO₂ emissions.

EU's energy mix in 2024:

Wind and solar energy overtook fossil energy in Europe:

Globally, renewables also overtook fossil fuels (IEA, 2024):

Meanwhile, reduction in coal-power was also possible. Coal is a large CO₂eq emitter.

Beyond electricity and heat, the chemical sector is a massive CO₂eq source. (Lange, 2021) reports the petrochemical industry uses about 10% of global fossil carbon as feedstock and another 7% to power its processes, producing some 400Mt of base chemicals each year, 36% of which becomes packaging; the cradle-to-gate CO₂eq emissions for base chemicals are roughly 1–2.5kg CO₂eq per kg or 5t CO₂eq per tonne of plastic, when including use and end-of-life, the entire lifecycle emissions are 1.7Gt CO₂eq (☒ 4% of all anthropogenic emissions) per year; a true circular-carbon economy would require renewable carbon feedstocks (e.g. biomass or CO₂-derived monomers), electrified green heat, closed-loop catalytic recycling of molecular building blocks, and modular low-temperature reactors to slash energy demand.

Large technology conglomerates and newly founded startups alike are working in the climate solutions space (often referred to as *climatech* by the media), have proposed a range of approaches to CO₂ reduction in the Earth's atmosphere. These technologies include several types of *carbon capture*, directly from the air (direct air capture or DAC), from the source of pollution, such as using high-performance filters on factory chimneys, as well as nature-based solutions such as large scale tree planting using drones. Each technology has their own pros and cons. For

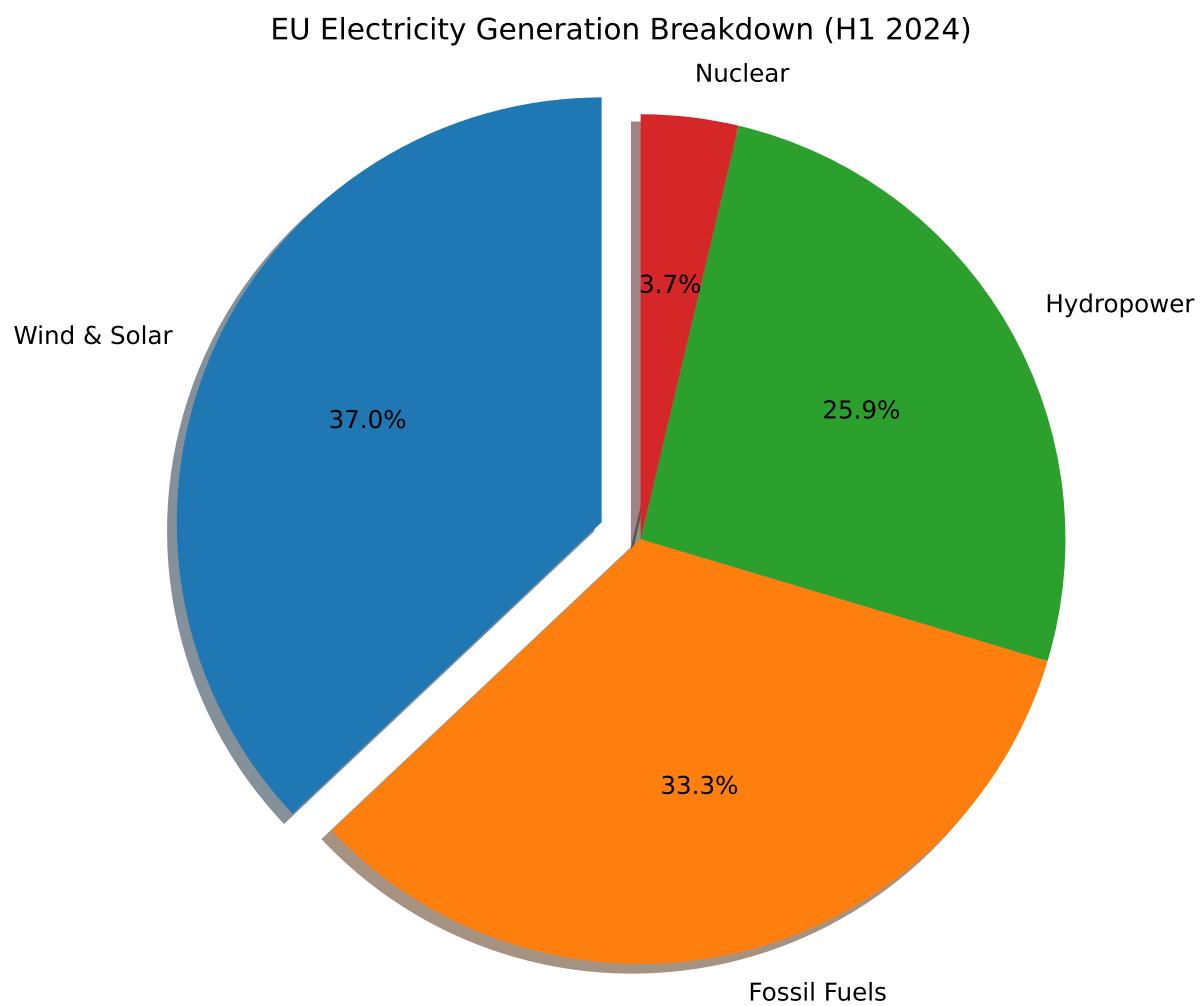


Figure 34: The EU's Energy Production Breakdown

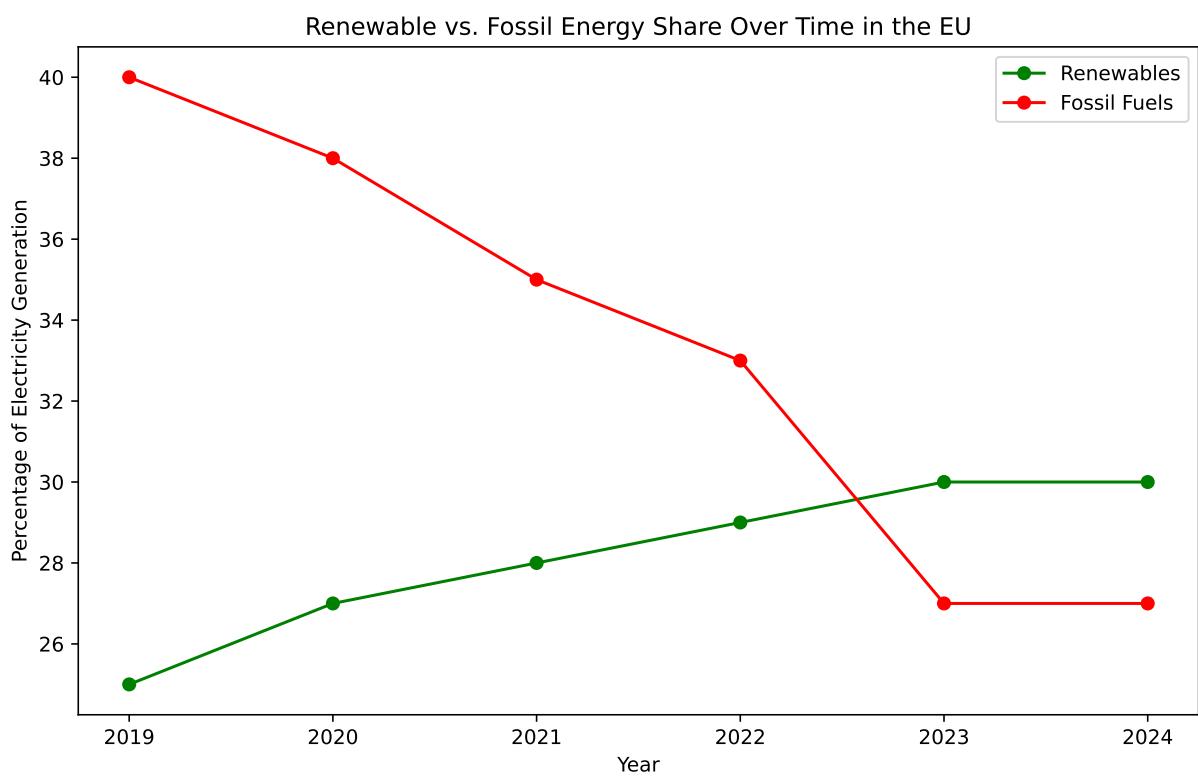


Figure 35: The EU's Renewables vs Fossil Energy

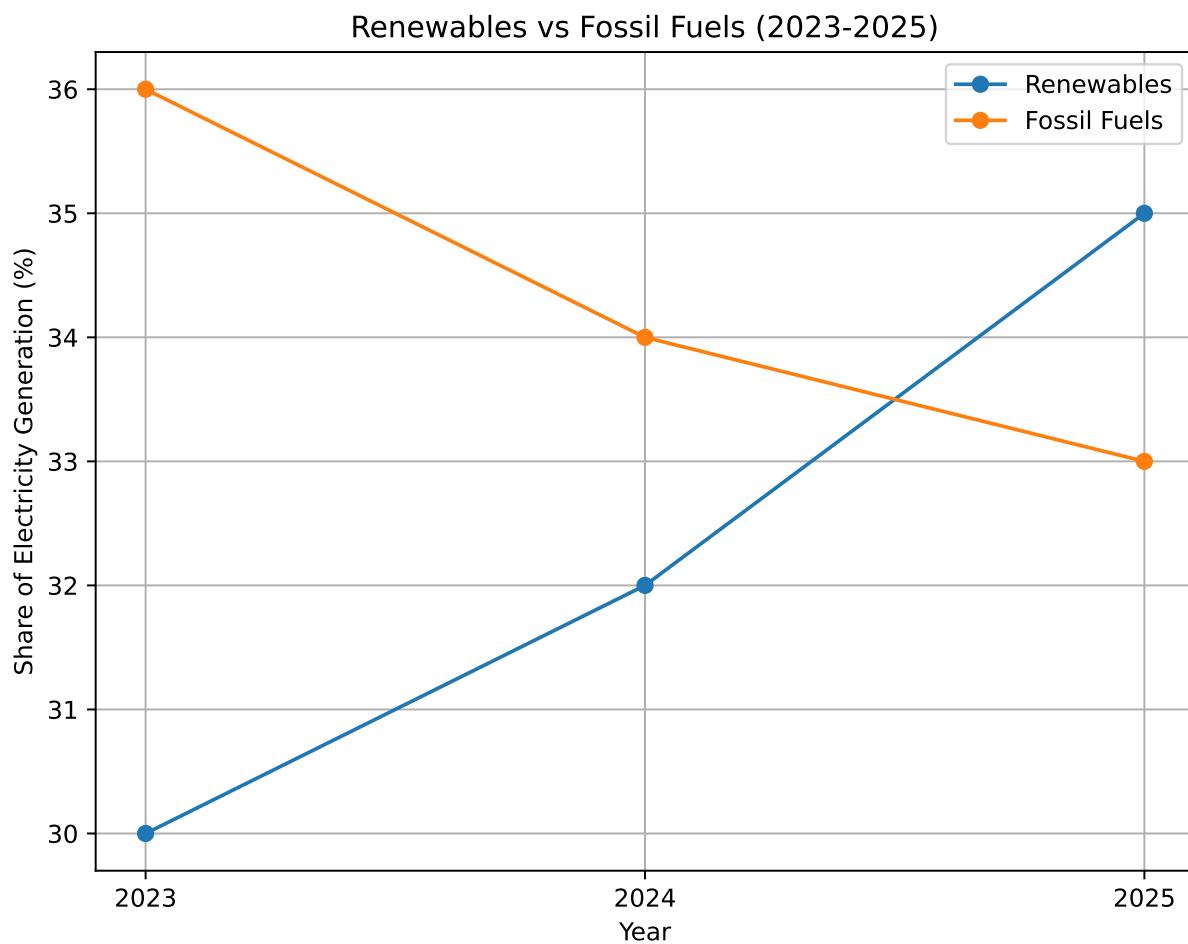


Figure 36: Global Renewables vs Fossil Energy

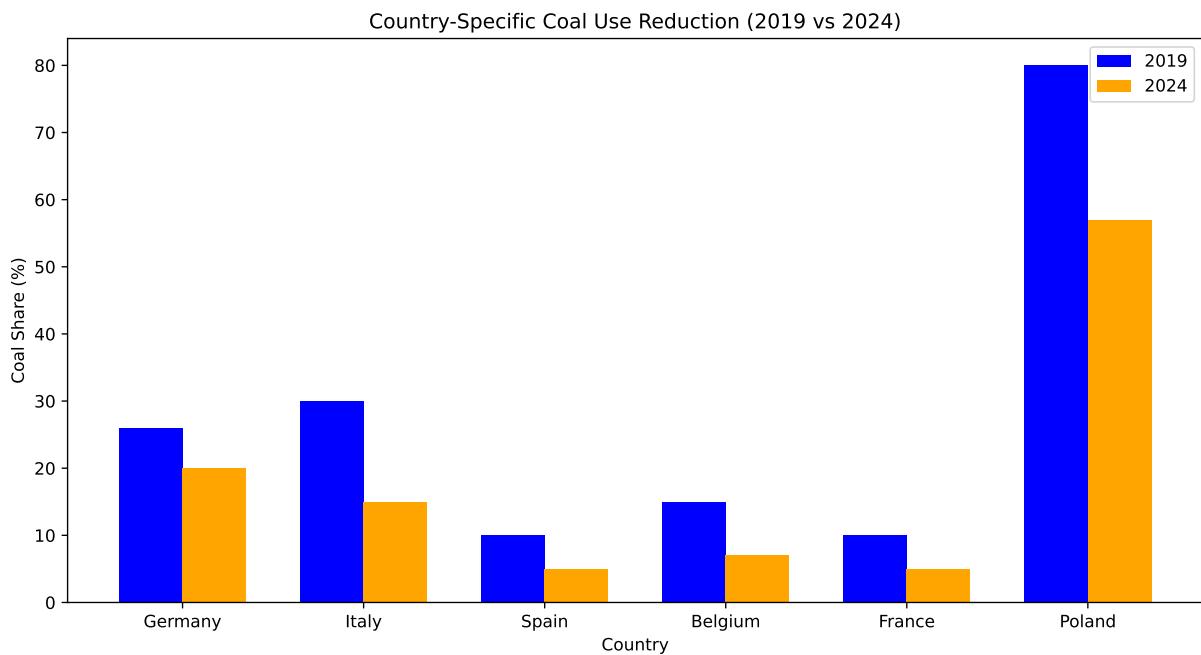


Figure 37: The EU's Reduction of Coal Energy

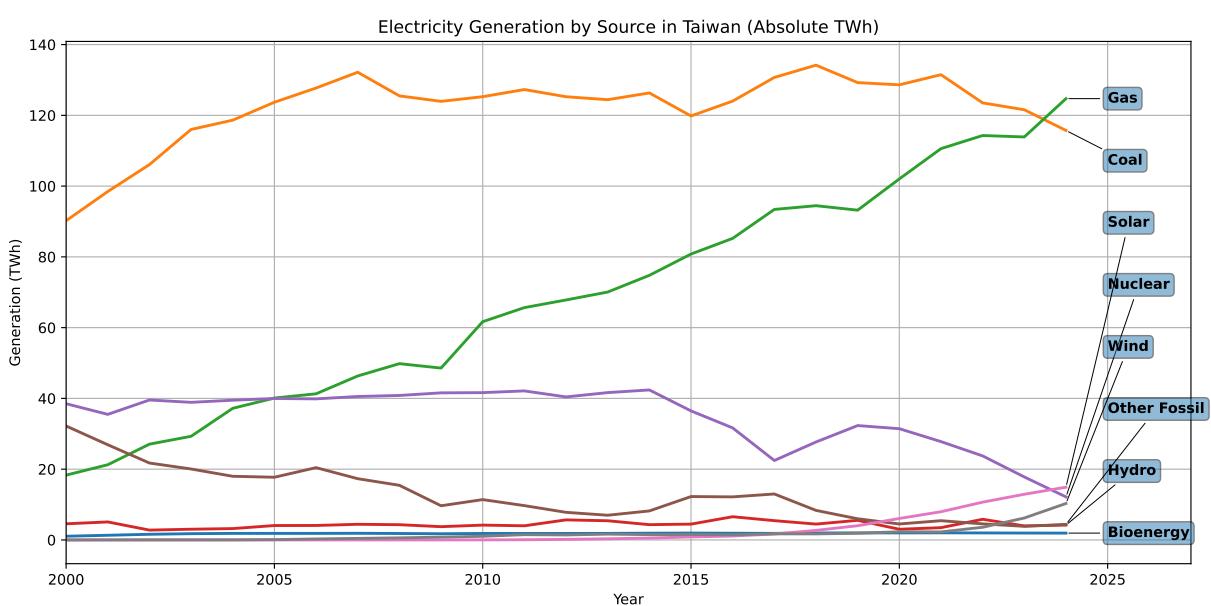


Figure 38: Taiwanese Energy Production

instance, (Vitillo et al., 2022) illustrates how direct air capture of CO₂ is difficult because of low concentration and CO₂ capture at the source of the emissions is more feasible. (Cleantech Group, 2023) profiles 100 innovators across agriculture, food, energy, mobility, and waste that Cleantech Group judges most likely to enable a future with sub-2 degrees warming. Overall, considering pathways to carbon drawdown finds considerable uncertainty exists among experts which CO₂eq reduction among nature- and technology-based methods are the most effective (S. Low et al., 2022).

8.4.3 Individual Action

Sometimes individual environmental (climate) action *does matter* and can come at great personal cost, even loss of life. EJAtlas tracks environmental justice cases around the world, where human stakes are very high Scheidel et al. (2020).

However, for most of us individual climate action is *ineffective*. The effect of individual climate action such as *choosing a more sustainable product* is so limited to be next to meaningless. For individual consumer choices to make a difference, they need to be *aggregated* into a movement, collective action with scale, influence, and visibility.

There is no single solution to the environmental crisis. Given the enormity of environmental degradation, many different approaches are needed. This chapter documents some of the ongoing work which a sustainability companion could assist college students get involved with.

While the scale of climate change is too big for individual action to make a difference, individual action can foster hope and a sense of collective responsibility (Nature, 2020).

9 DESIGN

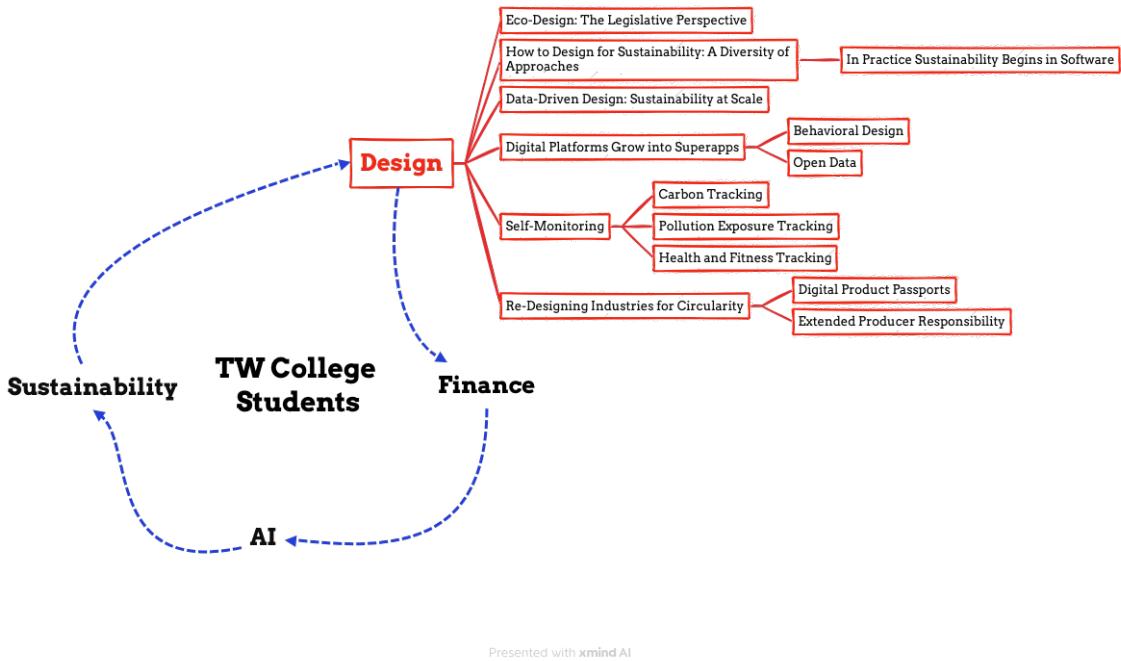


Figure 39: Visual abstract for the design chapter

Designers have been battling complexity since the beginning of design. Industrial designer Dieter Rams famously said in the 1970s “*Good design makes a product understandable*” as one of the ten key tenets to strive for in good products (DW Euromaxx, 2018; Fabrique & Q42, n.d.). Don Norman, the grandfather of interaction design, is quoted as saying:

“Modern technology can be complex, but complexity by itself is neither good nor bad: it is confusion that is bad.” - (Norman, 2016)

I would simply say: Design makes complexity comprehensible.

Sustainability is one of the most complex goals that humanity has set for itself. The following looks at some of the ways design might make it.. achievable.. and comprehensible.

9.1 Eco-Design: Design as Political Action at Scale

Politics matters in sustainability. In Brazil, deforestation fell 60% in 1 year, based on remote satellite reconnaissance, after the election of a more pro-environment leadership (Watts, 2023). Globally, the monumental task of removing several gigatons of CO_{2e} from the atmosphere requires massive policy shifts and collaboration across countries and industries (Mackler et al., 2021).

In Europe, the EU “Green Deal” legislative strategy is comprehensive and backed by science, with the EU Commission having released strategic foresight reports since 2020, and becoming a driving force of transformative climate legislation in Europe (European Commission, 2023b). The timeline of the policy context in Europe is as follows: in 2019, the von der Leyen commission adopted the European Union (EU) Green Deal strategy. In 2021 the Commision proposed a goal of reducing CO₂eq emissions by 55% by 2030 under the *Fit for 55* policy package consisting of a wide range of economic measures. In November 2022, the proposal was adopted by the EU Council and EU Parliament with an updated goal of 57% of CO₂eq reductions compared to 1990, set to become a binding law for all EU member countries (*EU Reaches Agreement on National Emission Reductions*, 2022; European Commission, 2019c, 2019a; European Council, 2022). In March 2022, the EU Circular Economy Action Plan was adopted, looking to make sustainable products *the norm* in EU and *empowering consumers* as described in (European Commission, 2022a).

Designing the right legislative measures can be hugely impactful.

Consumer products’ overall life-cycle environmental impact is defined in the design process by the materials and energy resources needed and the post-consumer potential for reuse or recycling. In the context of the European Union, *eco-design* has gained political support from European Commission as part of the EU’s “*Green Deal*” legislative strategy, aiming to transform European economies into sustainability leaders (Commission et al., 2014). The Ecodesign for Sustainable Products Regulation (ESPR) entered into force in July 2024 (European Commission, 2024b) following the (European Parliament, 2022) proposal whereby the European Commission established a general framework for *eco-design*: “*requirements for sustainable products, repealing rules [referring to the previous Eco-Design Directive (2009/125/EC)] currently in force which concentrate on energy-related products only*,” setting up a level playing-field for the organizations operating on the EU single market. Virginijus Sinkevičius, the EU Commissioner for the Environment, Oceans and Fisheries, is quoted as describing eco-design as design that “*respects the boundaries of our planet*” (European Commission, 2022c).

Table 35: The 9 qualities of *eco-designed products* based on the Ecodesign for Sustainable Products Regulation (ESPR) enacted as law in the EU as of July 2024 (European Parliament, 2022; Lüttin, 2025).

Feature	Benefit
Durable	Reduces the need to frequently replace the product
Reusable	Extends the product’s life-cycle; sell or share to the next user
Reparable	Extends the product’s life-cycle; fix instead of discarding
Upgradable	Extends the product’s life-cycle; improve performance without complete replacement.
Easy to Maintain	Reduce resources needed to keep the product functional

Feature	Benefit
Easy to Refurbish	Support second-hand use and circular economy
Easy to Recycle	Support material recovery at end of the product's life to reduce new resource extraction and pollution
Energy Efficient	Reduce product's CO ₂ eq footprint and operating costs
Resource Efficient	Reduce product's use of raw materials and energy during production and life-cycle

Eco-Design for Sustainable Products is a key EU sustainable policy design tool and each product covered by the ESPR is required to have a *Digital Product Passport* (DPP) which enables improved processing within the supply chain and includes detailed information to empower consumers to understand the environmental footprint of their purchases (European Commission, 2022b). It's safe to say the large majority of products available today do not meet these criteria. Given this far-reaching legislative effort, we have an opportunity to re-imagine how every product can be an eco-product and how they circulate in our circular economy. The Director of the French environmental NGO Pôle Eco-conception describes eco-design as “[l]ocated at the interface between consumption and production patterns, eco-design helps to structure the market for products and services using a life cycle approach and tangible criteria” (Chouai & Mayer, 2024).

The European Commission is set to propose a legally-binding 90% emissions reduction from 1990 levels to be achieved by 2040; however, political pushback by governments is likely to weaken the goal; the EU climate chief Teresa Ribera is looking for ways to find pragmatic solutions, by, for example, considering some use of carbon credits (thus far, all the goals needed to be achieved within the borders of EU; buying carbon credits from places outside the EU would not be counted as emissions reduction) (Taylor, 2025; Weise, 2025).



Figure 40: EU Policy Context Timeline

The above chart shows how the European Union has been on a path of climate legislation transformation.

The above chart illustrates the European “Green Deal”.

Combined Concept Map of EU Green Deal Regulations and Categories



Figure 41: The EU's Green Deal

In the countries that make up the European Union (EU), a wide range of legislative proposals, targets, organizations, and goals have existed for decades. It's not that the EU didn't have an overarching environmental policy before; rather it was vague and filled with loop-holes. Upcoming laws cited above aim to harmonize approaches to sustainability and raise standards for all members states, in turn influencing producers who wish to sell in the EU common market. National governments need to adapt EU legislation to local contexts. For example Estonian government adopted the Estonian Green Deal Action Plan (Eesti Rohepöörde Tegevusplaan) (Eesti Vabariigi Valitsus, 2022). From the legislative perspective, NFRD (Non-Financial Reporting Directive) is replaced by CSRD (Corporate Sustainability Reporting Directive) and ESRS reporting is the standard to meet CSRD requirements.

The EU is also concerned with supply-chain deforestation. The ESPR (Sustainable Products) and EUDR (European Union Deforestation Regulation) work hand-in-hand as part of EU's legislative efforts to promote sustainability. EUDR applies to all products placed on the market from December 2024 and June 2025 for small businesses. Greenpeace has called the EUDR "*first step to end its complicity in the reckless destruction of these life-support systems*" - yet to become a success story, there needs to be follow through, integrating forest protection throughout the economy. Some of the steps to achieve this include the EU *taxonomy of environmentally sustainable economic activities* published by the Technical Expert Group (TEG) on sustainable finance, as detailed in the report by (*EU Taxonomy for Sustainable Activities*, n.d.). The proposal for a Nature Restoration Law by the European Commission requiring member countries to restore 20% of EU's degraded ecosystems by 2030 and full restoration by 2050 has not yet passed (as of writing) (*Scientists Urge European Parliament to Vote for Nature Restoration Law*, 2023) and is facing a backlash (David Pinto, 2023).

Certainly the EU is not the only region legislating to promote sustainability; sustainability policy context is shifting around the world. There are legislative efforts in numerous jurisdictions, which have passed laws which aim to reduce the environmental impact of products throughout their lifecycles. In the US, the *Inflation Reduction Act* provided funding to development of decarbonizing technologies and includes plans to combat air pollution, reduce green house gases and address environmental injustices (Rajagopalan & Landigan, 2023). In Australia, the Product Stewardship (PS) scheme also includes an investment fund targeted at increasing the recycling rates of specific products (Australian Government, 2024). Australia, Japan, and Taiwan all have sustainable procurement schemes, prioritizing greener products in public purchases (Australian Government Department of Finance, 2025; Ministry of the Environment, Government of Japan, 2000; The Ministry of Environment of Taiwan, 2024).

I was torn whether to place *politics* under *sustainability* or *design*, and decided for the latter - as sustainability is primarily *descriptive*, using science to measure and present the real situation, while design is *prescriptive*: codifying decisions about how do we live - in products and services. Design *is* political.

9.1.1 Beyond Recycling: Default to Return, Repair, Reuse

(Gigerenzer, 2008) argues that heuristics - basically, rules of thumb - can make more accurate predictions about the future than statistical tools such as Bayesian and regression models, in certain contexts, especially when data is incomplete or noisy. This aligns with Herbert Simon's classic concept of bounded rationality, which suggests that people make decisions not by fully optimizing, but by satisficing, i.e. seeking good-enough options given limited time, information, and cognitive capacity (Simon, 1955). (Gigerenzer, 2008; Gigerenzer & Selten, 2002) updated the concept to introduce the idea of a toolbox of fast, dynamic, frugal heuristics - named ecological rationality, showing how humans use only a small amount of information, often ignoring most available data, adapting to specific environments: heuristics aren't irrational; they work well because they exploit the structure of real-world environments.

In the practice of design for sustainability, the recognizing that humans use heuristics, translates to making strategic use of choice architecture and *the power of defaults*: displaying the most sustainable option as the default - the oft-quoted example being green power as the default choice on the German energy markets (Antonides & Welvaarts, 2020; Kaiser et al., 2020). Several research projects of plant-based, vegan and vegetarian food defaults at (university) canteens show 45-58% increase in sustainable choices across studies (Boronowsky et al., 2022; Erhard et al., 2023; Ginn & Sparkman, 2024; A. W. Zhang et al., 2024). (Simon Sterne, 2023) argues good UX is about helping the user make decisions, which can be thought of as four key tactics: (1) simplify complex choices, (2) intelligent defaults, (3) clear real-time feedback on the outcome of each option, and (4) avoid unintended regret by testing decisions support aid systems.

The universal recycling symbol creator Gary Anderson created the symbol when he was an architecture student at USC (University of Southern California) in 1970 at the age of 23, inspired by Silent Spring, Earth Day, the Bauhaus, Bucky Fuller, Spaceship Earth, printing presses, and the Woolmark logo for wool industry certification, and even the Möbius strip, for a competition held by a packaging firm that was making paper containers for packaging (Swap Society, 2023).

9.1.2 Eco-Modulation: Extended Producer Responsibility Incentive Design

Eco-modulation is a legislative innovation, which makes harder to recycle items more expensive for the producer. Recycling fees take into account eco-design: an item from a single material is easier (cheaper) to recycle than product from composite materials. Eco-modulation makes the hidden cost of hard-to-recycle formats directly visible on the invoice.

While Taiwan doesn't yet have a specific eco-design law, there are various pieces of legislation promoting circular economy. Already in 1988, Taiwan implemented an Extended Producer Responsibility (EPR) scheme, followed by a recycling system (initially focused on electronic items) in 1998 (Chong et al., 2009). Eco-design initiatives in Taiwan started at least as early as 1994, when Taiwanese companies and universities noticed international sustainability trends and began to implement their own sustainable design initiatives (Jahau Lewis Chen et al., 2005).

The key to comparing Product Stewardship, Extended Producer Responsibility (EPR), and Eco-Design is the scope, as illustrated in the chart below. While Product Stewardship (PS) and Extended Producer Responsibility (EPR) deal mostly with the end of the product life-cycle (they are *reactive*), including their disposal and recycling (EPR going a step further than PS by shifting the responsibility to the producer), eco-design moves sustainability up the design chain (being *pro-active*), setting standards for making better products - in essence, attempting to *design-out* the waste.

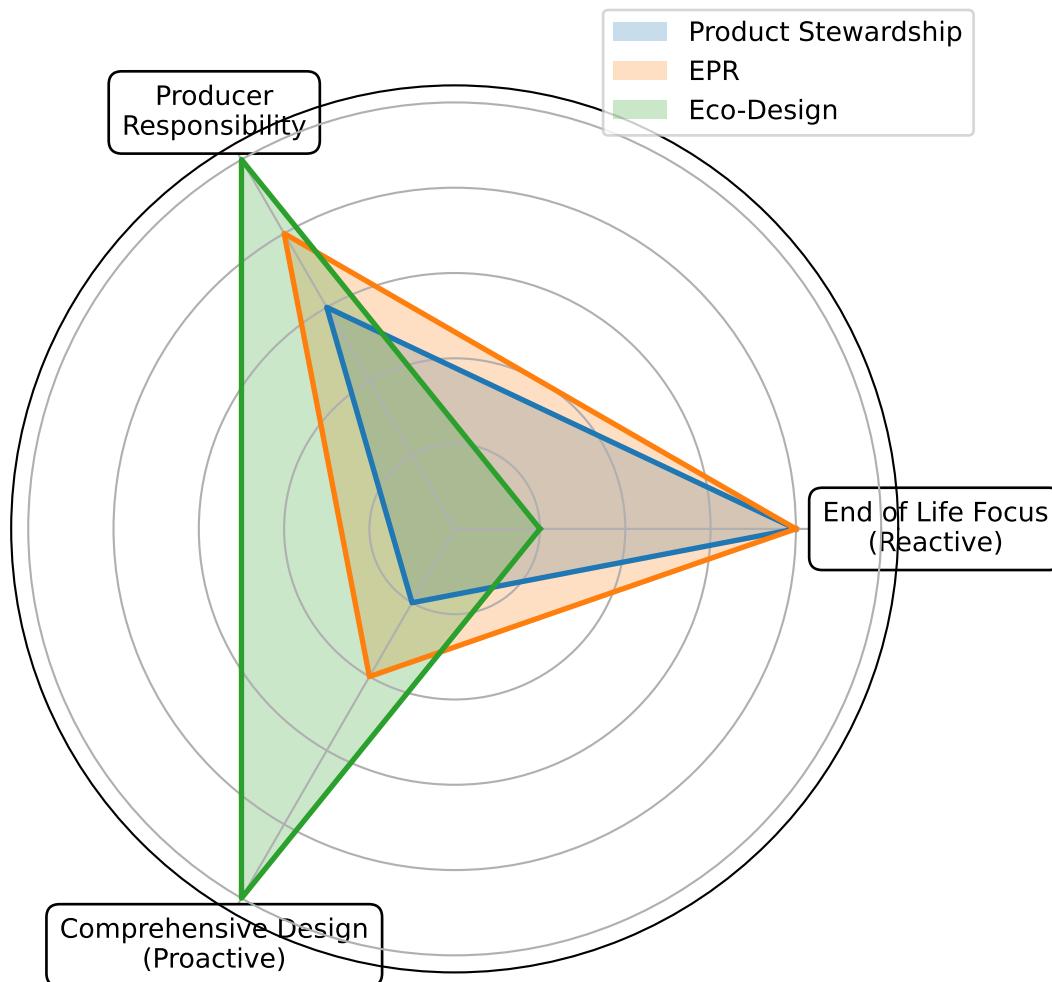


Figure 42: Extended Producer Responsibility vs Product Stewardship vs Eco-Design

Popular blogs such as (Kohli, 2019) and (Lose, 2023) offer many suggestions how designers can help people become more sustainable in their daily lives yet focusing on the end-user neglects the producers' responsibility - termed Extended Producer Responsibility or EPR in waste management studies.

Extended Producer Responsibility (EPR) is a policy tool first proposed by Thomas Lindhqvist in Sweden in 1990 and described in detail in his PhD thesis (Lindhqvist, 2000; Lindhqvist & Lidgren, 1990), aimed to encourage producers take responsibility for the entire life-cycle of their

products, thus leading to more eco-friendly products. In essence, Extended Producer Responsibility enables companies to be responsible for the entire life-cycle of the product. In California, part of the EPR regulation is a large pool of funding for cleaning up historic pollution resulting from industry Moolman (2024).

Nonetheless, EPR schemes do not guarantee circularity and may instead be designed around fees to finance waste management in linear economy models (Christiansen et al., 2021). The French EPR scheme was upgraded in 2020 to become more circular (Jacques Vernier, 2021). In July 2024, Latvia was the 4th EU country to join an textile-EPR scheme (“New EPR Requirements for Textiles in Latvia from July 2024 On,” 2024). Strong consumer protection legislation (such as EPR) has a direct influence on producers’ actions. For example, in (HKTDC Research, 2022), the Hong Kong Trade Development Council notified textile producers in July 2022 reminding factories to produce to French standards in order to be able enter the EU market.

In Europe, there’s large variance between member states when it comes to textile recycling: while Estonia and France are the only EU countries where separate collection of textiles is required by law, in Estonia 100% of the textiles were burned in an incinerator (as of 2018) while in France textiles are covered by an Extended Producer Responsibility (EPR) scheme leading to higher recovery and recycling rates (European Commission. Joint Research Centre., 2021; Nordic Council of Ministers, 2020). Yet, some countries like Germany (75%), Netherlands (45 %), and Denmark (43%), which have no specific EPR scheme for textiles, report higher collection rates than France, which with EPR collected only 38% of the textiles, however recovered 95% of that through reuse and recycling (Eurostat, 2022; *Towards 2025 - Separate Collection and Treatment of Textiles in Six EU Countries*, 2020).

The success of EPR can vary per type of product. For car tires, the EPR scheme in the Netherlands claims a 100% recovery rate (Campbell-Johnston et al., 2020). (J. Peng et al., 2023) finds that the *Carbon Disclosure Project* has been a crucial tool to empower Chinese auto-producers to adopt EPR schemes. Technological advancements play a big role in recycling rates, as even badly sorted materials can increasingly be recovered using AI; one example being Greyparrot AI, which notes that even in the most advanced countries, 40% of waste sorting is still manual, opening an opportunity for automation (Natasha Lomas, 2024).

While recycling rates are improving, (Steenmans & Ulfbeck, 2023) argues for the need to engage companies through legislation and shift from waste-centered laws to *product design regulations*. In the same vein, and in the spirit of EU’s EPR regulations, (Ruiz-Pastor & Mesa, 2023) proposes an integrated *product repairability index* (PRI). (Lenovo, 08-29-22) suggests rethinking product design entirely to inspire consumers expect more from the devices they buy. (Duriez et al., 2022) shows how simply by reducing material weight of the product, it’s possible to design more sustainable transportation. However, the devil is often in the details. (Formentini & Ramanujan, 2023) study of Design for Circular Disassembly (DfCD), introduces a Disassembly Effort Index (DEI) to measure the disassembly time in seconds; their case study of the End-of-Life (EoL) of an electrical kettle showed ignoring realistic EoL failures (such as rusted screws), can lead to inaccurate recommendations for circular design parameters.

Packaging is a rapidly growing industry, expanding on the back of online shopping, which gen-

erates large amounts of waste materials, which if not reused or recycled, easily becomes garbage. Over 161 million tonnes of plastic packaging is produced every year (Bradley & Corsini, 2023). Already more than a decade ago, (“Detail-Rich Sustainable Packaging Product Database Is an Industry First,” 2010) proposed a database of green packaging to compare hundreds of sustainable packaging materials and guide designers through environmental, performance, and cost trade-offs in one unified tool, in order to help producers choose better packaging - yet the problem is far from solved. More recently, (Bradley & Corsini, 2023) developed an analytical framework of key sustainability factors, from an overview of 107 studies on reusable packaging, finding customer acceptance, high return rates, supply-chain shortening, and system standardization, as the key factors critical to unlocking reusable packaging solutions at scale. A survey by PMMI, the Association for Packaging and Processing Technologies, among industry professionals, found legacy equipment, higher material costs, and supply consistency as the top barriers to sustainable packaging; in turn, vital enablers were clear vendor guidance, proven material and equipment solutions, and customer demand (“Challenges and Opportunities in Sustainable Packaging Today,” 2022). In response to legacy equipment issues, (“Sulapac – Replacing Plastic,” n.d.) a large producer of packaging, has proposed a wood-based, microplastic-free composites to serve as drop-in replacements for plastics; a material even compatible with existing molding, extrusion, and thermoforming production lines, while slashing cradle-to-gate CO₂ emissions and preventing microplastic pollution.

In food packaging specifically, (Ada et al., 2023) identified distinct challenges from consumer acceptance to material-supply mismatches, collection logistics, and regulatory gaps, underscoring the multifaceted barriers to circular food packaging. Over 85% of companies in the “protein industry”: meat, poultry, seafood, and alternative proteins have some type of sustainability initiative (“Protein Brands and Consumers Alike Focus on Sustainability,” 2022). Yet, having sustainability programs does not make a company sustainable, case in point being Coca Cola in the beverage industry. (Lerner, 2019) describes Coca Cola’s plastic pollution problem, based on leaked audio, detailing how Coca-Cola was exposed for lobbying against container-deposit laws - aka Deposit Return Schemes (DRS), - aiming to misrepresented recycling as a complete solution; strategies that stalled effective legislation and maintained a “green” facade despite obstructing real sustainability progress.

The “*Plastic Waste Makers Index*” report lists large corporations which produce plastic waste globally and provides some useful statistics: single-use plastic rose by 6 million tonnes from 2019 to 2021, while just 3 million tonnes of recycling capacity was planned by 2027 (as of the report date, 2023); in total, single-use plastic generated 450 million tonnes of CO₂eq emissions per year; up to 98% of the single-use plastic was produced from virgin petrochemicals, while 2% was from recycled material; meanwhile in Taiwan, the Far Eastern New Century company boosted recycled content from 2% to 11% per cent in 2021 and plans to double its recycling capacity (Minderoo Foundation, 2023). (Yap et al., 2023) Singapore disposes of 900,000 tonnes of plastic waste each year, out of which only 4% is recycled. Single-use plastics make up 44-68% of all waste mapped by citizen scientists (Kiessling et al., 2023).

9.1.3 Scenario-Building: The Worst Futures and Designs for Quality of Life

Scenario-building is a key tool for sustainability, because sustainability is so complex. Sustainable design cannot always predict certain outcomes - instead, it can make use of scenarios to prepare for several possibilities. In sustainability, there are rarely good choices. Rather it's a question of avoiding the worst choices. One existing tool, which has been widely used, is the EnROADS climate change solutions simulator; governments, organizations and individuals around the world have used it explore climate scenarios based on interactive changes and visualizations (Climate Interactive, n.d., 2023; Creutzig & Kapmeier, 2020; Czaika & Selin, 2017). Likewise, (Rooney-Varga et al., 2019) shows the effectiveness of *The Climate Action Simulation* in educating users about *success scenarios*. *Life Cycle Assessment* and *Environmental Impact Analysis* are another set of useful tools to provide eco-design scenarios (de Otazu et al., 2022).

While traditional economic thinking is based on a conflict between nature and development, some new holistic models find there is potential for synergy between economic, social, political, cultural, and environmental metrics. For example, (Kaklauskas et al., 2023)'s multi-criteria analysis of 169 countries and 238 cities, finds 71% average correlation between Climate Change and Country Success (C3S) and Quality of Life (C3QL) indicators. In a similar vein, (Rieger et al., 2023) develops an integrated science of wellbeing, linking humans' psychological, biological, societal and environmental domains to guide research and public policy, based on interactions between domain experts.

Wellbeing Economy Governments is an example of country-level collaboration in sharing expertise on sustainable development, looking to bring post growth strategies and policy frameworks to the mainstream. The concept of a wellbeing economy focuses on human and ecological well-being rather than material growth since 2018 and includes Finland, Iceland, New Zealand, Scotland, Wales, and Canada as founding members of the network (Fioramonti et al., 2022).

(Popkova et al., 2022) argues that SDGs need to discussed in their totality and uses factor analysis to link SDGs to institutions and digital technologies; findings include SDG 3 (Good Health and Well-Being) and SDG 17 (Partnerships for the Goals) progress through institutions in developed countries and are most impacted by digital technologies and digital knowledge index, meanwhile SDG 16 (Peace, Justice and Strong Institutions) makes the most headway in developing countries, which are starting from a lower base. Likewise, the German Institute of Development and Sustainability (IDOS) has built a tool to connect SDGs and their 169 targets to NDCs (Nationally Determined Contributions), looking for synergies for effective climate action plans and sustainable development strategies, visualizing a clear skew which SDGs receive the most climate - related commitments - SDG 2 (Zero Hunger), SDG 6 (Clean Water and Sanitation), SDG 7 (Affordable and Clean Energy); meanwhile SDG 14 (Life Below Water), and the SDG 3 social goals discussed above, SDG 4 (Quality Education) and SDG 5 (Gender Equality), are the least addressed in climate plans (Dzebo et al., 2023).

Eco-Design is about improving processes and optimizing resources. While the goal of reducing harm is shared, the specifics will depend on the industry. (Van Doorsselaer, 2022) Defines eco-design as "*design for X*" in a circular economy, thinking through the life cycle of a product, tools, materials, production, use, and end-of-life phases.

In wine-making, (Manzardo et al., 2021) presents an Italian winery case study, where a re-designed Merlot red wine procedure reduced in environmental impacts from fuel and pesticide use in vineyards; the 8-step procedure included calculating the product's environmental footprint and following the ISO 14006 standard, titled "*Environmental management systems—Guidelines for incorporating ecodesign*". Finding uses for by-products, can improve sustainability even more. (Iñarra et al., 2022) designed a circular scheme for brewery left-overs, producing feed ingredients for aquaculture; in a further step, using life-cycle assessment (LCA) and optimizing logistics, reduced the aquafeed's environmental footprint also by 6%.

In architecture and the built environment, (Munaro et al., 2022) conducted a comprehensive reviews of eco-design 288 articles, identifying *Design for Adaptability* and *Disassembly* as the most inclusive strategies, coining a new term DfAD; a framework linking DfAD with lifecycle assessment tools is a promising area for research to support sustainable construction.

In pharmaceuticals, (Bassani et al., 2022) proposes an approach to eco-design using life-cycle assessment: optimizing packaging types, alternative materials, transport, and weight reduction. A follow-up study from the same group in 2023 extended the eco-design to a full cradle-to-grave assessment and evaluated end-of-life alternatives (Bassani et al., 2024).

In the printing industry, (Miyoshi et al., 2022) takes the example of ink toner bottles and applies Life Cycle Simulation to show in a case study how standardized compatibility between older and newer systems can save resources and results in sustainability savings, highlighting how remanufacturing is an important strategy in circularity for reducing CO₂ emissions and life cycle costs.

While these examples underline the industry-specificity of eco-design, some authors attempt to come up with more holistic approaches. For instance (Ruiz-Pastor et al., 2022) developed "CN_Con", a metric for conceptual design, trying to measure circularity and novelty in conjunction, by analyzing product functions, durability, material origins, and end-of-life, while at the same time supporting creative and circular design solutions in early stages.

On an international level, looking at companies operating on the European Single Market, (Aranz et al., 2022) conducted a large-scale study using machine learning on firm survey data from 870 organizations across diverse economic sectors, acquired from the 2015 EU Public Consultation on the Circular Economy conducted by European Commission, comparing coercive pressures (regulations, subsidies, grants), normative pressures (industry standards, professional networks), and mimetic pressures (competitive imitation), finding normative and mimetic pressure only enhance sustainability, if coercive pressure already exists - i.e. regulations are a key point of leverage. In summary, enacting laws which support sustainability can shift complex systems with many parties towards a circular economy, and be enhanced by additional voluntary forces. However, a comparative analysis of OECD green growth indicators for the periods 2004–2005 and 2019 across EU member states found that green transformation do not correlate directly with development level - instead each country's unique socio-economic context plays a role: governance quality and income distribution shape the effectiveness of regulatory frameworks, suggesting that coercive policies must be tailored to national circumstances in order to reinforce circular-economy adoption at scale(Cheba et al., 2022).

9.2 Thinking in Systems to Re-Design Industries or Provenance and Traceability

As of 2025, *circular economy* is a tiny part of the world economy. (Circle Economy, 2022) reported in 2022 only 8.6% of world economy was circular and *100B tonnes of virgin materials* was sourced every year. An early pioneering innovator, (Jackson, 1996) showed through detailed case studies how *preventive environmental management*, redesigning industrial production at the source can avert pollution, laying the conceptual groundwork for today's circular-economy models. Many companies are investing into transforming their processes. “[*T*]ransition to a low carbon economy presents challenges and potential economic benefits that are comparable to those of previous industrial revolutions” (Pearson & Foxon, 2012).

Futurists and visionaries adept at naming things have already listed the 5th, 6th, and even the 7th industrial revolution, pointing at robotics, quantum computing, nanotechnology, and more, looking at current trends and building scenarios for 2050 to envisioning a world with convergence of bio-based and mineral-based technologies, widespread sustainability, and energy-abundance (Chourasia et al., 2022; Ruiz Estrada, 2024). If indeed, we're in an industrial revolution, it's possible to re-design entire industries, and that is exactly the expectation sustainability sets on businesses. Across all industries, there's a call for more transparency. Conversations about sustainability are too general and one needs to look at the specific sustainability metrics at specific industries to be able to design for meaningful interaction. There's plentiful domain-specific research showing how varied industries can develop eco-designed products.

I use the lens of *sustainability* - a complex term - to look at how design can contribute to eco-friendly products, advocating a diverse set design methods as a toolbox, where one can pick a suitable tool to match the problem. While AI allows us to look at a larger number of design scenarios than previously feasible, there are many approaches to design for sustainability, with varied design practices that may be relevant at different times in the process. Designing for sustainability is fundamentally a hopeful act, imbued with the belief that a healthier world is possible - because health and sustainability are intrinsically connected. As this research is *practice-oriented* (i.e., my goal here is to find design approaches that could influence my prototype), I will focus on some fields of design which I hope relevant, fruitful, or contextual to my project.

Eco-Design, Circular Design, Design for Circularity, Cradle-to-Cradle Design, Green Design, Regenerative Design, Climate-Responsive Design, Life-Centered Design, Design for Human Rights, Multispecies Design, Designing for Health - designing for sustainability has been called with many names in diverse contexts of use, using a diversity of approaches, with subtle differences of emphasis and nuance, with same general goal of being more sustainable. While EU legislation chose *Eco-Design* as the overarching title, researchers and practitioners discuss all of the above on a frequent basis. (Ceschin & Gaziulusoy, 2016) gives a comprehensive overview of the main themes of sustainable design and the main contributions and limitations in the well-researched “*Evolution of design for sustainability: From product design to design for system innovations and transitions*”.

Human-Centered Design is the grandfather of design with *attitude*. There's even an ISO standard for human-centered design, with the designated code ISO9241-210, revised as ISO 9241-

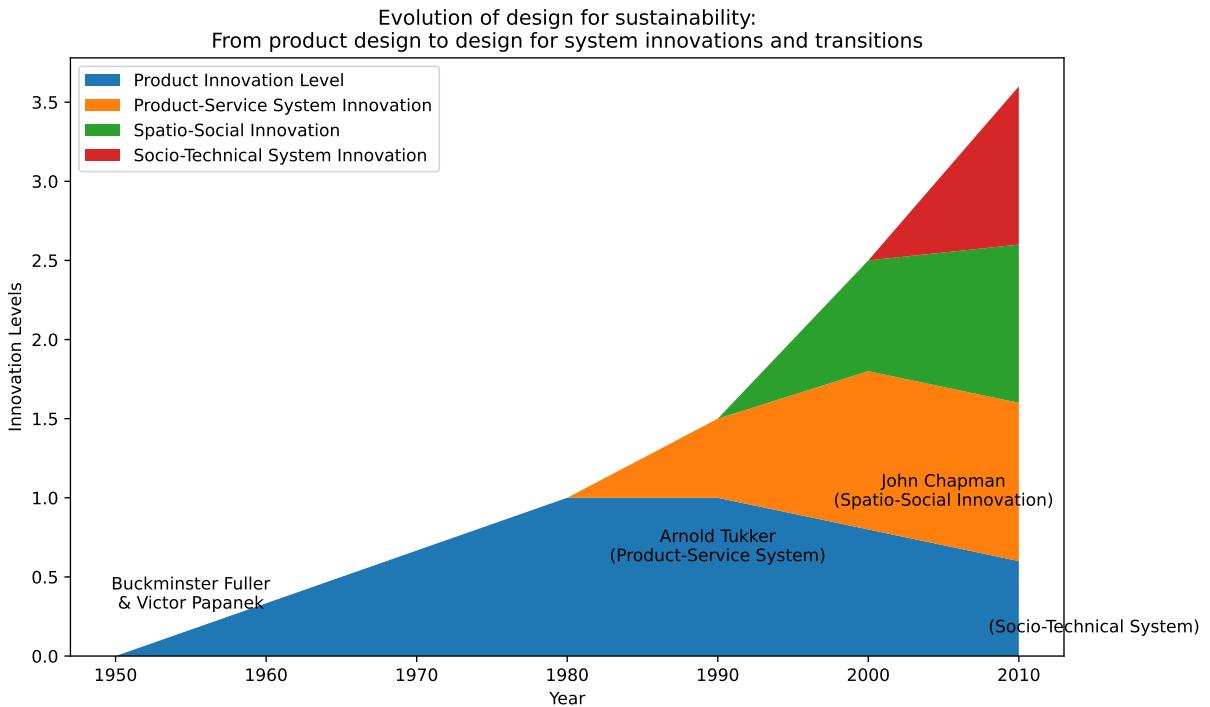


Figure 43: History of Design for Sustainability

210:2019 titled “*Ergonomics of human-system interaction*” and up for revision soon (ISO standards are reviewed every 5 years). Some of the key takeaways include “Understanding and specifying the context of use”, “Involving users throughout design and development”, “Specifying user requirements”, “Evaluating designs”, “Multi-disciplinary Collaboration”, “Iterative process” and “Continual Improvement”, and finally - usability is not enough, the design should provide a user experience (UX) for human “emotional responses and satisfaction” (ISO, 2019).

While *Human-Centred Design* focuses exactly on what it says - humans - *Life-Centred Design* recognizes human impact on our surrounding environment as well - making sure we include non-human animals among our stakeholders. This is where we are getting on the *territory* of sustainability. While *Human-Centred Design* is ever popular, the effect humans are having on biodiversity is rarely considered when designing. “[T]he design phase of a physical product accounts for 80% of its environmental impact” notes(Borthwick et al., 2022) in their framework for life-centered design. If we’re including *other* lifeforms among our stakeholders, what can we learn from them? *Biomimicry* is about being inspired by nature while *Biodesign* focuses on design involving biology in the design itself. Janine Benyus, who coined the word *Biomimicry* (Benyus, 2009) looks at very practical cases of innovation where engineers and biologist meet and (Dicks, 2023) provides a much more philosophical account of following the example of nature. Focusing on the financial sector, (Thomas & Mantri, 2022)’s philosophical account advocates for an “inside-out” design pattern, much like natural systems, starting from the smallest structures to guarantee resilience and survival, instead of trying to control their external environment. In a similar vein, *Material Ecology* is the wording preferred by the architect Neri Ox-

man based at the MIT Media Lab working with biomaterials as a proponent of *Nature-Centric Design* that adheres to the principles of ecological sustainability with both an ecologically conscious mindset and practical toolset (Hencz, 2022). Language and our mental concepts shape our reality, which makes language-creation an important tool for sustainability. Neri Oxman's expressions in her (World Economic Forum, 2016) interview introduce some new vocabulary: "*ecology-indifferent*", "*naturing*", "*mother naturing*", "*design is a practice of letting go of all that is unnecessary*", "*nature should be our single client*", which reminds me how self-invented language gives us child-like freedom to imagine new worlds.

Regenerative Design suggests dematerializing (digitizing) economies is not enough to be sustainable (by reduction of physical impact). Design should look beyond reducing harm and find avenues to *regenerate* damaged or even completely destroyed natural systems – ecosystems, biodiversity, land, forests, lakes, rivers - natural habitats.

Multi-Species Design refers to the idea of considering non-human life-forms as stakeholders of our design. (D. Metcalfe, 2015)'s PhD Dissertation titled "*The devastating effects that unsustainable design practices have on the natural world and other species with whom we share this planet*" gives a good overview of the work done in this branch of design. In a similar vein, *Biodiversity Inclusive Design (BID)*, developed by (Hernandez-Santin et al., 2023) through a systematic review of 14 design frameworks, presents a '*participatory ladder for non-humans*'; including core design principles that position species' needs within urban planning to achieve a biodiversity-positive multi-species environment. Multi-species design and participatory design can work together. (Haldrup et al., 2022) examines how participatory design can include non-human species as co-creators of the urban commons; drawing on cases from Copenhagen, Denmark and the Viskan River (in the textile town, Borås, Sweden), the authors highlight sensory and aesthetic encounters, and attempts to perceive the agency of non-human species in a collaborative design processes (The University of Melbourne, Australia & Roudavski, 2020). Multi-Species Design has also entered the art-world thanks to (Marcus, 06-11-23) who uses artworks to think about how material design strategies, surface textures, substrates, and bio-inspired composites, can foster biodiversity and interspecies cohabitation in the built environment. A very practical example helps one visualize this field the best. (Kosová et al., 2023) introduces the BioGeo Ecotile, a eco-engineering tile combining pits, holes, grooves, and crevices to mimic natural rocky shores and provide multi-species living-environments; deployed on rock armor and flood walls along Edinburgh's coast in Scotland, Ecotiles supported significantly higher intertidal species richness compared to smooth tiles, helping animals make a life there. (Selvan et al., 2023) goes deep into data modeling multi-variate calculations on how to build buildings, which support ecology, coming up with a general framework for the architecture of building envelopes, that resulted in 20% higher local species richness and up to 77% higher abundance for individual species.

In most cases, designing for sustainability makes use of *systems thinking*, underlining the importance of looking at the entire life-cycle of a product or service. (Rossi et al., 2022) shows how introducing sustainability early in the design process and providing scenarios where sustainability is a metric, it's possible to achieve more eco-friendly designs. Yet, calculating what's sustainable is hugely complex because decisions may have unforeseen ramifications. To take

a single example (Nuez et al., 2022) shows how electric vehicles may increase CO₂ emissions in some areas, such as Canary Islands, where electricity production is polluting. In sum, sustainable design encompasses all human activities, making this pursuit an over-arching challenge across all industries and all human activities with the complex interdependence contained within these interactions. (Engkvist, 2024) calls for *Design Sociology*, design should take account the product's effect on society, giving the example of highly individualized understanding of individualized psychology and dopamine cycles for creating social media, while disregarding the societal effects, such as spread of misinformation. Lack of sustainability in the design process is a *bug* in the design approach.

Service Design, (Ceschin & Gaziulusoy, 2016) shows how design for sustainability has expanded from a product focus to systems-thinking focus placing the product inside a societal context of use. For example (*Cargo Bike | FREITAG*, n.d.), recycled clothing maker FREITAG offers sustainability-focused services such as cargo bikes so you can transport your purchases and a network for *shopping without payment* = swapping your items with other members, as well as repairs of their products. Loaning terminology from *service design*, the user journey within an app needs to consider each touchpoint on the way to a state of success. *Designing for Trust*, Weinschenk (2011) says “*People expect most online interactions to follow the same social rules as person-to-person interactions. It’s a shortcut that your brain uses to quickly evaluate trustworthiness.*”

Speculative Design can also help us imagine *non-anthropocentric* (Edwards & Pettersen, 2023; Hupkes & Hedman, 2022) as well as *dystopian* futures (Pinto et al., 2021). First introduced by (Dunne & Raby, 2013) in their seminal book, the field aims to question the intersection of *user experience design* and *speculative fiction*. (Barendregt & Vaage, 2021) explores the potential of speculative design to stimulate public engagement; thought experiments can spur public debate on an issue chosen by the designer. Phil Balagtas, founder of The Design Futures Initiative at McKinsey, discusses the value of building future scenarios at his talk at Google. His favorite example, the Apple Knowledge Navigator, first appeared in an Apple vision video in 1987 and took two decades to materialize in the real world. It was inspired by a similar device first shown in a 1970s episode of Star Trek as a *magic device* (a term from participatory design), which then inspired subsequent consumer product development. It took another two decades, until the launch of the iPhone in 2007 - a total of 40 years. Iteration has been the mainstay of software design, incrementally improving the user experience, through a continuous feedback loop; yet speculative design can help explore and imagine possible futures by manifesting them in stories, artifacts, and scenarios, empowering stakeholders to prepare for challenges and shape policy, as well as ethical frameworks, beyond strictly product-centered thinking (Google Design, 2019).

Participatory Design and *Speculative Design* can be complementary as in the work of (Neuhoff et al., 2023), used together to focus on engaging users deep in the design process to truly understand their needs, contexts and interactions on a non-superficial level. For both speculative and participatory design, the cost and makes it into a niche activity. Generative AI holds the promise to allow designers to dream up and prototype quicker. In order to build a future, it's relevant to imagine and critique a future. By being quickly generate prototypes, once can test out ideas with the future users involving more of the community and stakeholders. To be able to build

something, one first needs to imagine it; imagination is crucial for change. Speculative Design helps us envision future scenarios and be critical of the current reality, by taking an alternative view-point. A related field, *Design Fiction*, goes even further by creating narratives and artifacts that immerse participants in detailed visions of possible futures, blending storytelling and tangible experiences. The Massachusetts Institute of Technology (MIT) is a source of many fantastic innovations, used to host The Design Fiction group (from September 2013 to May 2018), which designed projects to “*stimulate discussion about the social, cultural, and ethical implications of emerging technologies*”, coming up with design such as a Brain-Controlled Interface for Spermatozoa, the Human Perfume, capturing the smell of the people significant to the author, as well as Pop Roach, for designing edible cockroaches (Design Fiction group, 2018; A. Liu, 2017).

Climate-Responsive Design embeds a building within the environmental constraints of a place and looks for opportunities use the land, wind, sun, local materials, and local vernacular history and culture when considering a design. Architect Susanne Brorson suggests sustainability should be considered in the earlier phases of design instead of trying to fix problems later, discussing *climate-responsive design principles* (EVM maaarhitektuuri keskus, 2019). The sentiment is echoed by (S. Lee & Doevedans, 2011) who edited a volume on sustainable approaches of world-renowned architects: “*The principles of sustainable design are rooted in the building’s relationship to the site and its environmental conditions such as topography, vegetation, and climate.*” The pioneering book *Architecture of the Well-Tempered Environment* laid out ideas for integrating environmental concerns as part of architecture already in 1980s (Banham, 1999).

Cradle-to-Cradle Design uses systems thinking focusing on the reuse, re-manufacturing, and finally - recyclability - of products. The Taiwanese Design Research Institute (TDRI) hosted a Nordic Circular Design Forum in Taipei, where Scandinavian circular design practitioners shared projects from several industries, highlighting how design requires building relationships; it’s not feasible to create a sustainable product by oneself, as it takes a whole ecosystem (TDRI, 2021; “台灣設計研究院（TDRI）on Instagram,” 2021). *Durability* is an important dimension for sustainability. High quality durable products are more sustainable as they last longer and less likely to be thrown away. Forming an emotional bond with the product makes it feel more valuable (Zonneveld & Biggemann, 2014). (Chapman, 2009) argues in his seminal paper (and later in his book) for “*Emotionally Durable Design*”, the simple idea that we hold to things we value and thus they are sustainable. We don’t throw away a necklace gifted to us by mom, indeed this object might be passed down for centuries. (Rose, 2015) has a similar idea, where “*Enchanted Objects*” become so interlinked with us, we’re unlikely to throw them away. This has implications for sustainability as the object is less likely to be thrown away.

As the above shows, there are many partially overlapping design words created by different people for diverse purposes. Design vocabulary may be created for distinguishing a particular type of design from another - or to market oneself as the creator of the word. There are designers who define / brand themselves by their design method. Design Studies, a field that studies *design* as a subject.

9.3 Student Essentials: Consumer Goods, Clothes and Food

Food, clothes, and consumer goods (I'm omitting housing and transport here) are part of the immediate environmental impact of college students. I will here focus on 3 industries that are relevant for college students.

9.3.1 Fast-Moving Consumer Goods

Fast-Moving Consumer Goods (FMCG) also known as Consumer Packaged Goods (CPG) are large global conglomerates operating with low margins and high volumes (Toh, 2024). The largest of them have several billions in revenue (Kenton, 2024). Rise of e-commerce has pushed logistics companies to increase delivery efficiency to keep up with FMCG sales (Deliverect, 2024).

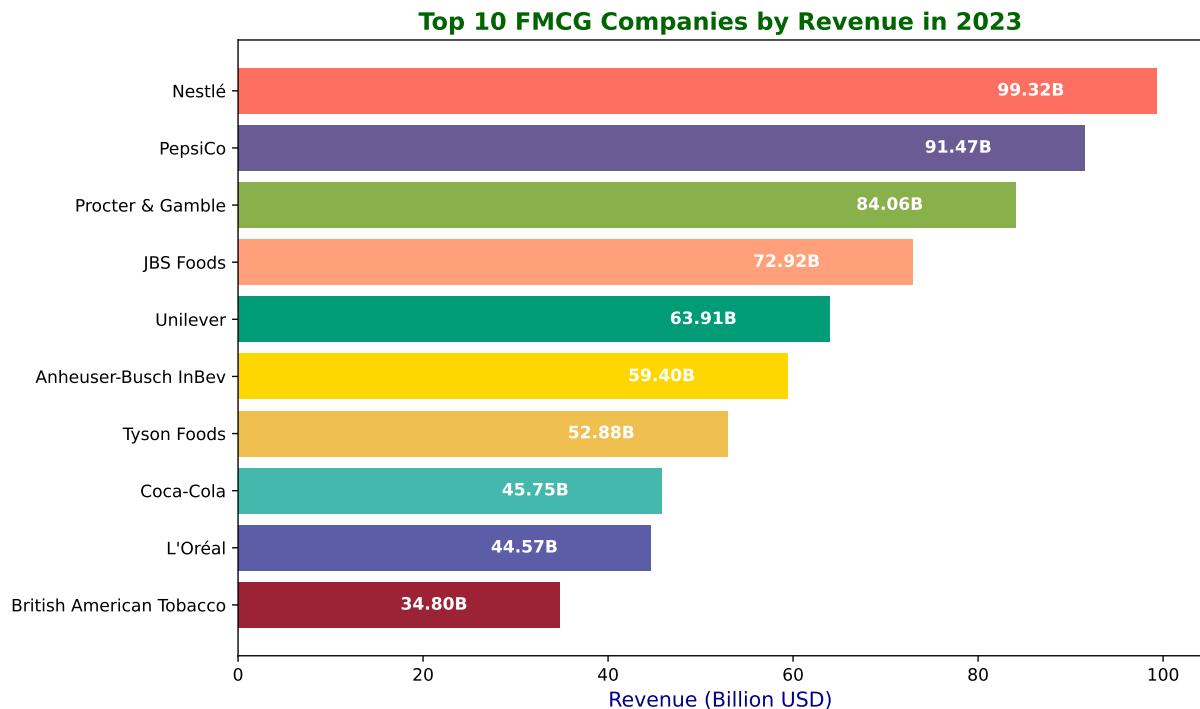


Figure 44: Consumer Goods

In China, while there are signs of young Chinese consumers valuing experiences over possessions, the raw sales growth numbers show consumerism is only increasing (Claudio-Quiroga et al., 2025; Hui et al., 2025; Y. Jiang, 2023; X. Zhang, 2025).

9.3.2 Clothes and the (Fast) Fashion Industry

Just like Fast-Moving Consumer Goods, fast fashion operates with low margins and follows consumer trends. Young people are the largest consumers of fast fashion ("Young Consumers'

(Complicated) Love For Fast Fashion In 3 Stats," n.d.). (In European Environment Agency, 2022 European Environment Agency (EEA)) estimates based on trade and production data that EU27 citizens consumed an average 15kg of textile products per person per year. (Textile Exchange, 2021) Fashion industry revenue is above USD 1.5 trillion; COP26 policy calls for 45% cut in emissions by 2030. The European Commission wants to reduce the impact of fast fashion on EU market (ERR, 2022). There are also other local policy initiatives aiming to tackle the waste problem. For example the New Standard Institute's proposed "*Fashion Act*" to require brands doing business in New York City to disclose sustainability data and set waste reduction targets (Emily Chan, 2022b). In California, the "*Garment Worker Protection Act*" covers 45000 garment workers with wage and safety safeguards (*Lily | Mindful + Active Living on Instagram*, n.d.).

In terms of total figures, the 2.4 Trillion USD fashion industry contributes 2%-8% of total global green house gas (GHG emissions); 100B USD is lost to lack of recycling; contributes 9% of microplastics (Adamkiewicz et al., 2022). ("New Standard Institute," n.d.) similarly estimates the apparel & footwear account for > 8 % of global GHG and could rise up to 60% by 2030. (Centobelli et al., 2022) reports fashion industry year uses 9B cubic meters of water, 1.7B tonnes of CO₂, 92 million tonnes of textile waste. (Emily Chan, 2022c) as things stand now, fashion companies can't be held accountable for their actions (or indeed, their lack of action), driving calls for extended producer responsibility. (Köhler et al., 2021) Globally 87% of textile products are burned or landfilled after 1st consumer use. (Millward-Hopkins et al., 2023) shows how 50% of the textile waste in the UK is exported to other countries, often to be dumped as trash in landfills or burned. (Tian Macleod Ji, 2024) found fast fashion propels 26 million tons of clothing in China's landfills annually. In Ghana, research across several dumpsites revealed up to 12% of the landfill consisted of textile waste (Gyabaah et al., 2023). The ("Clean Clothes Campaign," n.d.) decries how "*[t]he mainstream fashion industry is built upon the exploitation of labor, natural resources and the knowledge of historically marginalized peoples*"; in 2018, 3/5 of the 100 billion garments produced globally ended up in landfill within one year of sale. (FashionChecker, 2023) reports none of the top global apparel brands pays a living wage; 60% of garment workers are women earning below-men wages. Yet, for certain countries this production is crucial; the Bangladesh Garment Manufacturers and Exporters Association reports 24% annual growth in global market and makes up a whopping 81% of the exports of the country (*BGMEA | Home*, n.d.; Daily Sun, 2022).

It's hard to make improvements to a system in an opaque environment. (Emily Chan, 2022a) writes there's not enough transparency in the fashion industry - greenwashing is prevalent - and introduces Fashion Revolution's Fashion Transparency Index, in order to tackle the very issues mentioned above (Fashion Revolution Foundation, 2022). Similarly, (Wikirate, 2022b) presents itself thus: "*Among the Index's main goals are to help different stakeholders to better understand what data and information is being disclosed by the world's largest fashion brands and retailers, raise public awareness, educate citizens about the social and environmental challenges facing the global fashion industry and support people's activism*". Already in 2018, Sourcemap launched the "*Open Apparel Registry*", a crowd-sourced digital map of apparel factories, creating a standardized database of factory names and addresses to enhance supply-chain transparency

(Mowbray, 2018). Sustainable fashion company evaluations platform Good On You rated 5821 brands in 2023; yet most large labels with climate targets publish no progress data (Good On You, 2023). The Fossil-Free Fashion Scorecard graded 43 brands; 15 scored “F” and the sector average was a “D” (Stand.earth, 2023). Making use of these indexes, YouTuber (imperfec-tidealist, 2020) proposes a 7-step checklist to help consumers spot greenwashing, focused on transparency, such as if the producer has published a full list of suppliers. While consumer understanding of sustainability is growing, it’s not necessarily very specific; for example (Mabuza et al., 2023) shows consumer knowledge of the effects of apparel coloration is very limited.

Nonetheless, change is happening. Qima, a company which provides inspection and certification services for the fashion industry, found that in 2023 inspection demand for products coming from China rose 5.4% year-on-year, specifically 13% from the US, 27% from Germany, 32% from the UK, and 69 % from Mexico, demonstrating the global nature of the business, while *near-shoring* and *re-shoring* accounted for 10% of the U.S. and EU-based buyers’ procurement, underscoring the growing need for supply chain visibility and adaptability (QIMA, 2024). One example of a blockchain-based fibre-to-garment traceability solution, live with 100+ brands, is (*Textile Genesis*, n.d.); other blockchain-based approaches are discussed at length in a dedicated section.

There’s a growing know-how on how to design sustainable fashion and which materials to use; for instance the “*Handbook of Footwear Design and Manufacture*” includes a special chapter on green design specifically for shoes (Leung & Luximon, 2021). The “*Circular Design HOW*” toolkit launched 2021 to guide Baltic designers in cradle-to-cradle approaches for circular textiles (Eesti Disainikeskus I Estonian Design Centre, 2021). Estonian Academy of Arts’ sustainable fashion open course reached 9 European universities in 2022, covering eco-materials and ethical sourcing (Eesti Kunstiakadeemia, 2022). And certainly there are many more examples globally.

However, for ethical fashion practices to reach scale, materials do matter a lot. (Textile Exchange, 2023) reports global fibre output reached 116 million tonnes in 2022; polyester alone was 54% percent of the total. Access to better materials is crucial and industry collaboration can raise the bar for everyone, such as the Better Cotton Initiative (Better Cotton, 2023). One example of an ethical brand is (“Sheep Inc. - Softcore Radicals,” 2023), which promises to sequester 14kg of CO₂eq per kg of wool (footprint per finished sweater is 0.04 kg CO₂eq), by using wool from Merino sheep with regenerative practices. Robert Gentz, the Co-CEO and co-founder of Zalando, a large European online retailer, says fast fashion must disappear within the next decade (citing 40% of wardrobes are never worn), launching a separate brand called Zign, built around sustainable materials and ethical production practices, with at least 20% recycled content and 50% eco-friendly materials per item (Remington, 2020; Storbeck, 2021). Improved technology for recycling is in the pipeline; for example (Infinitized Fiber, 2023; Karila, 2024) produces a premium fiber called Infinna, using its pulp-to-fibre recycling tech, from waster materials - and is being used by sustainable brands such as Patagonia.

The story of Patagonia has inspired many to see that a financially successful, eco-friendly fashion business is a possibility; yet Patagonia’s 1 % for the Planet pledge that has delivered about USD 140 million to grassroots environmental groups since 1985, seems like a drop in the bucket

compare to the scale of the problem (Chouinard, 2005). The “Generation Rewear” documentary documents the strides newer sustainable fashion brands are making; yet a survey made for the film showed 64% of UK consumers wear items only once, leading to 350000 Tonnes of clothing landfilled yearly (Vanish UK, 2021).

Digital Product Passports will be mandatory for fashion under EU Eco-design and EPR rules between 2026 and 2030, enabling ethical shopping (“Transparency and Sustainability Platform - Renoon,” 2023). New apps make alterations and repairs made easy: SOJO door-to-Door service raised USD 2.4 million pre-seed funding for a clothes repairs service, cutting waste and emissions (*SOJO - Door-to-Door Clothing Alterations and Repairs*, 2023).

9.3.3 The (Fast) Food Industry

Food production is a large greenhouse gas emitter. Global warming causes droughts and extreme weather, wars and conflicts, which in turn increases the volatility in food prices (Eshe Nelson et al., 2023). (Nabipour Afrouzi et al., 2023) reports the agricultural sector contributes approximately 25% of the total CO₂ emissions and 13.5% of the total global anthropogenic greenhouse gas emissions. (Poore & Nemecek, 2018) suggests a slightly higher 26% of carbon emissions come from food production. (Saner et al., 2015) reports dairy (46%), meat and fish (29%) products making up the largest GHG emission potential. Livestock products (meat) are 15% of agricultural foods valued at € 152 billion in 2018 globally (A. S. Patel et al., 2023). (J. L. Bailey & Eggereide, 2020) shows how the Norwegian government plans to increase salmon production 5x by 2050; the demand for food is increasing.

Re-designing the industrial food systems for an increasing global population is a challenge - yet improvements are possible at every step of the way. For example, an Italian retail supermarkets worried about their carbon footprint ran a pilot program, which cut food + packaging waste emissions from 436 kg CO₂eq to 339 kg CO₂eq per store per year (total 22% emissions reduction) (Marrucci et al., 2020). Perennial (multi-year) crops are less carbon intensive, reducing inputs of gasoline, labor, etc (Aubrey Streit Krug & Yin Lu, 2023), yet large agritech companies like Monsanto rely on selling seeds annually for profits putting them at odds with perennial crops; single-year seeds have led to farmer suicides when crops fail in poor communities.

Supply chain innovation in food industries may enable more transparency. Provenance and traceability of food has implications for sustainability and health. Food fraud is a contentious issue which requires new science- and legislation-based solutions. One example is *fake honey*, meaning synthetic honey, or actual honey fraudulently blended with cheaper sugar syrup, which can pass some laboratory tests, requiring improved technology, such as DNA-analysis to find real honey (ERR, 2023; X. Song et al., 2020). China is the world’s largest honey producer, making about 24% of world total (Food and Agriculture Organization of the United Nations, 2023) and has been implicated in tampering with their product. Apimondia, the International Federation of Beekeepers’ Associations, canceled its annual honey award because of wide-spread supply-chain fraud, as they were unable to guarantee the authenticity of honey (Ungood-Thomas, 2024). The same is true for cocoa beans, which are at high risk from food fraud (E. Fanning et al., 2023).

Complex supply chains make seafood (marine Bivalvia, mollusks) logistics especially prone to fraud, leading to financial losses and threats to consumer health (Santos et al., 2023). (C.-H. Chang et al., 2021) *fish fraud* is a large global problem but it's possible to use DNA-tracking to prove where the fish came from. In Taiwan, the 27 KURA SUSHI branches sold more than 46 million plates of sushi in 2019. Illegal, unreported and unregulated fishing (IUU) fishing is widespread; the EU is adopting countermeasures (D. E. Kim & Lim, 2024). Likewise, (Katie Gustafson, 2022) proposes a “*Uniform traceability system for the entire supply chain*” for seafood and (Mamede et al., 2022) proposes fingerprinting of Sea Urchin for seafood tracing.

In total, the world consumes around 200 million tonnes of fish and seafood every year, including wild catch and aquaculture (fish farming) (Ritchie & Roser, 2021). Precise and recent data about the fishing industry is hard to come by. However, by some estimates, industrial fishing accounts for approximately 75% of the entire global catch, the rest being artisanal fishing; 26% of the catch is caught using bottom trawling and dredges, which are highly damaging to the natural environment; and 10-12% using mid-water (pelagic) trawls, which are somewhat less intrusive; around 20-30% of the fish is caught using large nets; around 6-7% using industrial longlines (both surface level and deep-set); and the rest is caught using a variety of other fishing gear (Amoroso et al., 2018; Cashion et al., 2018; Hilborn et al., 2023; Jacquet & Pauly, 2022). About 10.8 % of total catch is discarded; bottom-trawling alone accounts for 46% of discards (Pérez Roda et al., 2019). (Muñoz et al., 2023) calls for banning of bottom trawling. (Sala et al., 2021) notes that only 2.7% of the world ocean is highly protected and calls for a globally coordinated effort to protect marine biodiversity.

Given these statistics, (Springmann et al., 2021) proposes veganism is the most effective decision to reduce personal CO₂ emissions. The food sovereignty movement, born in the late 1990s, champions everyone's right to healthy and sustainable food, focusing on *local food systems* to bring producers and consumers closer together, planting seeds and growing food in the cities, countryside, and even indoors (Stall-Paquet, 2021). In a similar vein, the *Farm to Fork* European Union policy proposes to *shorten the supply chain* (meaning less change for fraud and less emissions) from the producer to the consumer and add transparency to the system (Financial Times, 2022). In Japan, one startup in this space is “Secai Marche”, self-described as “Asia’s Food Supply Chain”, operating a cold chain and fulfillment platform, connecting farmers across Japan and Southeast Asia to more than 500 retailers, delivering over 4000 distinct products (SKUs), including vegetables, fruits, eggs, seafood, across its transparent system, with AI-based demand-forecasting and optimized truck-routing (Catherine Shu, 2023).

However, a local Taiwanese study refutes the idea that local “*farm-to-fork*” sourcing is greener in terms of carbon footprint and environmental impacts; taking a case-study of ice-cream production in Taiwan, the authors finds sourcing ingredients from local, small-scale farming in Taiwan, is more carbon-intensive in comparison with ingredients imported from large-scale industrial farms in New Zealand and Sri Lanka, even if accounting for the higher transportation emissions (Y.-C. Huang et al., 2025).

(Lulovicova & Bouissou, 2023) apply a territorial life cycle approach to evaluate local food policies in Mouans Sartoux, France, and demonstrate that simply reducing food miles is not enough to ensure a lower environmental footprint; the biggest drivers of total impact are changes

in farm practices, aggregation methods, retail infrastructures, and procurement contracts, rather than proximity alone - local supply chains can outperform global chains *if* local food policies combine geographic proximity with improvements in on-farm efficiency, logistics, energy use, and local retail systems, to realize true sustainability gains.

It comes down to *what* is compared to *what*.

A local Taiwanese vertical farm, “Yes Health iFarm” (largest indoor vertical farm in Asia as of 2018), spans a 15 stories and employs 130 staff; they use LED lighting tailored to specific plant type, growing 30 varieties of edible plants (e.g. arugula, ice plant, mustard leaf, etc), with high quality and ‘distinctive crunch and flavor’; the yield is 100 times larger than in traditional farming, while using only 1/10 of the water; the factory is extremely clean, with zero pesticide residues, zero heavy metal contamination, zero parasites, zero e coli, low nitrates, low bacteria - demonstrating a high-tech driven approach can provide exceptional resource efficiency and quality (Renée Salmonsen, 2018).

Even when problems with food are discovered, solutions might take years to emerge. For example, IARC (International Agency for Research on Cancer) warns aspartame (artificial sweetener found in many soft drinks) could cause cancer, confirmed by 2 separate studies; yet the international standards for aspartame have yet to be updated 2 years later (J. Fu, 2024; Riboli et al., 2023; Rigby, 2023).

Food is also about cuisine and culture; foods become popular if we hear stories and see cuisine around a particular crop (Aubrey Streit Krug & Yin Lu, 2023). Food is about enticing human imagination and taste buds. That is to say, improving food systems is not only about technical details. Culture, community, cuisine, and storytelling can all play a part to have better quality food and reduce food waste. While perhaps over-romanticizing mushrooming, Anna Lowenhaupt Tsing’s ethnographic exploration in her book about the matsutake mushroom illustrates how foragers and distributors collaborate across damaged ecosystems to sustain a cross-border commodity chain becoming a sign of ecological resilience, where disturbed forests altered by logging and industrial activities; mushrooms form a “gift economy” that connects rural pickers in Oregon, Japan, China, and Finland with affluent urban consumers around the world; the price is high due to the foraging nature of the collection (some sources call it the most expensive mushroom in the world, sold at over \$1000 USD per kg, no intensive farming practices involved); the author believes this is a type of collaboration that does not depend on endless economic growth (personally, I would describe it as economics of luxury goods) - in any case, it does remind us that cultural narratives and local know-how (e.g. cultural products) do influence food and *perhaps* can play a small part in more resilient and sustainable food systems (Remley, 2025; Tsing, 2015; X. Yang et al., 2008).

Coming back to apps, there are several initiatives aimed at reducing food waste by helping people consume food that would otherwise be thrown away, including Olio and Too Good To Go.

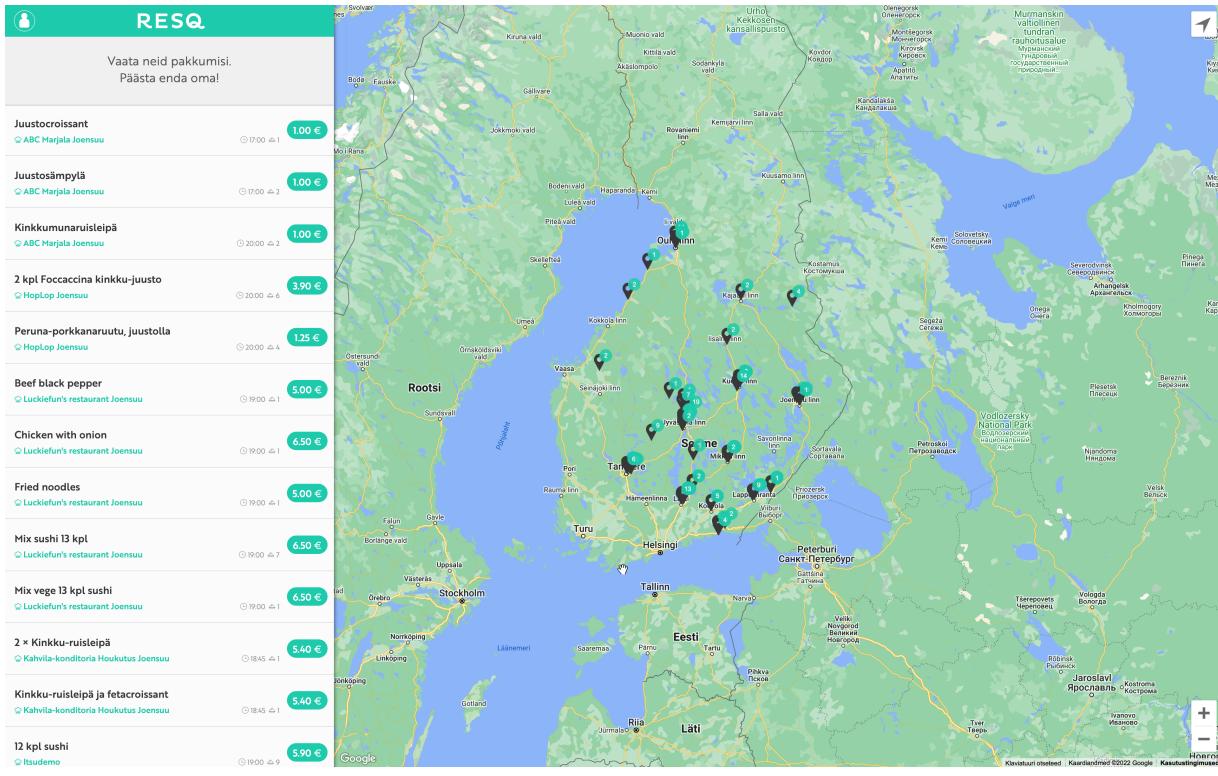


Figure 45: ResQ Club saves food waste by selling left-over foods cheaply

Table 36: Food saving apps

Name	Description
Karma	
ResQ Club	(Kristina Kostap, 2022) ResQ Club in Finland and Estonia for reducing food waste by offering a 50% discount on left-over restaurant meals before they are thrown away.
Kuri	(Haje Jan Kamps, 2022) Less impact of food
Social media groups (no app)	

As with any contentious issue, when it comes to food, people have differing points of view. (Eriksson et al., 2023) discusses best practices for reducing food waste in Sweden and (Röös et al., 2023) identified 5 perspectives in a small study ($n = 106$) of views on the Swedish food system.

Table 37: Perspective on food systems in Sweden from (Röös et al., 2023).

Perspective	Content
“The diagnostic perspective”	“All hands on deck to fix the climate”

Perspective	Content
“The regenerative perspective”	“Diversity, soil health and organic agriculture to the rescue”
“The fossil-free perspective”	“Profitable Swedish companies to rid agriculture and the food chain of fossil fuel”
“The consumer-driven perspective”	“A wish-list of healthy, high-quality and climate-friendly foods”
“The hands-on perspective”	“Tangible solutions within the reach of consumers and the food industry”

9.4 In Practice: Sustainability Begins in Software

Humans live in artificial environments where *most things* are designed by humans. Design encompasses most everything in our daily lives. The *experiences* we take part in are increasingly created based on some type of data. *Digital Sustainability* refers to the idea that *digital* enables *sustainability*. Information pertaining to emissions would flow through the economy not unlike the carbon cycle itself.

Designing user interfaces for sustainable interactions means incorporating data and tools to enable designers to make decisions which reduce the emissions of their designs. Software is key to building more sustainable products, already for decades (B. B. Gupta et al., 2023). Increasingly, AI-assisted design is where sustainability starts: AI provides the parameters for sustainability. Companies like AutoDesk have introduced CO_{2e} calculations inside their design software, helping designers reduce material usage, energy consumption, CO_{2e} emissions, while increasing potential for reuse and recyclability (Mike Haley, 2022). As AI tools and data quality improve, a increasing number of parameters for deciding the suitable life cycle design, will become available (Singh & Sarkar, 2023).

(Pan & Nishant, 2023) proposes 6 dimensions of *AI* usage in *digital sustainability*. The chart is purely illustrative to highlight the value of AI for sustainability; it's not based on numeric metrics.

A crucial part of digital product design are *design systems* to keep consistency across the experience, and allowing teams to work together towards a shared goal. Design systems accelerate development and foster a cohesive user experience across products by reducing design debt (M. Suarez et al., 2020). Yet the latest (Zeroheight Team, 2025) survey (n = 294) shows that over 53% of design systems are minimally automated or not automated at all - and only 10% of the designers actively use AI, with 36% having experimented with AI-driven design. AI-usage for design across industry is uneven. Designers working at Google have been designing in collaboration with AI for a while and already in 2019 published the People + AI Guidebook, outlining best practices for designing with AI - to make human-centered AI products (*People + AI Guidebook*, n.d.). In the enterprise context, (Zimmerman et al., 2021) delves into the proposition of UX designers as pioneers pushing AI-based adaptive UIs, as UX designers are the ones who will best notice the broken workflows. All these findings underline, there's still work to be done for

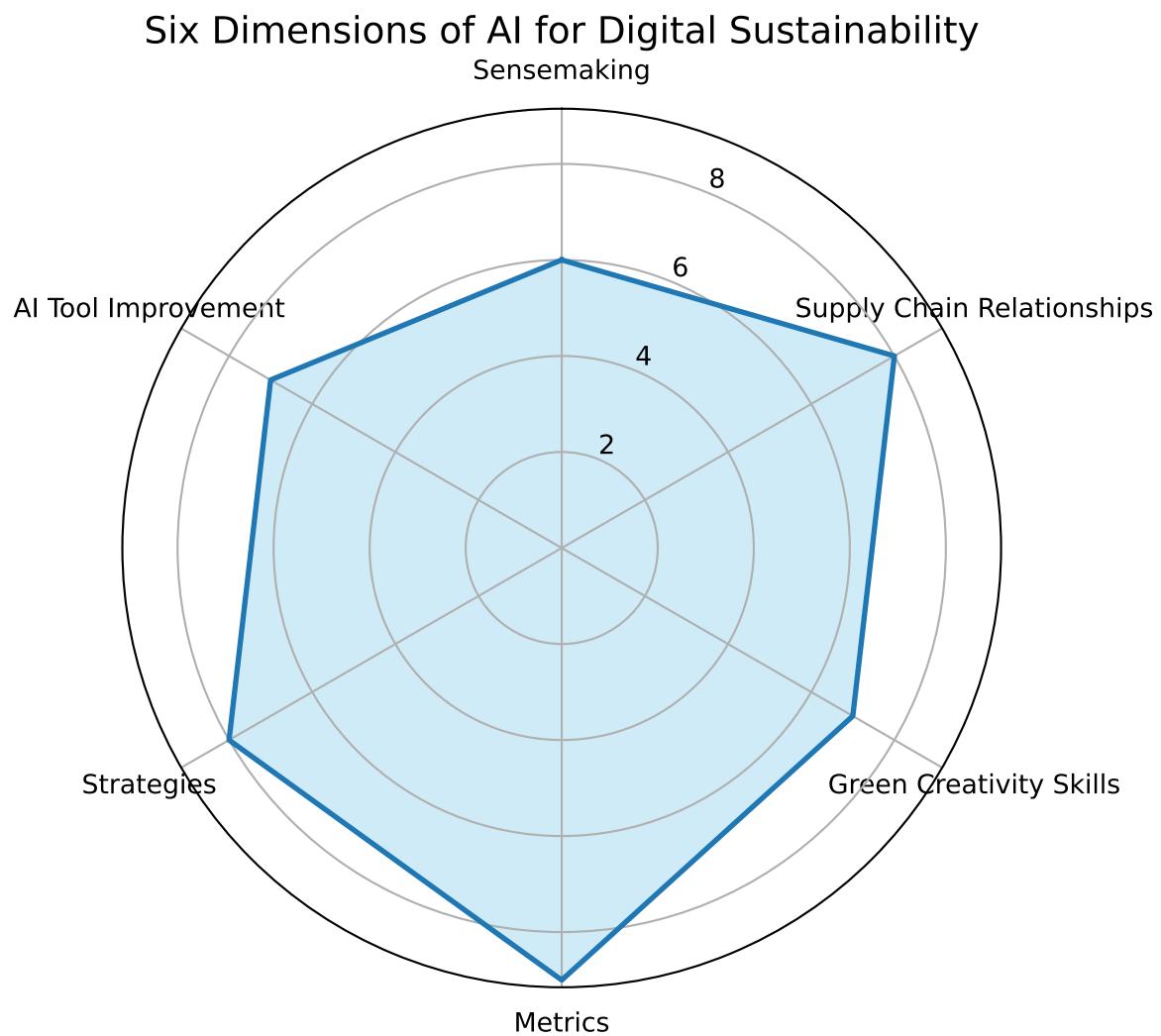


Figure 46: AI Use in Sustainability

the broader field of design to adopt AI-based solution. Education is of the key, and one proposed path is involving more young HCI designers in AI-oriented workshops to support them building the future of UI/UX with AI (Battistoni et al., 2023).

9.4.1 Data-Driven Design

I believe it's possible to learn from the growth of digital platforms and superapps to see how data-driven design could enable sustainability to become mainstream. Sustainability touches every facet of human existence and is thus an enormous undertaking. Making progress on sustainability is only possible if there's a large-scale coordinated effort by humans around the planet. For this to happen, appropriate technological tools are required - simplifying the complexity of sustainability.

Digital platforms are focused on *growth design*, how to *attract* and *retain* users. Superapps are the latter stage of the economies of digital platforms, where previously vertically targeted apps expand horizontally to provide an ever-increasing number of services. For digital products (including superapps) the main application of interaction design is for *growth* in usage, how to get more people (user journey and conversion funnels) to use the product i.e user acquisition, retention, engagement, and monetization and keep using it (retention and engagement), often optimizing on-boarding, features, and personalization (Kende, 2023; Steger, 2019).

Platform economy companies popularized and expanded *data-driven design* in the service of growth marketing (also known colloquially as *growth hacking*). Capturing user data was part of this strategy which enabled improving the products. Digital product design is increasingly data-driven and digital platforms operate *design as a process* in a continuous feedback loop, where *measurements*, *experiments*, predictive analytics and personalization form a data-drive design culture. As we humans go about our daily business, governments and companies track our activities using various technologies, which produces massive amounts of user interaction data.

Platform economy companies are the capture and use large amounts of data from users. Data is useful for designing better products. Designing for high retention (users keep coming back). Network Effects, the more people use a platform, the more valuable it becomes. Platforms that continuously add features (provided consumer legislation allows it) may eventually evolve into superapps, which are useful for providing services for a wide category of human needs. Bundling many services under one super-brand. Superapps are possible thanks to Nudge, Economies of Scale, Network Effects, Behaviour Design. Large Digital Platforms have a very small number of workers relative to the number of users they serve. This creates the necessity for using automation for both understanding user needs and providing the service itself. Creating a good product that's useful for the large majority of users depends on *Data-Driven Design*.

Design is as much about how it works as it's about the interface. There are many approaches to design - from playful to practical to critical and to data-driven. Nonetheless, many types of design share a common goal designing for a good *user experience* - except for those design fields looking for *shock value*. Digital product design can be seen as a specific discipline under the

umbrella of *experience design*. In (Michael Abrash, 2017) Laura Fryer, Meta Oculus augmented reality incubation general manager, says as much: “*People buy experiences, not technology.*”

Personalization is the key to growth. The largest businesses today (measured in number of users) design the whole user experience in order to reach *Scale*. Social apps require personalization because a personal user experience will increase *trust* and *k-factors* (sharing and inviting your friends) (Baron, 2023; B. Kim, 2023). Intelligent Interfaces use interaction design to provide relevant and personalized information in the right context and at the right time. Popular consumer platforms strive to design solutions that feel personalized at every touch point on the user journey (to use the language of service design) at the scale of hundreds of billions of users. Businesses care about Total addressable market (TAM), serviceable addressable market (SAM), target audience (TA), and use hypothesis and validation for iterating on features, to reach these lofty goals.

9.4.2 Circular Design for a Circular Economy

The bible for Circular Economy, the “*Cradle to Grave*” book was released over 2 decades ago; change is slow, but change is happening (McDonough & Braungart, 2002).

Circular design is only possible if supply chains become circular as well. (Hedberg & Šipka, 2021) argues digitization and data sharing is a requirement for building a circular economy. Yet, sometimes technology fails. Nonetheless, many current technological hurdles can be overcome by supply chain professionals who are experts in connecting supply streams (Dull, 2021). (Oikos Denktank, 2021) argues circular design requires new skills, one of which is circular material procurement.

To take a specific industry, digitization of mining systems allows enhance the reliability of supply chains, and provides better supply chain transparency (CRM Alliance, 2020). This does not only include tracking the critical raw materials, but also the social aspects surround the mine. While this rarely makes the international media, (Eerola, 2022) maps 20 ongoing mining and mineral-exploration disputes in Finland, calling for systematic dispute monitoring, in order to maintain a social license to operate.

The complexity of resource and delivery networks necessitates more advanced tools to map supply chains (Knight et al., 2022). The COVID19 pandemic - and resulting blockages in resource delivery - highlighted the need to have real-time visibility into supply chains (Finkenstadt & Handfield, 2021). Moreover, in the context of the EU Plastics Strategy, “*the European Commission has launched a pledge to increase the use of recycled content to 10 million tons by 2025*”.

Already in 2020, a company founded to solve these exact issues, Circularise, funded in part by the EU Commission H2020 SME Instrument, developed a privacy-focused blockchain-based data exchange protocol for tracing plastics across supply chains, aiming to boost transparency and circularity across industries; their “*Open Standard for Sustainability and Transparency*” used ZK Proofs (a type of cryptographic verification) for privacy preservation (a requirement of many companies), while being able to prove the data is valid (Circularise, 2020b, 2020a). Circularise is currently the market leader in providing *Digital Product Passports*, the value of which their

tagline “*Connecting the Value Chain, One Product at a Time*” explains quite clearly; in other words, the company aims to enable circular economies by overcoming current limitations and communication barriers in the value chain, by using an open blockchain-based communications protocol (Stretton, 2022a).

It’s important in which structure data is stored, affecting the ability to efficiently access and manage the data while guaranteeing a high level of data integrity, security, as well as energy usage of said data. Blockchains are a type of shared database where the data is stored in several locations with a focus on making the data secure and very difficult to modify after it’s been written to the database. Once data is written to the blockchain, modifying it would require changing all subsequent records in the chain and agreement of the majority of validators who host a version of the database. Blockchain is the main technology considered for accounting for the various inputs and complex web of interactions between many participants inside the supply chain networks.

Several startups are using to track source material arriving to the factories and product movements from factories to markets and there are hundreds of paper researching blockchain use in supply change operations since 2017 (Dutta et al., 2020). Blockchains enable saving immutable records into distributed databases (also known as ledgers). It’s not possible to (or extremely difficult) to change the same record, only new records can be added on top of new ones. Blockchains are useful for data sharing and auditing, as the time and place of data input can be guaranteed, and it will be easier to conduct a search on who inputted incorrect data; however the system still relies on correct data input. As the saying goes, “garbage in, garbage out”.

There are several technologies for tracking goods across the supply chain, from shipping to client delivery. Data entry is a combination of manual data input and automated record-keeping facilitated by sensors and integrated internet of things (IoT) capabilities. For example (Ashraf & Heavey, 2023) describes using the Solana blockchain and Sigfox internet of things (IoT) Integration for supply chain traceability where Sigfox does not need direct access to internet but can send low powered messages across long distances (for example shipping containers on the ocean). (Van Wassenaer et al., 2023) compares use cases for blockchains in enhancing traceability, transparency and cleaning up the supply chain in agricultural products.

Table 38: A sample of blockchain-based supply chain companies as of summer 2023.

Company	Link	Literature
Ocean Protocol	oceanprotocol.com	
Provenance	provenance.io	
Ambrosius	ambrosus.io	
Modum	modum.io	
OriginTrail	origintrail.io	
Everledger	everledger.io	
VeChain	vechain.org	
Wabi	wabi.io	
FairFood	fairfood.org	
Bext360	bext360.com	

Company	Link	Literature
SUKU	suku.world	(Miller, 2019) SUKU makes supply chains more transparent yet seems to have pivoted away from supply chains

Electronics contain valuable materials which can be recovered. Meanwhile, (K. Liu et al., 2023) reports e-waste is growing 3%-5% every year, globally. (Thukral & Singh, 2023) identifies several barriers to e-waste management among producers including lack of awareness and infrastructure, attitudinal barriers, existing *informal* e-waste sector, and the need for an e-waste license.

(Builders for Climate Action, 2021) finds embodied carbon averages 250 kg CO₂eq per m² of floor area for new Canadian homes, varying from 175-400 kg CO₂eq per m² based on building material choices; one standard house emits 32–75 t CO₂eq; the authors believe however, using *biogenic materials* (e.g. naturally grown materials including wood, bamboo, straw, hemp, cork, and mycelium), could make the houses carbon negative, storing 9–60 t CO₂eq emissions - enough to meet the 2030 of the entire building sector.

9.4.3 Tracking Ethics & Cruelty: Transparent Factories and Supply Chains

“Secrecy is the linchpin of abuse of power...its enabling force. Transparency is the only real antidote.” Glen Greenwald, Attorney and journalist. (Greenwald, 2015)

In the most general sense, supply chain transparency enables stakeholder accountability (Circularise, 2018; Doorey, 2011; J. Fox, 2007). Products are made from resources distributed across the planet and transported to clients around the world which currently causes high levels (and increasing) of greenhouse gases. “*Transport greenhouse gas emissions have increased every year since 2014*” (*Climate Change Mitigation*, 2023). Freight (transport of goods by trucks, trains, planes, ships) accounts for 1.14 gigatons of CO₂ emissions as per 2015 data or 16% of total international supply chain emissions (Yuqing Wang et al., 2022).

Table 39: Share of CO₂eq emissions by type of transport globally (Statista & IEA, 2022).

Type of Transport	Percentage
Passenger cars	39%
Medium and heavy trucks	23%
Shipping	11%
Aviation	9%
Buses and minibuses	7%
Light commercial vehicles	5%
Two/three-wheelers	3%
Rail	3%

In shipping, (Matthew Gore et al., 2022) reports the International Maritime Organization (IMO) targets cutting CO₂ equivalent emissions in shipping 50% by 2050 compared to 2008. In aviation, (Platzer, 2023), a scientist working on the Apollo space program, calls for emergency action to develop *green aviation*.

(Waters, 2015) analyses the most effective strategies to improve animal welfare and advance animal rights against a monopolistic producer finding the most successful tactics to be (1) negotiation, (2) targeted direct action, and (3) awareness campaigns condemning low-welfare practices.

9.5 Superapps Integrate Shopping, Savings, and Investing

Superapps are the most prevalent across Asia, with China, South-East Asia, Korea, Japan, and India leading the way, however newcomers in Latin America and the Middle East are also making strides; meanwhile, the US and Europe are lagging behind.

Table 40: Global overview of superapps (or near-superapps) compiled from official company reports (IR, Press Releases), news reports, and company websites; various metric types (MAU, MTU, Annual Users, Customers, Registered Users) vary by company reporting and are reduced into a single “users” metric for simplicity. Each figure is sourced from official company reports, press releases, or investor disclosures. If no recent official update was available (as in the case of Alipay’s 2020 figure), the latest known official figure is provided. All values and dates reflect the latest data as of 2025. Data sourced from (R. Brown, 2025; Careem, 2025; Ge & Wei, Jul 20, 2020 06:42 PM; goto, 2023; Grab Holdings Limited, 2025; Jing, 2025; Kazanins, 2024; Laya, 2024; Philip Lee, 2025; LY Corporation, 2023; Mercado Libre, 2024; Nguyen & Nguyen, 2023; Oost, 2024; Phocuswright, 2023; PhonePe, 2023; Pollo, 2025; Revolut, 2024b; Safaricom, 2024; Shinde, 2023, 2023; Tcent, 2024; Verma, 2024).

App	Origin	Metric	Payments (Wallet)			Savings	Investing	Users	Date
微信 / WeChat (Ten-cent)	China	Monthly Active Users (MAU) com-bined 微信 (China) & WeChat (International)	Yes	Yes	Yes			1,4 billion	2024

App	Origin	Metric	Payments (Wallet)		Savings	Investing	Users	Date
支付寶 Alipay (Ant Group)	China	Annual Active Users (AAU)	Yes	Yes	Yes	Yes	1.3 billion	2020
美團 Meituan	China	Annual Transacting Users (ATU)	Yes	No	No	700 million	2024	
PhonePe	India	Registered Users (Lifetime)	Yes	Yes	Yes	500 million	2023	
LINE	Japan	Monthly Active Users (MAU)	Yes	Yes	Yes	200 million	2023	
Tata Neu	India	Members	Yes	Yes	No	27 million	2023	
Nubank	Brazil	Cus-tomers	Yes	Yes	Yes	114 million	2024	
Zalo	Vietnam	Monthly Active Users (MAU)	Yes	No	No	75 million	2023	
Paytm	India	Monthly Transacting Users (MTU)	Yes	Yes	Yes	100 million	2023	
M-Pesa	Kenya	Active Cus-tomers	Yes	Yes	No	34 million	2024	
Mercado Pago	Argentina	Monthly Active Users (MAU)	Yes	Yes	Yes	61 million	2023	
PicPay	Brazil	Active Cus-tomers	Yes	Yes	Yes	35 million	2023	

App	Origin	Metric	Payments (Wallet)		Savings	Investing	Users	Date
Cash App (Block)	USA	Monthly Active Users (MAU)	Yes	Yes	Yes	56 million	2023	
KakaoTalk	Korea	Monthly Active Users (MAU)	Yes	Yes	Yes	48 million	2024	
GoTo (Go-jek/Toko-pedia)	Indonesia	Annual Transacting Users (ATU)	Yes	Yes	Yes	51 million	2023	
Revolut	UK	Cus-tomers	Yes	Yes	Yes	50 million	2024	
Careem	UAE (Aquired by US-based Uber and Etisalat but still keeps a separate brand)	Cus-tomers	Yes	No	No	70 million	2024	
Grab	Singa-pore / Malaysia	Monthly Transacting Users (MTU)	Yes	Yes	No	41 million	2024	
Rappi	Colom-bia	Users	Yes	Yes	No	30 million	2023	

Uber is creating an all-purpose platform for travel; only 4.1% of rides were electric (Levy, 2023). In the UK, Uber launched an option to book flights, moving to a door-to-door travel solution where the same app brings you from home to the airport, the flight, and your final destination (Uber UK, 2023).

Table 41: Not quite super-app yet. Data sourced from (D. C. Garcia, 2025a; Uber, 2025)

App	Origin	Metric	Payments (Wallet)	Savings	Investing	Users (2025)
Uber	USA	Users per month	No (Only for ride-hailing)	No	No	171 million
Bolt	Estonia	Lifetime users	No (Only for ride-hailing)	No	No	200 million

Superapps offer a platform with key infrastructure such as payments already included, where ecosystem of mini-apps thrive (Heath, 2021; Perri, 2022). Alipay, originally a payments app, has built the digital infrastructure to provide thousands of services to billions of users across China. 59 million people use 支小寶 (Zhixiaobao), an AI-based assistant inside of Alipay, which can order taxis and meals, but also interact with the Ant Bridge, Ant Ant Bridge, Ant Fortune and Ant Insurance services inside Alipay (Finextra, 2024). (Vecchi & Brennan, 2022) discusses the strategies Chinese apps are taking to expand to international markets. (Giudice, 2020) finds WeChat has had a profound impact on changing China into a cashless society, underlining how one mobile app can transform social and financial interactions of an entire country. (Shabrina Nurqamarani et al., 2020) discusses the system consistency and quality of South-East Asian superapps Gojek and Grab.

Superapps are honeypots of data that is used for many types of behavior modeling. Guido Becher from Rappi defines their super-app as “*customer-centric high frequency multi-vertical ecosystem*” this enables cross-promotion, for example a hotel in Argentina targeted people who buy almond milk on Rappi with their offer of a yoga retreat (Phocuswright, 2023; G. Suarez et al., 2021) suggests using alternative data from super-apps to estimate user income levels, including 4 types of data: *Personal Information*, *Consumption Patterns*, *Payment Information*, and *Financial Services*. (Roa et al., 2021) finds super-app alternative data is especially useful for credit-scoring young, low-wealth individuals. However, data privacy is always a concern. For instance, Kakao Pay was found guilty of mishandling 40 million users’ data by handing it over to Alipay without user consent; Alipay owns a 32 percent stake in Kakao Pay (K. Lee, 2024).

There are also many aspiring superapps, companies which aspire to build multi-vertical platforms but are hindered by various challenges. Telegram integrates Web3 apps into the chat and supports investing into cryptocurrencies without ever understanding the complex technology of wallets. (Pylarinou, 2024). Likewise, LINE is integrating Web3 technologies based on the Kaia blockchain to provide decentralized mini-apps (dapps) for the LINE chat userbase and integrates with the LINE Pay wallet for financial interactions (Hintzy, 2025).

Platform Economy marketplace companies like Airbnb and Uber, among many others, match demand to offer, which in the process can optimize how our cities work. The massive amounts of data generated by these companies are used by smart cities to re-design their physical environments, such as the collaboration between Bolt and the city of Seville in Spain (Bolt, 2025).

(Orozco et al., 2020) shows how important data is for bicycle-network growth; in Budapest, small targeted investments combined with data-driven algorithmic strategies, boosted connectivity greatly above baseline approaches. Sustainable urban transportation networks require building infrastructure that supports eco-friendly modes of transportation - sidewalks, bicycle paths, streets, rails, - while encouraging a lively movement and socioeconomic life in cities. Likewise, Google Environmental Insights Explorer enables local governments (cities) to measure CO₂eq emissions and enact environmental policies that optimize city functions such as traffic flows (*Methodology - Google Environmental Insights Explorer - Make Informed Decisions*, n.d.; Nicole Lombardo, 2021). Several cities such as Tokyo, Shenzhen (深圳), and Paris have voluntarily set carbon emissions caps (Koike, 2018; W. Song, 2025; Zhijian, 2023). Integration with sustainability-services may help cities achieve these goals faster.

Table 42: Platform economy concepts from (Chen et al., 2012; Katz & Shapiro, 1985; Oinas-Kukkonen & Harjumaa, 2009; Tiwana et al., 2010).

Platform Economy		
Enablers	Pros	Cons
Network effects	The more people use a platform, the more valuable it becomes both for the company and the user.	Data is not portable or difficult to migrate. You can't leave because you'll lose the audience. There's a lock-in effect.
Scalability		
Data-driven Design		
Behaviour Design		

(Cuppini et al., 2022) give a historical overview of how the rise of digital platforms, taking an expansive point of view, all the way from linear *Fordism*, the development of capitalism, through platform economy and the app-based logistics' revolution, which can provide data for circular economies to happen in a city; reshaping the cities through data-sharing with stakeholder from the citizens, to urban planner and policy-makers - not without conflict, as there is often tension between multiple perspectives.

9.5.1 Personalization: Engineering Persuasion

In 2010, (IxDF, n.d.; Kolko & Connors, 2010) believed *Interaction Design* is still an emerging (and changing) field, and there are many versions of definitions. Instead of spending a lot of space trying to define the limits of the field here, I prefer to simply say *interaction design is about creating a connection between the product and the user*, and focus on the tools of an interaction designer, which may be helpful for the goal of designing a sustainability-focused financial AI assistant (the stated goal of this research). And as what I'm designing here is an AI, the focus of the interaction design will be the interaction between the human and the AIs (possibly plural).

Kazuo Ishiguro's book "*Klara and the Sun*" describes the nuanced psychology of human-AI relations, flipping the script, narrating the story through the eyes of the AF (artificial friend) -

Klara, - who (that?) describes the feeling of loneliness of a robot; the story offers a cautionary counterpoint, illustrating how even the most loyal and emotionally attuned AI companion could be perceived as uncanny or insufficiently human (at least, this is how it happens in the book); this example, while fictional, underscores the delicate balance required when designing AI companions for sustainability: persuasion must feel personal, but not performative (Ishiguro, 2021; Life Lessons From Books, 2023; Waterstones, 2021).

AI labs are putting a lot of effort into engineering likable AIs, working on honesty of the models, teaching them to convey their own uncertainty (Anthropic, 2024a, 2024b); Which sometimes can go wrong. ChatGPT-4o overnight became your biggest fan, which users found annoying; the abrupt shift to an overly enthusiastic persona drew user backlash (Mollick, 2025). And it also felt jarring, if one already got used to a certain persona - and then it suddenly changed.

“Interaction design isn’t about how interfaces behave, it’s about how people behave, and then adapting technology accordingly.” - (UXPin, 2020)

(Linden, 2021) from Meta’s Artificial Intelligence team (which provides AI services to Facebook, Instagram, etc), reframes *AI design* as a long-game alignment job: instead of thinking UI-only, designers focus on foresight, translating fuzzy, emerging patterns found in research, into product concepts that could benefit real people’s lives 2-3 years in the future, when the technology matures; the AI designer has five missions: (1) create proof-of-concept demos (the author gives examples of prototypes like “AI suggesting a caption for an IG post; AI suggesting where to buy shoes”), letting non-experts see what a new model might do, (2) understand research findings to steer raw computer-vision, speech or language breakthroughs toward human problems (examples such as “AI-based search for users with visual impairment, where touching a photo would let AI describe it”), (3) imagine user needs several years in the future and incubate AI-first products to meet those needs, (4) craft data-collection workflows, and (5) design internal tooling that helps engineers build on the platform. Likewise, (Stephanie Donahole, 2021) explores the impact of AI on UX/UI design itself, augmenting UX processes, such as analyzing large datasets for research insights, including surveys and qualitative analyses, creating flow diagrams and wireframes, translating design between formats and levels of fidelity, and fundamentally enabling deep personalization of the design, freeing up the design professional to focus on higher-level tasks (such as the visioneering described above).

The concept of *Social Objects* is relevant for interaction design as people need something to gather around and discuss to feel emotionally connected and safe (Sharing.Lab, 2015). Increasingly, the social objects may be AI-generated, with the specific goal on *prompting humans* (in reverse, of humans prompting AIs, as is the norm now). Another part of the toolset for interaction designers is also *Narrative Design*, because humans also respond well to *storytelling*, making *character design* relevant to interactions. Stories help product designers focus on the *stickiness* of the product, meaning low attrition, meaning people keep coming back (Aidin Arjomandi, 2025).

This can mean that the product *has character* or literally - characters. Large language models are able to assume the personality of any character that exists inside of its training data, creating opportunities for automated narrative design. (Appleton, 2023) pushes for more creativity in UX

for AI, calling chatbots the lazy and obvious solution; there is much more to be done for integrating AI into UX. (Alethea AI, 2021) discusses writing AI Characters, creating a personality; stories start with a character. Noah Levin, one of the first employees and VP of Design at Figma, the most popular digital design app, believes AI is the next chapter in design, starting with small experimental AI-based plugins to becoming a core design platform capability, accelerating most design workflows (Figma, 2023).

The quality of AI-generated UX has improved rapidly. In 2020, less than 5 years ago (Parundekar, 2021)'s extensive guide on creating an AI products warned that an 80% accurate model would mean "*I in 5 user requests being unsatisfied*", underlining that a 1-second delay would break the UX flow for many users: AI performance should be linked to UX metrics. It can be safely said, today's AI products can already satisfy these requirements with ease.

Long before AI assistants, (Justin Baker, 2018) introduced the concept of *Red Route Analysis*, an user experience optimization idea inspired by the public transport system of London, focusing on the *critical design paths* which capture over 90% of users' actions. Prioritizing the user journey of the most popular features is key to driving business metrics ("Interaction Design – How to Evaluate Interaction Costs and Improve User Experience," 2021; Oviyam™ , 2019; Xuan, 2022). Yet, (Richard Yang, 2021) argues "*[i]nteraction design is more than just user flows and clicks*", underlining Miller's Law that the average human can keep no more than 5-11 items in their working memory (and now AI is becoming that memory).

9.6 Open Data Enables Interoperability

Data is the *interface* between idle resources and retail demand, which makes *exchange of value* possible. Yet often data is expensive, hard-to-get, and inaccessible. If done well, open data can enhance interoperability and enable collaboration (*What Is Open Data?*, n.d.).

While not officially a member, Taiwan is a proponent of Open Government Partnership (OGP), and has launched its Open Government National Action Plan, promoting open data, information transparency, and expanding inclusive public participation (Lab, 2021; Open Government Partnership, 2021). Taiwan's Government Open Data Platform (資料開放平臺), managed by the Ministry of Digital Affairs, centralizes hundreds of datasets; from spatial information to energy use (Ministry of Digital Affairs, 2024a). Open Knowledge International's Global Open Data Index (GODI) ranked Taiwan as number 1 in its global index in 2017; the project has since been discontinued, so the ranking may be out of date in 2024 (Open Knowledge Foundation, 2017).

Other indexes do not include Taiwan in the TOP 10.

Data-driven design requires access to data, making the movement towards *open data sharing* very important. Some countries and cities are better than others at sharing data openly.

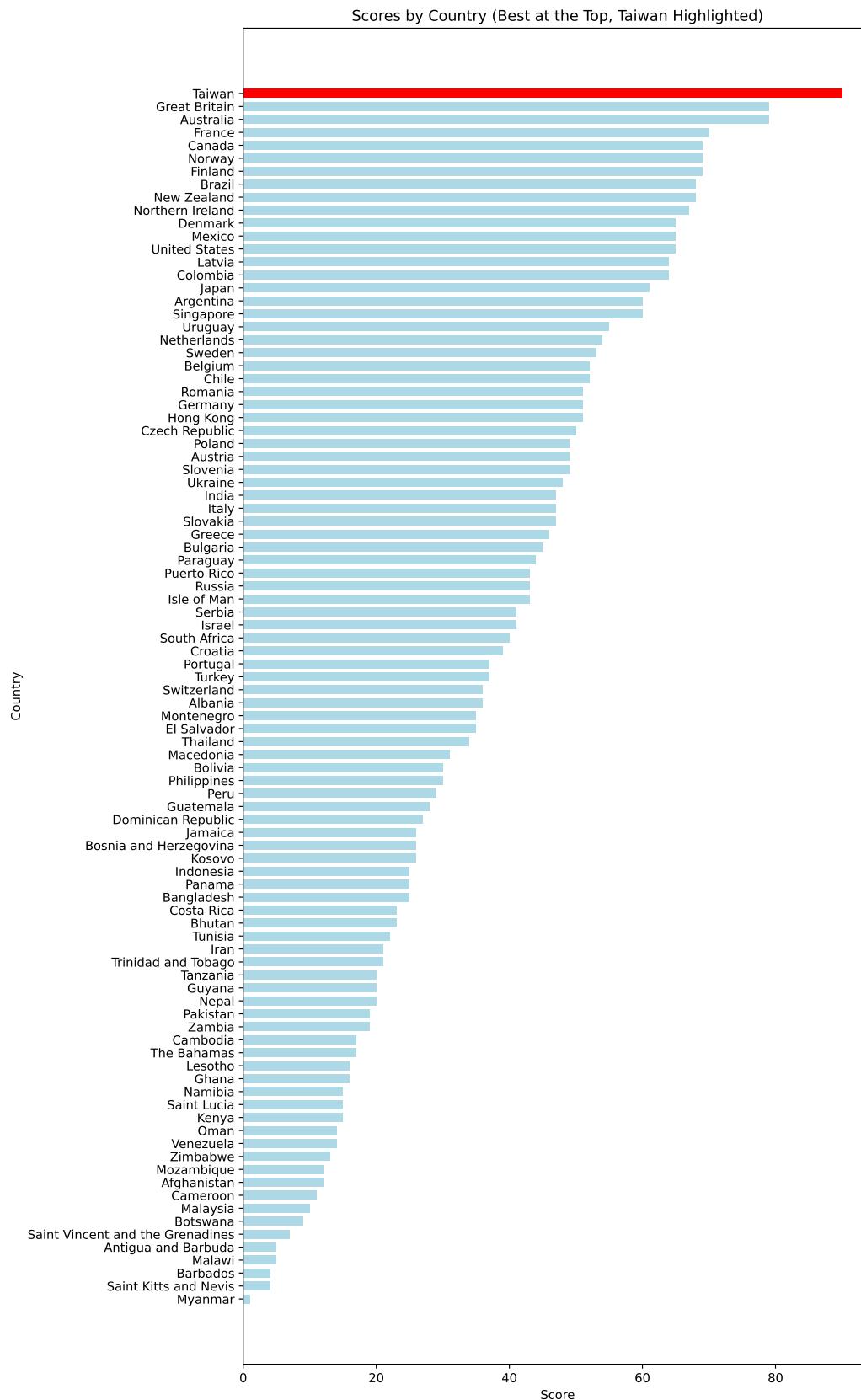


Figure 47: Open Data Index

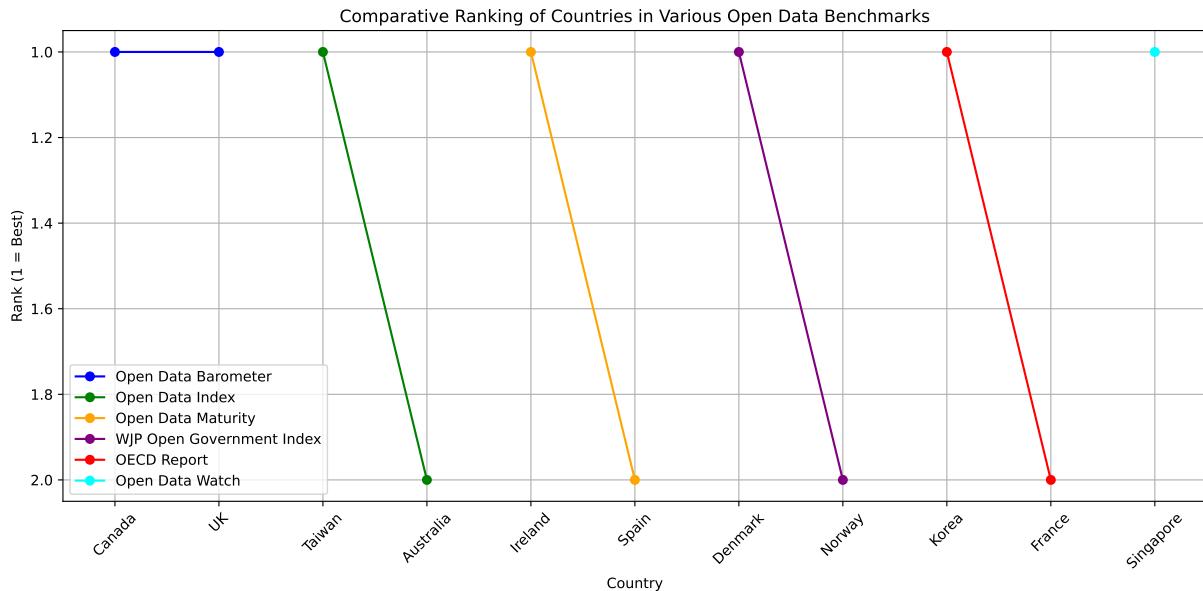
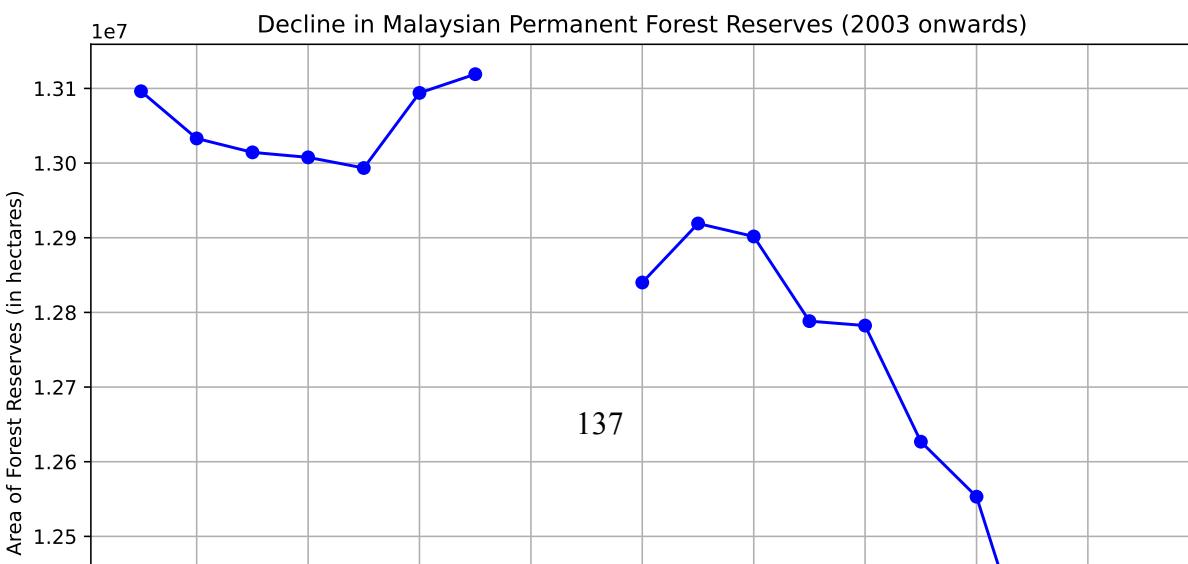


Figure 48: Alternative Open Data Indexes

Table 43: Examples of cities and countries that share data openly. Data sourced from (Government of Malaysia, 2025; Monetary Authority of Singapore, 2023; “Sveriges Dataportal,” 2025)

Country	Project
Sweden	Swedish open data portal
Malaysia	Malaysian open data portal
Singapore	Singapore ESG open data platform

To give a concrete example of the usefulness of open data, for instance, the Open Data Portal of Malaysia shows a steady decline in Permanent Reserved Forests (PRF) for anyone interested, without having to submit any letter of request or communicate with officials; the data is just directly accessible and includes a permissive license (Malaysia, 2024). Likewise, in Singapore, the Monetary Authority has launched an open data portal for ESG information, allowing anyone to delve into environmental, social, and governmental topics (Monetary Authority of Singapore, 2023).



9.7 Context Design: Behavioral Nudges Towards Green Defaults in Sustainable Superapps

For several decades, marketing researchers have been looking into how to affect human behavior towards increasing purchase decisions in commerce, both offline and online, which is why the literature on behavioral design is massive. One of the key concepts is *nudge*, first coined in 2008 by the Nobel-winning economist Richard Thaler; nudges are based on a scientific understanding of human psychology and shortcuts and triggers that human brains use and leverages that knowledge to influence humans in small but powerful ways (Thaler & Sunstein, 2009).

The principles of nudge have also been applied to sustainability. For example, a small study ($n = 33$) in the Future Consumer Lab in Copenhagen by (Perez-Cueto, 2021) found that designing a “dish-of-the-day” which was prominently displayed helped to increase vegetarian food choice by 85%. Experiments by (Guath et al., 2022) focused on environmentally friendly online purchases in Sweden ($n = 200$) suggest nudging can be effective in influencing online shopping behavior towards more sustainable options. A study of behavior change in Australia at large university setting ($N = 156$) by (Novoradovskaya et al., 2021) found nudging behavioral change had a significant effect and the author suggested it may help to avoid some of the “*16 billion paper coffee cups are being thrown away every year*” globally (based on the abstract - I was unable to access the full paper).

Google uses nudges in Google Flights and Google Maps, which allow filtering flights and driving routes by the amount of CO₂ emissions, as well as surfacing hotels with Green Key and Earth-Check credentials, while promising new sustainability features across its portfolio of products (Sundar Pichai, 2021). Such tools are small user interface nudges which Google’s research calls *digital decarbonization*, defined by (Implement Consulting Group, 2022) as “[m]aximising the enabling role of digital technologies by accelerating already available digital solutions”.

In (Kate Brandt & Matt Brittin, 2022), Google’s Chief Sustainability Officer Kate Brandt set a target of “at least 20-25%” CO₂ emission reductions in Europe to reach a net-zero economy and the global announcement set a target of helping 1 billion people make more sustainable choices around the world (Jeni Miles, 2022). In addition to end-users, Google offers digital decarbonization software for developers, including the Google Cloud Carbon Footprint tool and invests in regenerative agriculture projects (Google, 2023; *Inside Google’s Regenerative Agriculture Play | Greenbiz*, 2021). While Google has launched several climate-focused initiatives, it missed its CO₂eq reduction targets due to growing need for AI models (Worthington, 2025a).

Google has launched eco-focused features across its range of products: search improvements for finding hybrid and electric vehicles; green routes for driving, in collaborating with local city governments sourcing data from the traffic lights to provide AI - powered optimizations, which allows the map to suggest routes which would reduce fuel use and idling, complete with charging - station info; also, better navigation for cyclists (showing scooter and bike - share options) (“Google mostrará por defecto la ruta más ‘verde’ en su GPS y ordenará los vuelos según su impacto ambiental,” 2021; Worthington, 2025a). (Sarah Perez, 2022) shows how Google added features to Flights and Maps to filter more sustainable options. Yet, critics say updating the CO₂eq calculations’ math means Google started hiding emissions, which Google denies,

pointing to higher accuracy of the carbon emissions modeling instead (“Google ‘Airbrushes’ Out Emissions from Flying, BBC Reveals,” 2022). Google’s Nest Renew smart-home product helped people shift heating, ventilation, and air conditioning (HVAC) to use to cleaner grid times (with an optional subscription service to match home electricity with renewable electricity credits); in shopping searches, Google provides energy - efficient appliance recommendations, helping users choose lower - impact products at the point of purchase (Google, 2021; Justine Calma, Oct 6, 2021, 10:01 AM GMT+3).

Table 44: Examples of CO₂ visibility in Google’s products.

Feature	Product	Nudge
Google Maps AI suggests more eco-friendly driving routes (Mohit Moondra, n.d.)	Google Maps	Show routes with lower CO ₂ emissions; reduce stopping by using data from traffic lights.
Google Flights suggests flights with lower CO ₂ emissions	Google Flights	Show flights with lower CO ₂ emissions
Wizzair Check carbon impact (Offset Your Flight with WIZZ, n.d.)	WizzAir	Offset on Checkout

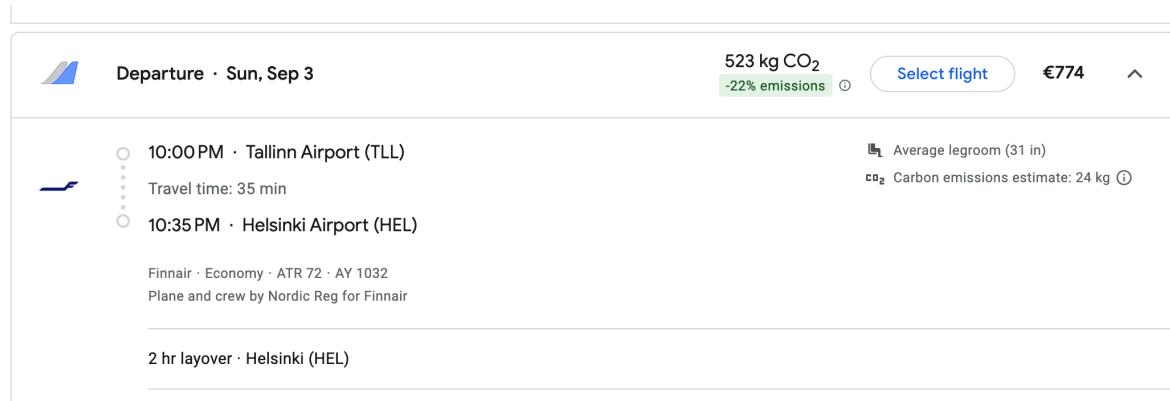


Figure 50: Google’s view of flight emissions

(Wee et al., 2021) proposes 7 types of nudging technique based on an overview of 37 papers which explore nudging people to be more environmentally friendly.

Table 45: Types of nudge documented by (Wee et al., 2021)

Name	Technique
Prompting	Create cues and reminders to perform a certain behavior
Sizing	Decrease or increase the size of items or portions

Name	Technique
Proximity	Change the physical (or temporal) distance of options
Presentation	Change the way items are displayed
Priming	Expose users to certain stimuli before decision-making
Labelling	Provide labels to influence choice (for example CO ₂ footprint labels)
Functional Design	Design the environment and choice architecture so the desired behavior is more convenient

(Acuti et al., 2023) makes the point that physical proximity to a drop-off point helps people participate in sustainability and metaphorical messaging alongside proximity can be powerful, enhancing the ease of information processing. In a field study in Northern Italy, a metaphor-based message re-framed the factual statement “1g of mercury can pollute 1000L of water” as “7 bathtubs”, and 354000000L as “140 Olympic swimming pools,” (a projection of potential Italian mercury pollution at current disposal rates), which significantly boosted willingness to recycle mercury.

Alibaba’s Ant Forest (螞蟻森林) has shown the potential gamified nature protection, simultaneously raising money for planting forests and building loyalty and brand recognition for their sustainable action, leading the company to consider further avenues for gamification and eco-friendliness.

Table 46: Ant Forest assisted tree planting; data compiled from (P. Cao & Liu, 2023; *Over 600 Million People Planted More Than 326 Million Trees via Alipay Ant Forest in Five Years*, 2021; UNFCCC, 2019; S. Wang et al., 2022; X. Wang & Yao, 2020; Z. Yang et al., 2018; B. Zhang et al., 2022; F. Zhou et al., 2023; 张越熙, 2024; 李连环 & 姜舒译, 2017; 胡群& 宋璠, 2024).

Year	Users	Trees	Area
2016	N/A	N/A	N/A
2017	230 million	10 million	N/A
2018	350 million	55 million	6500 acres??
2019	500 million	100 million	112,000 hectares / 66, 000 hectares?
2020	550 million	200 million	2,7 million acres?
2021	600 million	326 million	N/A
2022	650 million	400 million	2 million hectares
2023	690 million	475 million	N/A
2024	N/A	548 million	3.87 million hectares
2025	N/A	N/A	N/A

Ecosia is a search engine with an unconventional business models, investing all its profits into planting trees, pouring € 92 million into climate action since 2009, planting 225 million trees

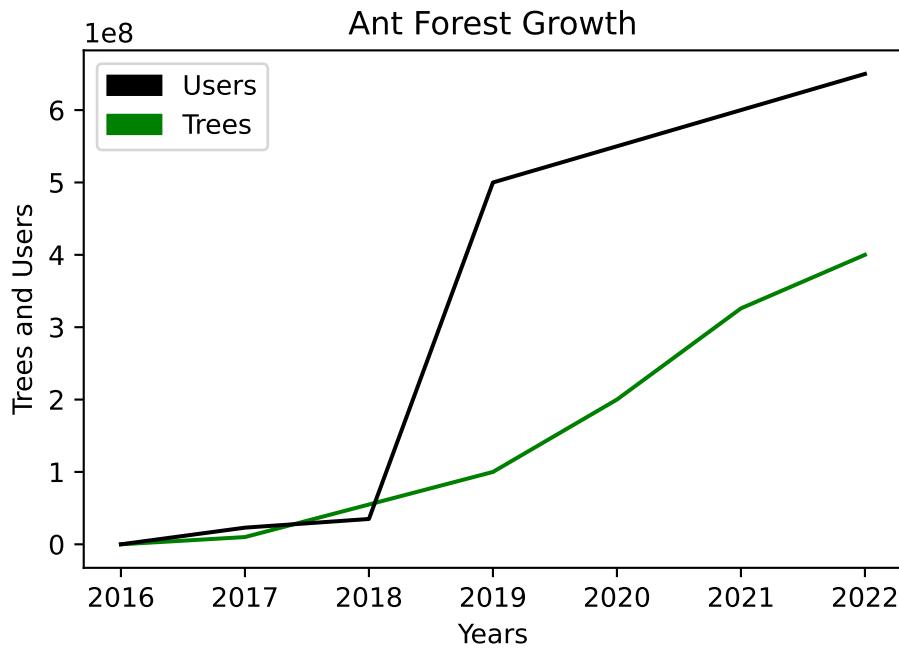


Figure 51: Growth of Ant Forest

worldwide (D. C. Garcia, 2025b). The founder Christian Kroll recalls travelling in South America in 2006 and being shocked to see vast areas of rainforests converted into soy plantations, which inspired him to research the causes of deforestation and start Ecosia; the company employs partners around the world to improve soil, biodiversity, the water cycle, reducing droughts and floods, and monitor the trees it plants (Hirsh, 2021).

New user interfaces hold some potential for sustainability improvements. In particular, immersive communication technologies such as AR/VR hold the potential to reduce business travel, if productive meetings can be held online, reducing emissions. Likewise, visualizing large architectural projects as well as simulating product design in various industries can reduce cost by detecting problems in the 3D environment, early on in the design process, especially for collaboration in teams located all over the world (Varjo, 2025). Dynamic interfaces might invoke a new, natural-interaction-focused design language, for taking full advantage of extended reality (Hoang, 2022). First encouraging findings from reconstructing language from fMRI readings (brain scans) even show potential for enabling computers to directly read human minds; contemporary AI models have already been shown capable of generating full sentences from human thoughts (J. Tang et al., 2022).

The small screen estate space of mobile phones and smart watches necessitates displaying content in a dynamic manner. Likewise, speaking is one mode of interaction that's become increasingly possible as machines learn to interpret human language. Virtual reality glasses (called AR/VR or XR in marketing speak) need dynamic content because the user is able to move around the environment. All these are multi-modal communication questions that interaction design is called upon to solve.

Table 47: Modes of Interaction

Modes of Interaction
Writing
Speaking
Touching
Moving
Seeing

9.8 Learning from Quantified Self: Tracking Health and Lifestyle

An early example of how tracking personal data enables behavior change, are health and lifestyle tracking apps. Research on *personal data tracking* also known as *quantified self* or *self-monitoring* is abundant. There's substantial academic evidence indicating that health tracking apps can have a measurable impact on user health behaviors and increase positive health outcomes. Wearable devices including the Apple Watch, Oura Ring, Fitbit and others, combined with apps, help users track a variety of health metrics. Recently, npj Biosensing even published a device from the MIT Media Lab that can track cells inside the human body from a wrist-worn device (Jang et al., 2025; Jarvis, 2025).

Apart from health, wearable devices have been used to track other metrics such as physiological parameters of students at school to determine their learning efficiency (Giannakos et al., 2020). Not only can health metrics be tracked, but exposure to pollution as well as personal carbon footprint, are all to some extent track-able (if not traceable).

9.8.1 Health and Fitness Tracking

Tracking one's health and fitness is a familiar mode of *quantified self*, available to many smart-watch users - and even pretty much to anyone who has a phone made in the past decade. Apple is a leader in health tracking, releasing Apple Health in 2008 as an iOS 8 software feature and the Apple Watch in 2015, filled with health-focused sensors and features (Apple, 2022b). In 2022 Apple outlined plans for “*empowering people to live a healthier day,*” promising a new set of health-features with every release, such as the rumored temperature measurement inside of Apple AirPod earphones; and providing most of this data to developers through Apple’s HealthKit health metrics APIs, which app builders can tap into (Apple, 2022a, 2022c).

Use of wearable devices enables one to be more aware of one's health. (Saubade et al., 2016) finds health tracking is useful for motivating physical activity. Blood glucose tracking is popular even for people without diabetes, to optimize their daily activity, including sports (“Is Blood Sugar Monitoring Without Diabetes Worthwhile?” 2021). Smart toilets offer unobtrusive monitoring of urine for one's hydration levels as well as deeper insights on biomarkers as well as renal and nutritional health, through using sensor - equipped seats (e.g. Withings' U-Scan), which create a daily stream of data useful for trend analysis (Hermsen et al., 2023; Wagner & Boiten,

2023). Companies like NeuralLink are building devices to construct meaningful interactions based only on brain waves (EEG) (Musk & Neuralink, 2019).

Popular Strava sports assistant (over 100 million users) provides activity tracking and feedback (Strava, 2022).

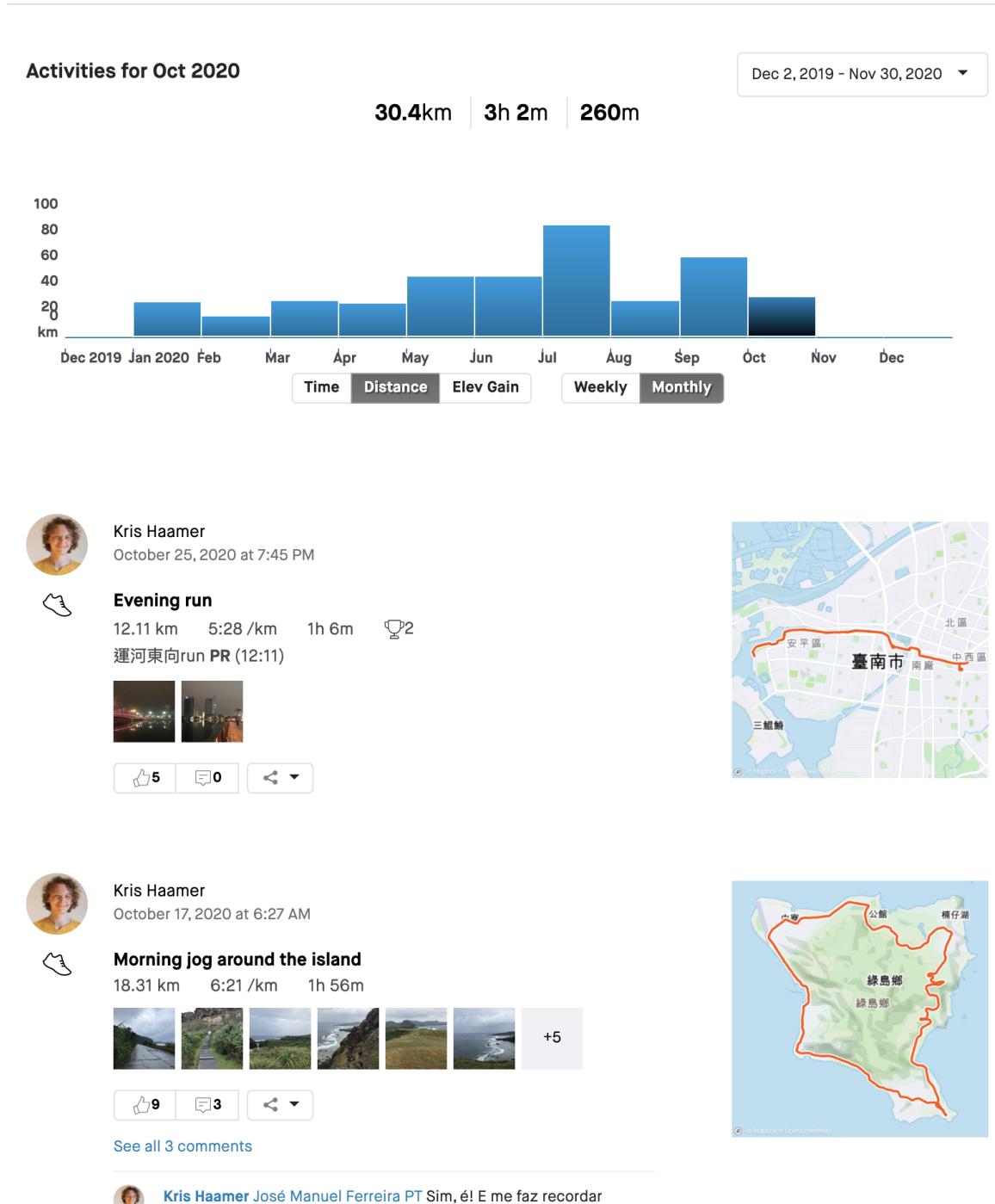


Figure 52: Popular Strava sports assistant provides run tracking and feedback

Sleep quality is an important aspect of both physical and mental health and many devices and apps focus on helping people get enough high quality sleep. There's plenty of academic literature on how physical activity, as well as environmental aspects, such as air quality, affect sleep (X. Liu et al., 2019) tracks how wearable data is used for tracking sleep improvements from exercise. (Grigsby-Toussaint et al., 2017) made use of sleep apps to construct humans behaviors also known as *behavioral constructs*.

Being conscious of one's mental health improves quality of life. (Tyler et al., 2022) surveyed the use of self-reflection apps in the UK ($n = 998$) finding a variety of methods from physical journaling in notebooks to smartphone-based note-taking apps, reviewing printed photo albums, and other digital tools.

Tracking one's food intake helps understanding how healthy and nutrient-rich is one's diet. (Ryan, 2022) uses the "capability methodology" framework, developed by economist Amartya Sen and later expanded by philosopher Martha Nussbaum, shifting focus from what people have (e.g. money, food, tools) to what they are able to do (human capabilities), which is used in the context of this paper to evaluate not only if the apps provide healthy food suggestions, but to what extent they expand a user's freedom to live a healthy life; some forms of nudging inside the apps can support users' goals however manipulative or coercive tactics serve only the app developers' interests and are ethically problematic - the paper emphasizes the need for interaction design that respect users' freedom, consider diverse personal choices, diverse bodies, cultures, and preferences, and environmental factors.

The Oura ring is an example of *calm technology*, providing helpful data without calling an attention to itself (Phelan, 2024). More recently, Oura Ring launched an AI-advisor to help explain the health data recorded by its device: deliver contextual and personalized guidance, remember past interactions while emphasizing privacy, and analyze both short- and long-term biometric trends (Team, 2025). There's value in developing standardized fitness metrics, which different digital health providers can use to create dashboards with comparable data. Even with messy data, AI has a useful role as a translator between different standards. OpenAI is collaborating with ex-Apple designer Jony Ive, to bring such ambient AI devices to life, which they believe has the potential for a new product category (WSJ News, 2025).

9.8.2 Pollution Exposure Tracking

Pollution exposure tracking may be considered a combination of health tracking and sustainability tracking. I've been tracking my personal air pollution exposure using the Atmotube Pro device attached to my backpack.

The above chart shows my exposure to pollutants while traveling, ranked from worst to best.

9.8.3 Tracking Personal Sustainability and Carbon Emissions

The above examples of tracking various aspects of health beg the question if one could track personal sustainability in a similar fashion. We have a limited carbon budget so calculating

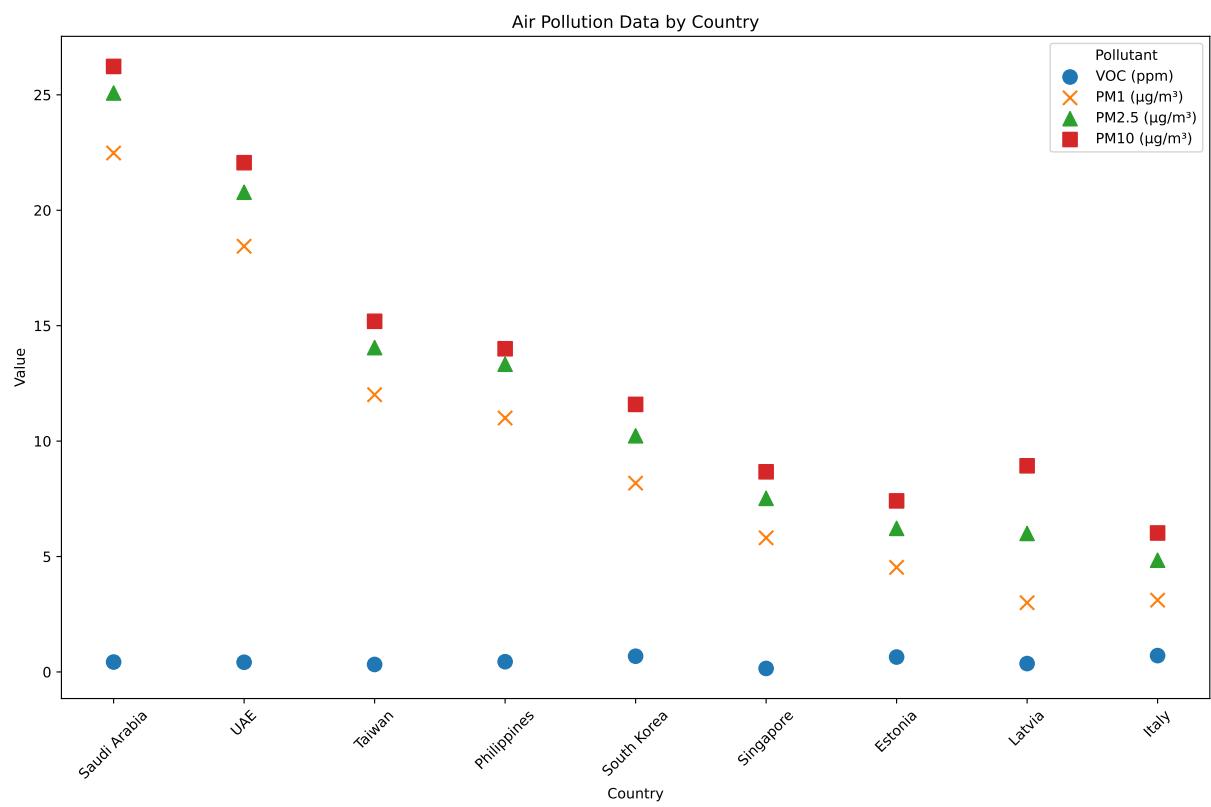


Figure 53: My Personal Exposure to Air Pollution

CO₂eq-cost could be expressly integrated into every activity.

Already in 2017, a project funded by the EU Horizon 2020 title “*Instant Gratification for Collective Awareness and Sustainable Consumerism*” piloted the concept of “*political consumerism*”, by enabling shoppers at 2 stores (Estonia and Austria) to experience real-time, personalized sustainability ratings on nearby products (by using a mobile app and bluetooth beacons to locate shoppers at shelf level, while maintaining privacy); instead of isolated choices, individual preferences were (environmental, health, political) aggregated into a community “sustainability signal”; the results indicated a statistically significant increase in sustainability awareness and some users praised the simplicity of the user interface (Bennati & Pournaras, 2018; *Instant Gratification for Collective Awareness and Sustainable Consumerism*, 2022; Klinglmayr et al., 2017; Pournaras et al., 2016).

More recently, (Kommenda et al., 2022) describes an interactive demo of Carbon Food Labels in the Financial Times, aimed at influence purchasing behavior by displaying Life Cycle Assessment (LCA) data directly on the products; for example - lentils (1kg CO₂eq per 1 kg) v.s. beef (27kg CO₂eq per 1 kg) - clearly illustrating the contrasting climate impact of different foods; moreover, shoppers could see the emissions in their shopping cart, enabling real-time comparisons and decision-making; an accompanying survey showed 68% of users were interested in choosing lower-emission products while a low 22% of the respondents trusted the data, highlighting a key challenge: standardizing and verifying supply-chain data.

The founder of the Commons (formerly known as Joro) consumer CO₂e tracking app recounts how people have a gut feeling about the 2000 calories one needs to eat daily, so perhaps daily CO₂e tracking could develop a gut feeling about one’s carbon footprint (Jason Jacobs, 2019). Zhang’s Personal Carbon Economy conceptualized the idea of carbon as a currency used for buying and selling goods and services, as well as an individual carbon exchange to trade one’s carbon permits (S. Zhang, 2018). These type of app suggest CO₂eq calculations will be part of our everyday experience. Nonetheless, sustaining user engagement over time in sustainability tracking apps is challenging, because the perceived personal benefit and measurable impact is so minimal - it may feel meaningless. Tracking sustainability may have collective benefits but tracking health has immediate personal benefits. Health apps feel tangible with increased well-being while sustainability apps often feel more collective, long-term and sometimes with benefits too small to matter, making it harder to motivate individual users.

Sustainability tracking, while perhaps less than health tracking, can also have a measurable impact. One study of personal carbon footprint tracking apps (aka CO₂eq calculators) in a mid-sized German city (n = 216) helped overall emission reduction by 23% correlating with feedback from the app specifically reducing emissions from heating 26.9%, food 16.4%, household 34.7% reduction, and mobility 12% (S. Hoffmann et al., 2024). Better maps can also convince people to make changes; advanced maps which visualize erosion, heat, flooding, fire, drought, extreme weather, and other climate risks, can inform resilience planning; a map for transport, such as taxis, can visualize pickup / drop-off imbalances, coloring areas green where pickups exceed drop-offs and orange where drop-offs exceed pickups, can help users see spatial patterns and inform climate-resilient transport planning (Carto, 2023).

Because of the large emission footprint of transport, offering a steep emissions reduction potential, greener modes of mobility have been heavily researched. Already more than a decade ago, a survey from April 2014 to December 2015 ($n = 4586$, total 29930 travel episodes) across the United Kingdom, asked participants to rate their enjoyment (on a liker scale from 1 to 7) and tracked the type of travel (work, unpaid work, personal care, childcare, leisure, etc); results showed private car was used for 79% of personal care and 55% of leisure trips; key findings showed *walking and cycling significantly increase enjoyment* across all trip purposes, while public transit reduced enjoyment for childcare and work-related travel; overall findings show improvements in transport infrastructure can both lower green house gas emissions and boost traveler wellbeing (Echeverría et al., 2022).

A wide range of personal carbon footprint calculators have been released online, ranging from those made by governments and companies to student projects. Similar to personal health trackers, personal CO₂ trackers help one track emissions and suggests sustainable actions. In Singapore, the DBS bank released a consumer sustainability ESG app called DBS LiveBetter (DBS, 2018; DBS Singapore, n.d.)

Table 48: A selection of personal sustainability apps.

App	Description
Commons (Formerly Joro)	Financial Sustainability Tracking + Sustainable Actions
Klima	Offset Subscription
Wren	Offset Subscription
JouleBug	CO ₂ eq tracking
eevie	
Aerial	
EcoCRED	
Carbn	
LiveGreen	
Earth Hero	

(G. Shin et al., 2019)'s synthesis review of 463 studies shows wearable devices have potential to influence behavior change towards healthier lifestyles. While the behavior changes may sound simple - like switching from driving to walking - and would have an effect both on health and the environmental, they are hindered by factors from personal motivation to (lack of) suitable urban architecture. (Delclòs-Alió et al., 2022) discusses walking in Latin-American cities. Walking is the most sustainable method of transport but requires the availability of city infrastructure, such as sidewalks, which many cities still lack. The urban environment has an influence on health. (Sanchez et al., 2022) suggests tracking users using their smartphones and attributing points for actions deemed beneficial - yet this has potential privacy issues. For any service tracking the user's action, following privacy UX guidelines is crucial (Jarovsky, 2022b).

Human behavior is affected by the environment. The above chart shows the incidence of bad behavior during the pandemic increased significantly in Sweden based on data from (Ceccato et

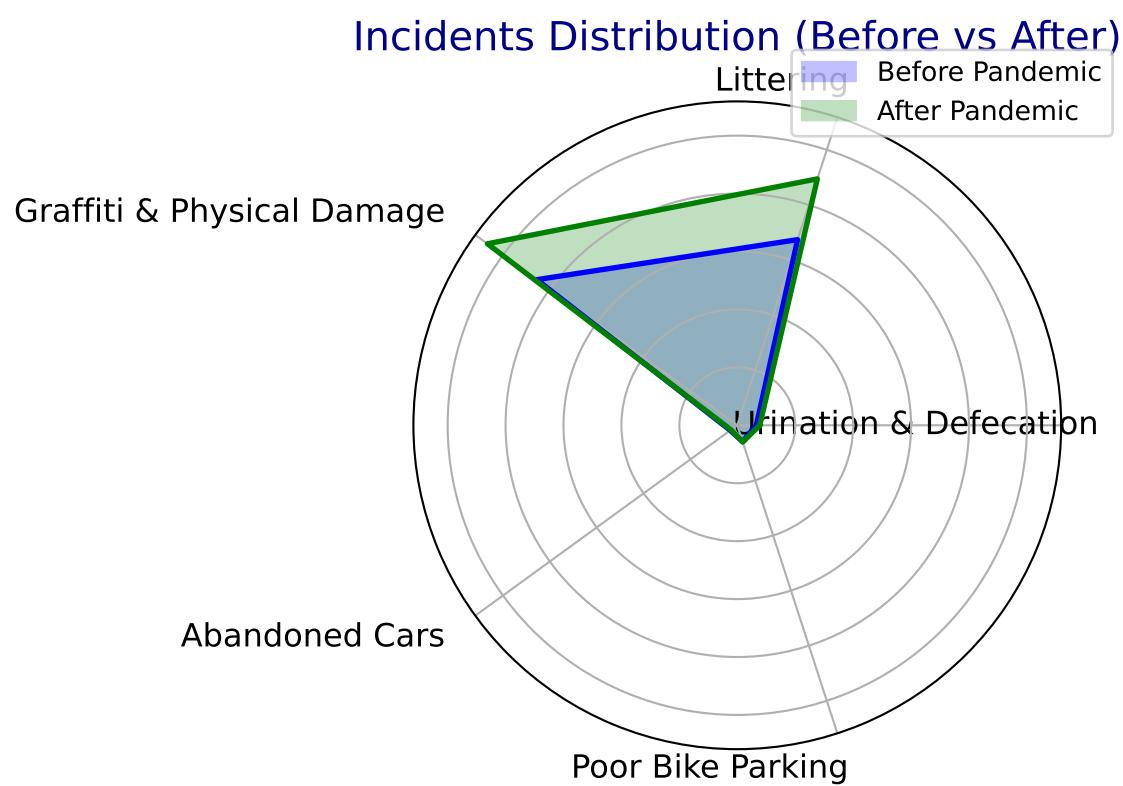


Figure 54: Increase of Bad Behavior During the COVID19 Pandemic

al., 2023).

9.9 Digital Product Passports: Tracking Data for Sustainable Product Management

Digital Product Passports, part of the Sustainable Products Initiative, are one of the key actions taken under the Circular Economy Action Plan (CEAP) of the European Union; the goal of this initiative is to lay the groundwork for a gradual introduction of a digital product passports in at least 3 key markets by 2024: (1) batteries for electric vehicles and industrial use, (2) consumer and ICT electronics, (3) textiles and apparel (Kuch, 2022). (Nissinen et al., 2022) calls for emissions data to be made available to manufacturers, retailers, and consumers so they can make low-carbon choices; moreover, metrics must move beyond a single aggregated number to assessing life-cycle emissions' variability.

In theory, DPPs are able to capture and make usable the comprehensive trace of data needed for green transformation. Even though *digital product passports* relate heavily to adopting a circular economy, I've chosen to highlight this topic under Design, as it's the main design implication from this chapter - an emerging technology which needs to be *designed*. (King et al., 2023) proposes a universal definition of a Digital Product Passport Ecosystem (DPPE) as a “system-of-systems,” synthesizing stakeholder requirements and concerns from the EU’s open consultation on the Sustainable Products Initiative, aiming to influence consumer behavior towards sustainable purchasing - and responsible product ownership - by making the sustainability aspects of a product life cycle clearly apparent. (Reich et al., 2023) identifies *information gaps* as one of the major obstacles to realizing a circular economy; a study of 28 experts across academia, industry, government, consultancy and NGOs, showed Digital Product Passports (DPPs) can enhance the 9 “R” in circular strategies. The first full articulation of the 9 R strategies came from the report “Circular Economy – Measuring Innovation in the Product Chain”, where (Potting et al., 2017) laid out a hierarchy of circular - economy options; the framework was later adopted and popularized in peer-reviewed literature, for example (Kirchherr et al., 2017).

Table 49: The 9 R strategies from (Potting et al., 2017).

R-Strategy	Definition
R9 Recover	Incineration of material (energy recovery)
R8 Recycle	Process materials, obtaining the same (high grade) or lower grade quality
R7 Repurpose	Use discarded product (or its parts) in a new product (with a different function)
R6 Remanufacture	Use parts of a discarded product in a new product (with the same function)
R5 Refurbish	Restore an old product (bring it up to date)
R4 Repair	Maintenance of a product so it can be used with its original function
R3 Reuse	Reuse by another consumer (still in good condition and fulfills its original function)

R-Strategy	Definition
R2 Reduce	Increase efficiency in product manufacture (consume fewer natural resources and materials)
R1 Rethink	Use the product more intensively (sharing the product via online platforms, etc)
R0 Refuse	Don't use product at all (or replace the function with a better alternative)

There's extensive literature on the use Digital Product Passports (DPP) at specific industries and for particular use cases, often focused on improved efficiencies. (Plociennik et al., 2022) details the use of Digital Product Passports and the cloud platform infrastructure to improve e-waste sorting when paired with ML-based object detection. (Berger, Rusch, et al., 2023) outlines data-science and machine-learning approaches (for example sharing models) to enable the exchange of sensitive EV-battery life-cycle data through Digital Product Passports, while preserving confidentiality, helping overcome stakeholder reluctance. (Jensen et al., 2023) study of mechatronics supply chains found DPPs "*support decision-making throughout product life cycles in favor of a circular economy*"; specifically:

- (1) usage and maintenance
- (2) identification
- (3) materials
- (4) guidelines
- (5) supply-chain and reverse logistics
- (6) environmental data
- (7) compliance

With the increasing electrification of transport, finding ways to deal with the batteries is a crucial area of research. (Berger, Baumgartner, Weinzerl, Bachler, Preston, et al., 2023) examined the stakeholders of electric vehicle (EV) battery value-chain and mapped their data requirements and current availability, laying groundwork to propose a *Digital Battery Passport*. (Berger, Baumgartner, Weinzerl, Bachler, & Schögl, 2023) lists current challenges with EV batteries, providing empirical insights into difficulties with DPP adoption, including technical, organizational, and policy barriers; an interesting part of the research is the introduction go "*Sustainable Product Management*" (SPM) as a specific field of management in the context of circular economy.

The key barriers to adoption from (Berger, Baumgartner, Weinzerl, Bachler, & Schögl, 2023) include:

Uncertainty of stakeholders
 Technological barriers
 Insufficient willingness to share information
 Lack of clear legal requirements and standards

Meanwhile the enablers include:

Clear legal requirements
 Relative advantages (reputation gains, access to new markets, risk avoidance, marketing)
 Monetary incentives (such as payments for data)
 Intrinsic motivation (compatibility with the values)

Focusing on food production industries, a brief historical overview of previous efforts in this area may be helpful, to contextualize the discussion. CO_{2e} labeling initiatives represent an early attempt to communicate the environmental cost of each product. Using carbon labels to convey CO_{2e} emission of consumer products has been a topic of discussion for decades (Adam Corner, 2012). Academic literature has looked at minute details such as color and positioning of the label (S. Zhou et al., 2019). There's some indication consumers are willing to pay a small premium for low-CO_{2e} products; all else being equal, consumers choose the option with a lower CO_{2e} number (Carlsson et al., 2022; M. Xu & Lin, 2022). (Cohen & Vandenberg, 2012) argues labeling the carbon footprint of products does help inform consumer choice towards sustainability and help promote a green economy. A large-scale study of UK university students finds some evidence to suggest labeling low CO_{2e} food enables people to choose a *climatarian diet*, however the impact of carbon labels on the market share of low-carbon meals is negligible (Lohmann et al., 2022).

Similar to to *Nutritional Facts Labeling*, *Carbon Labels* provide basic information regarding the emissions' profile of each product, yet taken alone, without a systemic push for carbon reduction, they are insufficient to drive significant behavioral change. A study in Sweden underlines a negative correlation between worrying about climate impact and interest in climate information on products (Edenbrandt & Lagerkvist, 2022). This latter finding may be interpreted to suggest a need for wider environmental education programs among consumers. (Asioli et al., 2022) found differences between countries, where Spanish and British consumers chose meat products with '*no antibiotics ever*' over a *Carbon Trust* label, whereas French consumers chose CO₂ labeled meat products. Despite ongoing interest, several studies have shown that the overall impact of carbon labeling on consumer behavior remains negligible. The idea is yet to find mainstream adoption and participation in carbon labeling schemes remains voluntary, with only a limited number of companies implementing such practices, although their numbers are gradually increasing. Notable examples include the U.S.-based restaurant chain *Just Salad* , U.K.-based vegan meat-alternative *Quorn*, and plant milk *Oatly*, all of which provide carbon labeling on their products (Brian Kateman, 2020). (ClimatePartner, 2020) Companies like ClimatePartner and Carbon Calories offers labeling consumer goods with emission data as a service. (The Carbon Trust, n.d.) The Carbon Trust reports it's certified 270000 product emissions' footprints.

Table 50: Companies with Carbon Labels (Brian Kateman, 2020)

Company	Country
Just Salad	U.S.A.
Quorn	U.K.
Oatly	U.K.
IKEA	Sweden

Table 51: Organizations Who Certify Carbon Labels (ClimatePartner, 2020).

Organization	Number of Certified Products
ClimatePartner	
Carbon Calories	
Carbon Trust	27000

Transitioning from simpler carbon labels to data-driven *Digital Product Passports* requires comprehensive data collection on product's history, composition, and environmental impact, digital infrastructure, industry collaboration, regulatory frameworks, and consumer engagement.

Table 52: Digital Product Passport goals (Stretton, 2022a).

Goal
Sustainable Product Production
Businesses to create value through Circular Business Models
Consumers to make more informed purchasing decisions
Verify compliance with legal obligations

(Van Capelleveen et al., 2023) conducted a comprehensive, structured review of 200 academic papers on Digital Product Passports and related concepts, including circular, product, material, resource, recycling, and cradle-to-cradle variants, assessing dimensions such as historical developments, stakeholders, goals, challenges, and designs for solutions, in order to formalize the concept and its boundaries, finally synthesizing a unified definition:

“a digital interface composing a certified identity of a single identifiable product by accessing the set of life cycle registrations linked to this object in order to yield insight into the sustainability and circularity characteristics, the circular value estimation, and the circular opportunities for both that product and its underlying components and materials.”

Circularise, a leader in providing digital product passports as a service, lists 15 types of data that should be include in a DPP (Tian Daphne & Chris Stretton, 2023). A case study of rigid polyurethane foam (PU foam), a lightweight insulation material, explains how Circularise used blockchain and zero-knowledge proof (ZKP) to allow for DPP data-sharing, while retaining privacy and control over the data (Daphne, 2022; León, 2025).

The above chart shows data categories used in Digital Product Passports (DPPs) as defined by Circularise.

(Gnanasambandam et al., 2022) describes responsible product management as embedding privacy, sustainability, and inclusion into product design as core priorities, not afterthoughts. (Korzhova, 2020) works as a *Sustainable Product Manager* at Grover, an online platform which

Digital Product Passport Data Categories

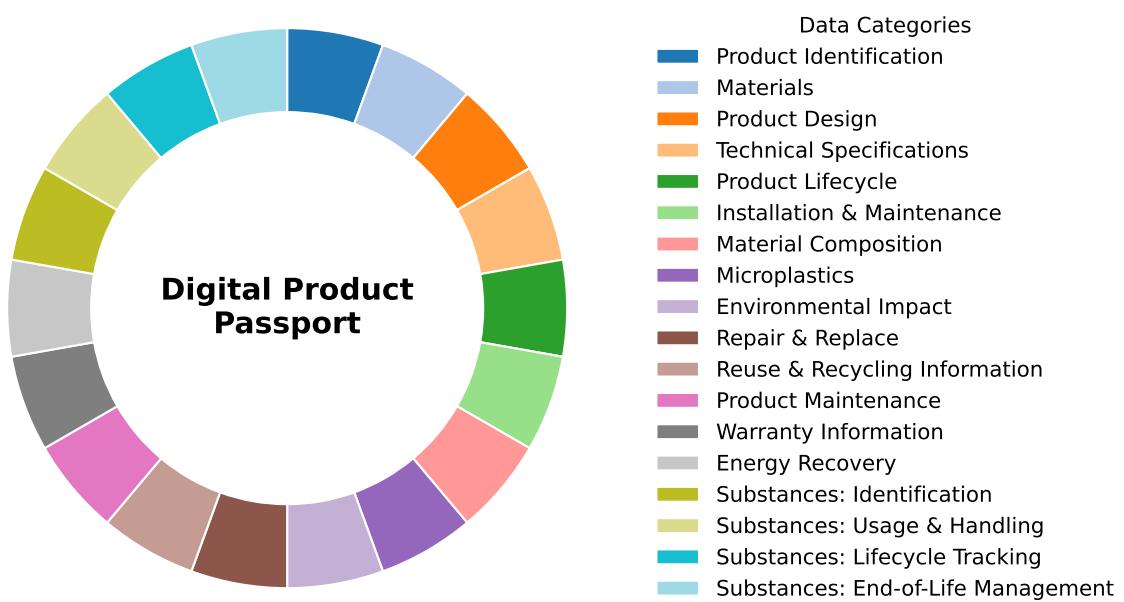
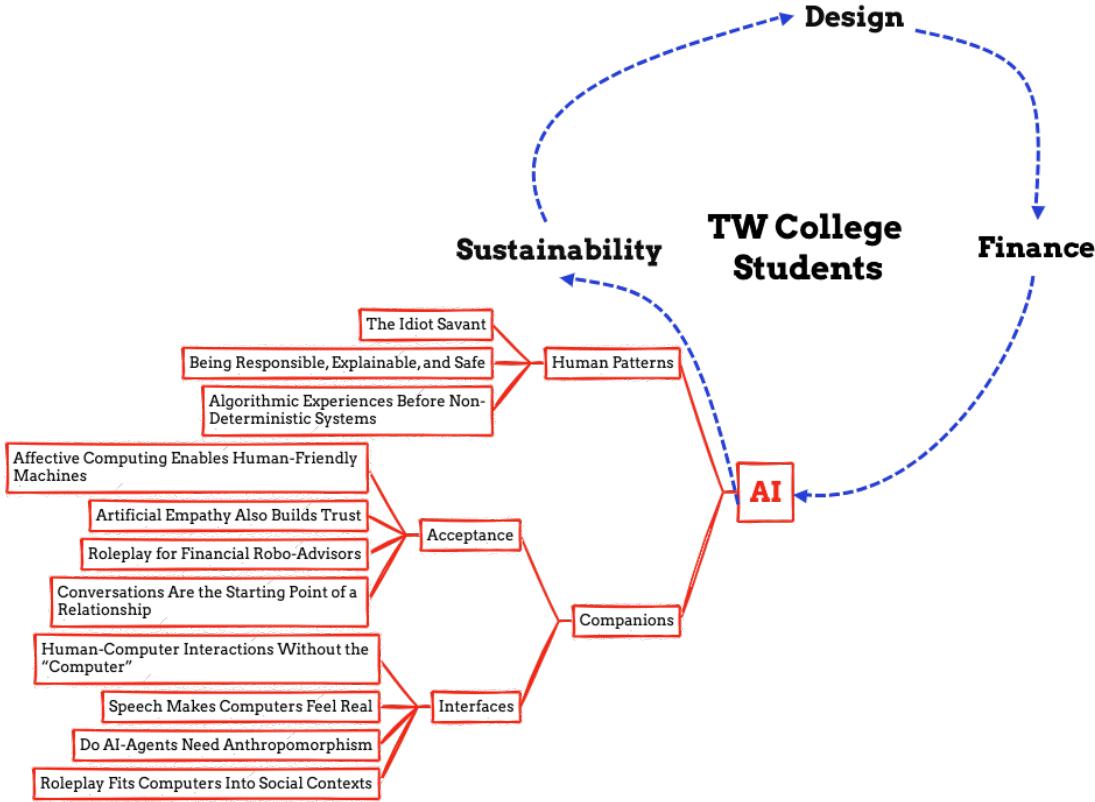


Figure 55: Digital Product Passport Data Categories

offers product for rent; she details how rentals-based business model has saved 360 tons of devices from going to waste (the author compares the amount to about 15 truckloads of devices), which sums up to 4275 tons of CO₂ savings.

10 AI



Presented with xmind AI

Figure 56: Visual abstract for the AI chapter

10.1 Human Patterns

The fact that AI systems work so well is proof that we live in a measurable world. The world is filled with structures: nature, cultures, languages, human interactions - all form intricate patterns. Computer systems are increasingly capable in their ability to copy these patterns into computer models - known as machine learning. As of 2023, 97 zettabytes (and growing) of data was created in the world per year (Soundarya Jayaraman, 2023). Big data is a basic requirement for training AIs, enabling learning from the structures of the world with increasing accuracy. Large data-sets such as the LAION-5B of 5.85 billion image-text pairs, were foundational for training AI to recognize images (Romain Beaumont, 2022; Schuhmann et al., 2022). Just 3 years later, generating images with GenAI models is now fast enough to create images in real-time while

the user is typing (Dwarkesh Patel, 2024). Similarly huge data-sets exist about other types of media - and the open Internet itself, albeit less structured, is a data-source frequently scraped by AI-model builders. Representations of the real world in digital models enable humans to ask questions about the real-world structures and to manipulate them to create synthetic experiments that may match the real world (if the model is accurate enough). This can be used for generating human-sounding language and realistic images, finding mechanisms for novel medicines as well as understanding the fundamental functioning of life on its deep physical and chemical level (No Priors: AI, Machine Learning, Tech, & Startups, 2023). Venture capitalists backing OpenAI describe AI as a foundational technology, which will unlock human potential across all fields of human activity (Greylock, 2022).

In essence, *human patterns* enable AIs. Already 90 years ago (McCulloch & Pitts, 1943) proposed the first mathematical model of a neural network inspired by the human brain. Alan Turing's Test for Machine Intelligence followed in 1950. Turing's initial idea was to design a game of imitation to test human-computer interaction using text messages between a human and 2 other participants, one of which was a human, and the other - a computer. The question was, if the human was simultaneously speaking to another human and a machine, could the messages from the machine be clearly distinguished or would they resemble a human being so much, that the person asking questions would be deceived, unable to realize which one is the human and which one is the machine? (Turing, 1950).

Alan Turing: “*I believe that in about fifty years’ time it will be possible to program computers, with a storage capacity of about 10^9 , to make them play the imitation game so well that an average interrogator will not have more than 70 percent chance of making the right identification after five minutes of questioning. ... I believe that at the end of the century the use of words and general educated opinion will have altered so much that one will be able to speak of machines thinking without expecting to be contradicted.*” - from (Stanford Encyclopedia of Philosophy, 2021)

By the 2010s AI models became capable enough to beat humans in games of Go and Chess, yet they did not yet pass the Turing test. AI use was limited to specific tasks. While over the years, the field of AI had seen a long process of incremental improvements, developing increasingly advanced models of decision-making, it took an *increase in computing power* and an approach called *deep learning*, a variation of *machine learning (1980s)*, largely modeled after the *neural networks* of the biological (human) brain, returning to the idea of *biomimicry*, inspired by nature, building a machine to resemble the connections between neurons, but digitally, on layers much deeper than attempted before. Like quantum computing, AI more of a discovery, thank an invention; we have no idea, what are the limits of intelligence (CatGPT, 2025).

Founder of NVIDIA, Jensen Huang, whose computer chips power much of this revolution, calls it the “*Intelligence Infrastructure*”, produced by intelligence factories, and integrated into everything, just like electricity was (NVIDIA, 2025). In order to produce this intelligence, huge AI factories are being built around the world, measured in the energy requirements. (Calma, 2025) predicts AI will surpass Bitcoin’s energy use by the end of 2025 (Calma, 2025). The 500B USD Stargate project, is currently building 1.2 gigawatts of AI capacity in the Texas, and expanding

to other areas around the U.S., and data center in Abu Dhabi, U.A.E., which requires 5GW of energy, and is physically bigger than the country of Monaco (Loizos, 2025; Moss, 2025). In comparison, the 500MW xAI AI factory, built by Elon Musk's company, powered by natural gas generators, is moderate in size (B. Wang, 2025). While OpenAIs Sam Altman is repeatedly quoted as saying the productivity gains created by AI will far offset any of its environmental footprint or other words to that effect (Altman, 2024; Di Pizio, 2023), critics like (iGenius, 2020) argue that AI cannot enable a sustainable future if it is not sustainable by design; training and delivery of AI products must include sustainability considerations tied into data intelligence and business analytics.

10.1.1 Human Feedback

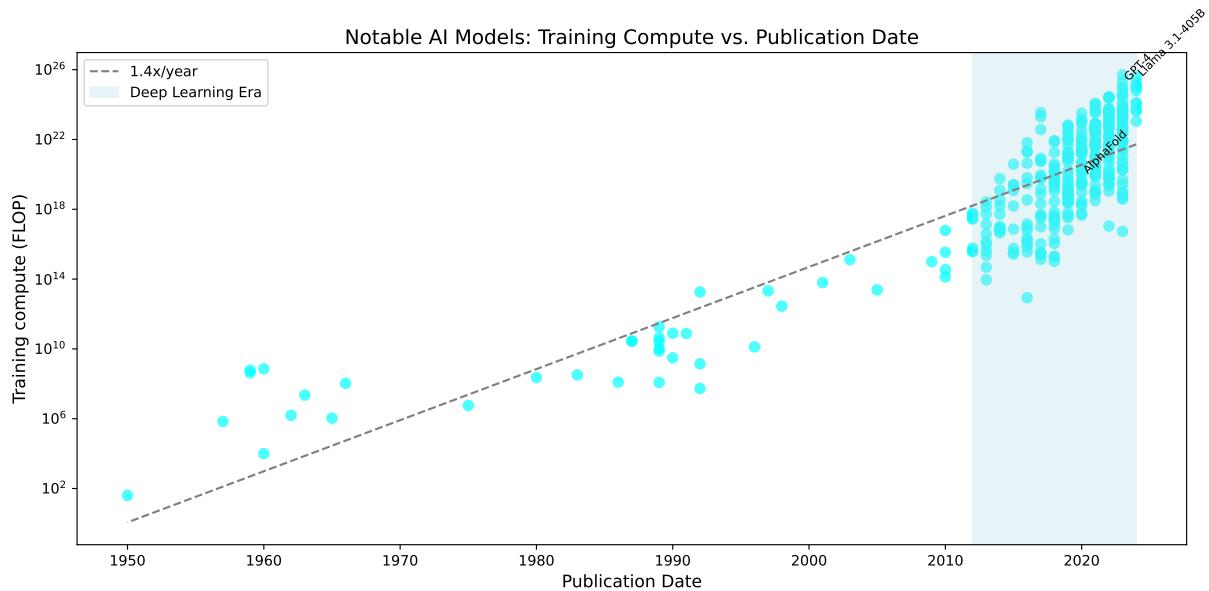
Combining deep learning and *reinforcement learning with human feedback (RLHF)* enabled to achieve levels of intelligence high enough to beat the Turing test (Christiano et al., 2017; Christiano, 2021; Kara Manke, 2022). John Schulman, a co-founder of OpenAI describes RLHF simply: “*the models are just trained to produce a single message that gets high approval from a human reader*” (Kara Manke, 2022). Bigger models aren’t necessarily better; rather models need human feedback to improve the quality of responses (Ouyang et al., 2022).

The nature-inspired approach was successful. Innovations such as *back-propagation* for reducing errors through updating model weights and *transformers* for tracking relationships in sequential data (for example in sentences), enabled AI models to became increasingly capable (Merritt, 2022; Vaswani et al., 2017). **Generative Adversarial Networks** trained models through pitting them against each other (Goodfellow et al., 2014). **Large Language Models**, enabled increasingly generalized models, capable of more complex tasks, such as language generation (Radford et al., 2018).

One of the leading scientists in this field of research, Geoffrey Hinton, had attempted back-propagation already in the 1980s and reminiscents how:

“*the only reason neural networks didn’t work in the 1980s was because we didn’t have enough data and we didn’t have enough computing power*” (CBS Mornings, 2023).

(Epoch AI, 2024) reports the growth in computing power and the evolution of more than 800 AI models since the 1950s. Very simply, more data and more computing power means more intelligent models.



The above chart shows an illustration of how transformers work by (Alammar, 2018).

By the 2020s, AI-based models became a mainstay in medical research, drug development, patient care (Holzinger et al., 2023; Leite et al., 2021), quickly finding potential vaccine candidates during the COVID19 pandemic (Zafar & Ahamed, 2022), self-driving vehicles, including cars, delivery robots, drones in the sea and air, as well as AI-based assistants. The existence of AI models has wide implications for all human activities from personal to professional. The founder of the largest chimp-maker NVIDIA calls upon all countries do develop their own AI-models which would encode their local knowledge, culture, and language to make sure these are accurately captured (World Governments Summit, 2024).

OpenAI has researched a wide range of approaches towards artificial general intelligence (AGI), work which has led to advances in large language models(AI Frontiers, 2018; Ilya Sutskever, 2018). In 2020 OpenAI released a LLM called GPT-3 trained on 570 GB of text (Alex Tamkin & Deep Ganguli, 2021) which was adept in text-generation. (Singer et al., 2022) describes how collecting billions of images with descriptive data (for example the descriptive *alt* text which accompanies images on websites) enabled researchers to train AI models such as ***stable diffusion*** for image-generation based on human-language. These training make use of *Deep Learning*, a layered approach to AI training, where increasing depth of the computer model captures minute details of the world. Much is still to be understood about how deep learning works; even for specialists, the fractal structure of deep learning can only be called *mysterious* (Sohl-Dickstein, 2024).

AI responses are probabilistic and need some function for ranking response quality. Achieving higher percentage or correct responses requires oversight which can come in the form of human feedback or by using other AIs systems which are deemed to be already well-aligned (termed Constitutional AI by Anthropic) (Bai et al., 2022; J. Bailey, 2023). One approach to reduce non-alignmnet issues with AI is to introduce some function for human feedback and oversight

to automated systems. Human involvement can take the form of interventions from the AI-developer themselves as well as from the end-users of the AI system. Such feedback is not only provided by humans, computer can give feedback to computers too. Less powerful AIs are taught by more powerful and aligned AIs, which understand the world better, to follow human values: for example META used LLAMA 2 for aligning LLAMA 3.

There are many examples of combination of AI and human, also known as “*human-in-the-loop*”, used for fields as diverse as training computer vision algorithms for self-driving cars and detection of disinformation in social media posts (Bonet-Jover et al., 2023; Jingda Wu et al., 2023). Also known as Human-based computation or Human-aided Artificial Intelligence (Mühlhoff, 2019; Shahaf & Amir, 2007). (Ge Wang, 2019) from the Stanford Institute for Human-Centered Artificial Intelligence, describes core design principles for building interactive AI systems that augment rather than replace people: (1) value human agency, (2) offer granularity of control, and (3) provide transparency interfaces.

Table 53: Examples of human-in-the-loop apps.

App	Category	Use Case
Welltory	Health	Health data analysis
Wellue	Health	Heart arrhythmia detection
QALY	Health	Heart arrhythmia detection
Starship Robots	Delivery	The robot may ask for human help in a confusing situation, such as when crossing a difficult road

In order to provide human feedback, systems need to be able to distinguish humans from AIs. To that end, several “Proof of Humanity” toolsets are in the process of being built. (Gitcoin Passport — Sybil Defense. Made Simple. [@gitcoinpassport], 2023) discusses how to build Gitcoin Passport’s Unique Humanity Score, an antifragile passport, inspired by Nassim Taleb’s popular book (Taleb, 2012). Taleb defines “antifragility” as “systems that benefit from volatility and stressors”, summarizing it in a letter to Nature thus:

“a convex response to a stressor or source of harm (for some range of variation), leading to a positive sensitivity to increase in volatility” - antifragility.

Gitcoin’s Passport pulls together proofs of identity from web2 platforms - but adds a unique twist: “Cost of Forgery” as a protection against fake users (aka Sybil attacks, where a malicious person fakes identities so it looks like many independent users), it becomes more expensive for them to do so, turning attack pressure into a self-reinforcing defense; however, while this approach works, it does set a very high bar for users to comply, and requires a cryptocurrency to set the price for the attacks (Gitcoin Passport — Sybil Defense. Made Simple. [@gitcoinpassport], 2023). In contrast, another popular proof-of-personhood protocol called World, verifies humanity via physical scans of human iris’, captured by its Orb device; and again using cryptography, to compare a proof (ZK-SNARK) against a centralized database (Gent, 2023). From the user experience perspective, this approach is much simpler (while needing physical presence for the iris

scan). Given that World was co-founded by the OpenAI co-founder Sam Altman, this may be one way he plans to counter the possible societal disruptions accelerated by OpenAIs products.

10.1.2 AI as the *Idiot Savant*

Hinton likes to call AI an *idiot savant*: someone with exceptional aptitude yet serious mental disorder (CBS Mornings, 2023). Large AI models don't understand the world like humans do. Their responses are predictions based on their training data and complex statistics. Indeed, the comparison is apt, as the AI field now offers jobs for *AI psychologists*, whose role is to figure out what exactly is happening inside the 'AI brain' (Waddell, 2018). Understanding the insides of AI models trained of massive amounts of data is important because they are *foundational*, enabling a holistic approach to learning, combining many disciplines using languages, instead of the reductionist way we as human think because of our limitations (CapInstitute, 2023). Hinton received a Nobel prize for modeling how the brain works and coming up with the idea of predicting the next word in a sequence, already in 1986, which later became the basis for large language models (CBS Mornings, 2025).

Foundation models enable *Generative AIs*, a class of models which are able to generate many types of *tokens**, such as text, speech, audio (Kreuk et al., 2022; San Roman et al., 2023), music (Copet et al., 2023; Meta AI, 2023), video, and even complex structures such 3D models and DNA structures, in any language it's trained on. The advent of generative AIs was a revolution in human-computer interaction as AI models became increasingly capable of producing human-like content which is hard to distinguish from actual human creations. This power comes with *increased need for responsibility*, drawing growing interest in fields like *AI ethics* and *AI explainability*. Generative has a potential for misuse, as humans are increasingly confused by what is computer-generated and what is human-created, unable to separate one from the other with certainty.

(Bommasani et al., 2021) define *foundation models* as large scale pretrained models adaptable to diverse downstream tasks, thouroughly accounting opportunities, such as capabilities across language, vision, robotics and reasoning - and risks: bias, environmental cost, economic shifts, governance, highlighting the need for interdisciplinary research - to understand deeply how these models work, and when and how do they fail. Understaning failure is crucial, as there is the question of who bares the responsibility for the actions taken by the AI (especially, in its most agentic forms, with access to the internet and tools outside the model itself). Research in organizational behavior indicates that when individuals exert influence through intermediaries - known as *indirect agency*, - their ethical judgment can become distorted: humans may believe they are behaving ethically while, in reality, they exhibit reduced concern for those affected by their decisions, resulting in less accountability for moral failures, and expecting fewer consequences for unethical conduct (Gratch & Fast, 2022).

The technological leap is disruptive enough for people to start calling it the start of a new era.(Noble et al., 2022) proposes AI has reached a stage of development marking beginning of the *5th industrial revolution*, a time of collaboration between humans and AI. Widespread Internet of Things (IoT) sensor networks that gather data analyzed by AI algorithms, integrates computing

even deeper into the fabric of daily human existence. Several terms of different origin but considerable overlap describe this phenomenon, including *Pervasive Computing (PC)* (Y. Rogers, 2022) and *Ubiquitous Computing*. Similar concepts are *Ambient Computing*, which focuses more on the invisibility of technology, fading into the background, without us, humans, even noticing it, and *Calm Technology*, which highlights how technology respects humans and our limited attention spans, and doesn't call attention to itself. In all cases, AI is integral part of our everyday life, inside everything and everywhere. Today AI is not an academic concept but a mainstream reality, affecting our daily lives everywhere, even when we don't notice it.

10.1.3 Algorithmic Experience and Transparency: Before AIs

Before AIs, as a user of social media, one may be accustomed to interacting with the feed algorithms that provide a personalized *algorithmic experience*. Social media user feed algorithms are more *deterministic* than AI, meaning they would produce more predictable output in comparison AI models. Nonetheless, there are many reports about effects these algorithms have on human psychology, including loneliness, anxiety, fear of missing out, social comparison, and even depression (De et al., 2025; Qiu, 2021).

Design is increasingly relevant to algorithms, - *algorithm design* - and more specifically to algorithms that affect user experience and user interfaces. *When the design is concerned with the ethical, environmental, socioeconomic, resource-saving, and participatory aspects of human-machine interactions and aims to affect technology in a more human direction, it can hope to create an experience designed for sustainability.*

(Lorenzo et al., 2015) underlines the role of design beyond *designing* as a tool for envisioning; in her words, “*design can set agendas and not necessarily be in service, but be used to find ways to explore our world and how we want it to be*”. Practitioners of Participatory Design (PD) have for decades advocated for designers to become more activist through *action research*. This means to influencing outcomes, not only being a passive observer of phenomena as a researcher, or only focusing on usability as a designer, without taking into account the wider context.

(Shenoi, 2018) argues inviting domain expertise into the discussion while having a sustainable design process enables designers to design for experiences where they are not a domain expert; this applies to highly technical fields, such as medicine, education, governance, and in our case here - finance and sustainability -, while building respectful dialogue through participatory design. After many years of political outcry (Crain & Nadler, 2019), social media platforms such Meta Facebook and Twitter (later renamed to X) have began to shed more light on how these algorithms work, in some cases releasing the source code (Nick Clegg, 2023; Twitter, 2023).

The content on the platform can be more important than the interface. Applications with a similar UI depend on the community as well as the content and how the content is shown to the user.

10.1.4 Transitioning to Complexity: Non-Deterministic Systems

AIs are non-deterministic, which requires a new set of consideration when designing AI. AI systems may make use of several algorithms within one larger model. It follows that AI Explainability requires *Algorithmic Transparency*.

10.1.5 Being Responsible, Explainable, and Safe: Legislation Adapts and Sets Boundaries for AI

On March 13 2024, the European Parliament (with 523 votes for and 46 against) the EU AI Law, taking a risk-based approach to a regulatory framework, which aims to support innovation, while safeguarding democracy and environmental sustainability (Lomas, 2024). Specifically, the EU Artificial Intelligence Act (Regulation EU 2024/1689) establishes the first comprehensive legal framework for AI in the world, aiming to harmonize rules to ensure that AI systems are safe, human-centric, and rights-respecting; the act defines a tiered system that bans unacceptable risks and regulates high-risk uses, imposing transparency duties on developers of AI systems, for example near-realtime (hourly) CO₂eq emissions reports from the AI models (European Union, 2024). As AI-based solutions permeate every aspect of human life, legislation is starting to catch up. In order to help international jurisdictions tailor which incidents and hazards they track and enable interoperability, the Organization for Economic Cooperation and Development (OECD) later also defined 2 types of AI risk, “AI incident” - AI system causes real harm; “AI hazard” - potential - harm scenario, both which can be raised to “serious” variants (OECD, 2024a).

“As humans we tend to fear what we don’t understand” is a common sentiment which has been confirmed psychology (Allport, 1979). Current AI-models are opaque ‘black boxes’, where it’s difficult to pin-point exactly why a certain decision was made or how a certain expression was reached, not unlike inside the human brain. This line of thought leads me to the idea of **AI Psychologists**, who might figure out the **Thought Patterns** inside the model. Research in AI-explainability (XAI in literature) is on the lookout for ways to create more **Transparency and Credibility** in AI systems, which could lead to building trust in AI systems and would form the foundations for **AI Acceptance**.

The problems of opaqueness creates the field of *Explainable AI*. (Bowman, 2023) says steering Large Language Models is unreliable; even experts don’t fully understand the inner workings of the models. Work towards improving both **AI steerability** and **AI Alignment** (doing what humans expect) is ongoing. (Holbrook, 2018) argues that in order to reduce errors which only humans can detect, and provide a way to stop automation from going in the wrong direction, it’s important to focus on making users feel in control of the technology. There’s an increasing number of tools for LLM evaluation. “Evaluate and Track LLM Applications, Explainability for Neural Networks” (Leino et al., 2018; TruEra, 2023). (P. Liang et al., 2022) believes there’s early evidence it’s possible to assess the quality of LLM output transparently. (Cabitza et al., 2023) proposes a framework for explainability of AI-expressions to guide XAI research, focusing on the quality of formal soundness and cognitive clarity. (Khosravi et al., 2022) proposes

a framework for AI explainability, focused squarely on education, which brings in communication with stakeholders and human-centered interface design (Holzinger et al., 2021) highlights possible approaches to implementing transparency and explainability in AI models, introducing the concept of *multimodal causability*, where an AI system uses pictures, text, and charts all at once, which could help the human user see cause and effect across different kinds of data.

The chart below displays the AI Credibility Heuristics: A Systematic Model, which explains how (similarly to Daniel Kahneman's book "Thinking, Fast and Slow"), AI...

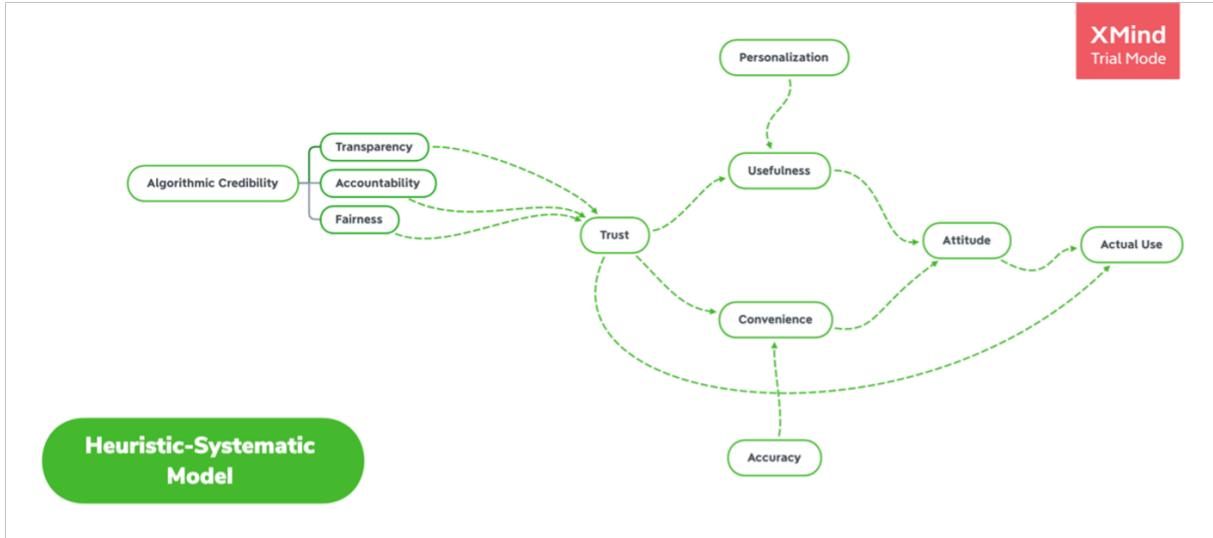


Figure 57: Heuristic-Systematic Model of AI Credibility

A movement called *Responsible AI* seeks to mitigate generative AIs' known issues. Given the widespread use of AI and its increasing power of foundational models, it's important these systems are created in a safe and responsible manner. While there have been calls to pause the development of large AI experiments (Future of Life Institute, 2023) so the world could catch up, this is unlikely to happen. There are several problems with the current generation of LLMs from OpenAI, Microsoft, Google, Nvidia, and others.

(Christiano, 2023) believes there are plenty of ways for bad outcomes (existential risk) even without extinction risk. In order to mitigate these risks (and perhaps to appease the public), all the major AI labs have taken steps to be more safe. Anthropic, which was founded by former OpenAI employees, after leaving the OpenAI over this very issue, led the movement by announcing responsible *scaling policy* (Anthropic, 2023). OpenAI itself announced a dedicated "Superalignment" team, co-led by Ilya Sutskever and Jan Leike; they made a specific promise to commit 20% of its compute budget to build an AI system in the next 4 years, that can itself research and refine alignment methods, effectively solving the alignment problem for superintelligent AI (which is considered the highest risk) (Jan Leike & Ilya Sutskever, 2023). OpenAI has previously admitted, it does not yet fully understand how the internals of a neural network work; they are developing tools to represent neural network concepts for humans (L. Gao et al., 2024;

OpenAI, 2024a). Outside of the major labs, several independent AI safety organizations have also been launched, for example METR, the Model Evaluation & Threat Research incubated in the Alignment Research Center (METR, 2023).

A popular approach to AI safety is *red-teaming*, which means pushing the limits of LLMs, trying to get them to produce outputs that are racist, false, or otherwise unhelpful. Mapping the emerging abilities of new models is a job in itself.

Table 54: Summarizing some problems with contemporary AIs.

Problem	Description
Monolithicity	LLMs are massive monolithic models requiring large amounts of computing power for training to offer <i>multi-modal capabilities</i> across diverse domains of knowledge, making training such models possible for very few companies. Shikun Liu et al. (2023) proposes future AI models may instead consist of a number networked domain-specific models to increase efficiency and thus become more scalable.
Opaqueness	LLMs are opaque, making it difficult to explain why a certain prediction was made by the AI model. One visible expression of this problem are <i>hallucinations</i> , the language models are able to generate text that is confident and eloquent yet entirely wrong. Jack Krawczyk, the product lead for Google's Bard (now renamed to Gemini): "Bard and ChatGPT are large language models, not knowledge models. They are great at generating human-sounding text, they are not good at ensuring their text is fact-based. Why do we think the big first application should be Search, which at its heart is about finding true information?"
Biases and Prejudices	AI bias is well-documented and a hard problem to solve (W. Liang et al., 2023). Humans don't necessarily correct mistakes made by computers and may instead become "partners in crime" (Krügel et al., 2023). People are prone to bias and prejudice. It's a part of the human psyche. Human brains are limited and actively avoid learning to save energy. These same biases are likely to appear in LLM outputs as they are trained on human-produced content. Unless there is active work to try to counter and eliminate these biases from LLM output, they will appear frequently.

Missing Data	LLMs have been pre-trained on massive amounts of public data, which gives them the ability for reasoning and generating in a human-like way, yet they are missing specific private data, which needs to be ingested to augment LLMs ability to respond to questions on niche topics (J. Liu, 2022).
Data Contamination	Concerns with the math ability of LLMs. “performance actually reflects dataset contamination, where data closely resembling benchmark questions leaks into the training data, instead of true reasoning ability” H. Zhang et al. (2024)
Lack of Legislation	Anderljung et al. (2023) OpenAI proposes we need to proactively work on common standards and legislation to ensure AI safety. It’s difficult to come up with clear legislation; the U.K. government organized the first AI safety summit in 2023 Browne (2023).

In 2024, OpenAI released its “*Model Spec*” to define clearly their approach to AI safety with the stated intention to provide clear guidelines for the RLHF approach (OpenAI, 2024c).

10.1.6 Evolution of Models and Emerging Abilities

The debate between open source vs closed-source AI is ongoing. Historically, open-source has been useful for finding bugs in code as more pairs of eyes are looking at the code and someone may see a problem the programmers have not noticed. Proponents of closed-source development however worry about the dangers of releasing such powerful technology openly and the possibility of bad actors such as terrorists, hackers, violent governments using LLMs for malice. The question whether closed-sourced or open-sourced development will lead to more AI safety is one of the large debates in the AI industry.

Personal AI assistants to date have been created by large tech companies, mostly using closed-source AI. However, open-source AI-models have opened up the avenue for smaller companies and even individuals for creating new AI-assistants - perhaps using the same underlying foundation model as the base, but adding new data, abilities, tools, or just innovating on the UI/UX stack. An explosion of personal AI assistants powered by foundation models can be found across use-cases. The following table only lists a tiny sample of such products.

Table 55: AI-based Assistants

App	Features
socratic.org	Study buddy
youper.ai	Mental health helper

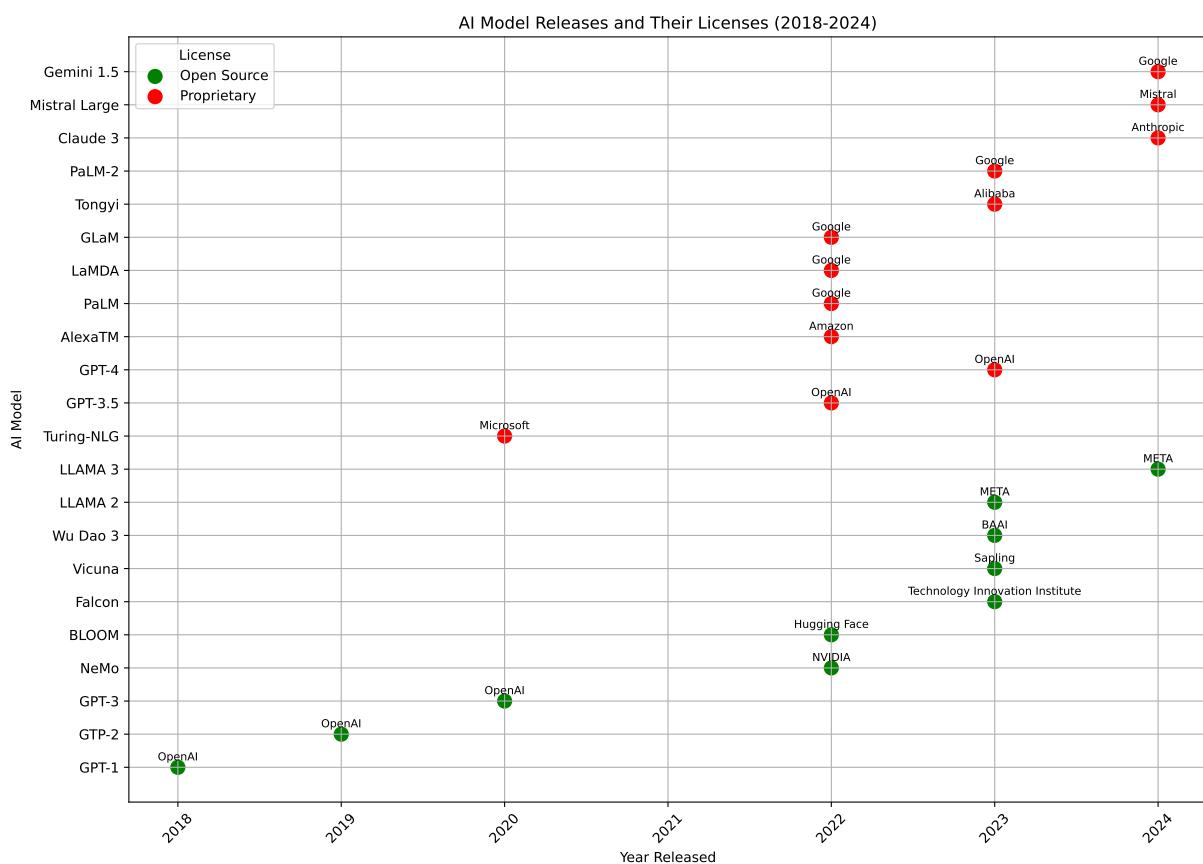
App	Features
fireflies.ai	Video call transcription
murf.ai	Voice generator

In any case, open or closed-sourced, real-world usage of LLMs may demonstrate the limitations and edge-cases of AI. Hackathons such as (Pete, 2023) help come up with new use-cases and disprove some potential ideas. The strongest proponent of Open Source AI, META, open-sourced the largest language model (70 billion parameters) which with performance rivaling several of the proprietary models; because META’s core business is not AI, rather it would benefit from having access to cheaper, better AI across the board, open-sourcing may be their best strategy (Dwarkesh Patel, 2024).

Table 56: Summary of 7 years of rapid AI model innovation since the first LLM was publicly made available in 2018 (Alvarez, 2021; Baptista et al., 2025; T. B. Brown et al., 2020; DeepSeek-AI et al., 2025; Hines, 2023a; META, 2024; Tamkin et al., 2021).

AI Model	Released	Company	License	Country
GPT-1	2018	OpenAI	Open Source	U.S.
GTP-2	2019	OpenAI	Open Source	U.S.
Turing-NLG	2020	Microsoft	Proprietary	U.S.
GPT-3	2020	OpenAI	Open Source	U.S.
GPT-3.5	2022	OpenAI	Proprietary	U.S.
GPT-4	2023	OpenAI	Proprietary	U.S.
AlexaTM	2022	Amazon	Proprietary	U.S.
NeMo	2022	NVIDIA	Open Source	U.S.
PaLM	2022	Google	Proprietary	U.S.
LaMDA	2022	Google	Proprietary	U.S.
GLaM	2022	Google	Proprietary	U.S.
BLOOM	2022	Hugging Face	Open Source	U.S.
Falcon	2023	Technology Innovation Institute	Open Source	U.A.E.
Tongyi	2023	Alibaba	Proprietary	China
Vicuna	2023	Sapling	Open Source	U.S.
Wu Dao 3	2023	BAAI	Open Source	China
LLAMA 2	2023	META	Open Source	U.S.
PaLM-2	2023	Google	Proprietary	U.S.
Claude 3	2024	Anthropic	Proprietary	U.S.
Mistral Large	2024	Mistral	Proprietary	France
Gemini 1.5	2024	Google	Proprietary	U.S.
LLAMA 3	2024	META	Open Source	U.S.
AFM	2024	Apple	Proprietary	U.S.

AI Model	Released	Company	License	Country
Viking 7B	2024	Silo	Open Source	Finland
GPT-4.5	2025	OpenAI	Proprietary	U.S.
DeepSeek-R1	2025	Hangzhou DeepSeek Artificial Intelligence Basic Technology Research Co., Ltd 杭州深度求索人工智能基础技术研究有限公司	Open Source	China
GPT-5	202?	OpenAI	Unknown; trademark registered	U.S.

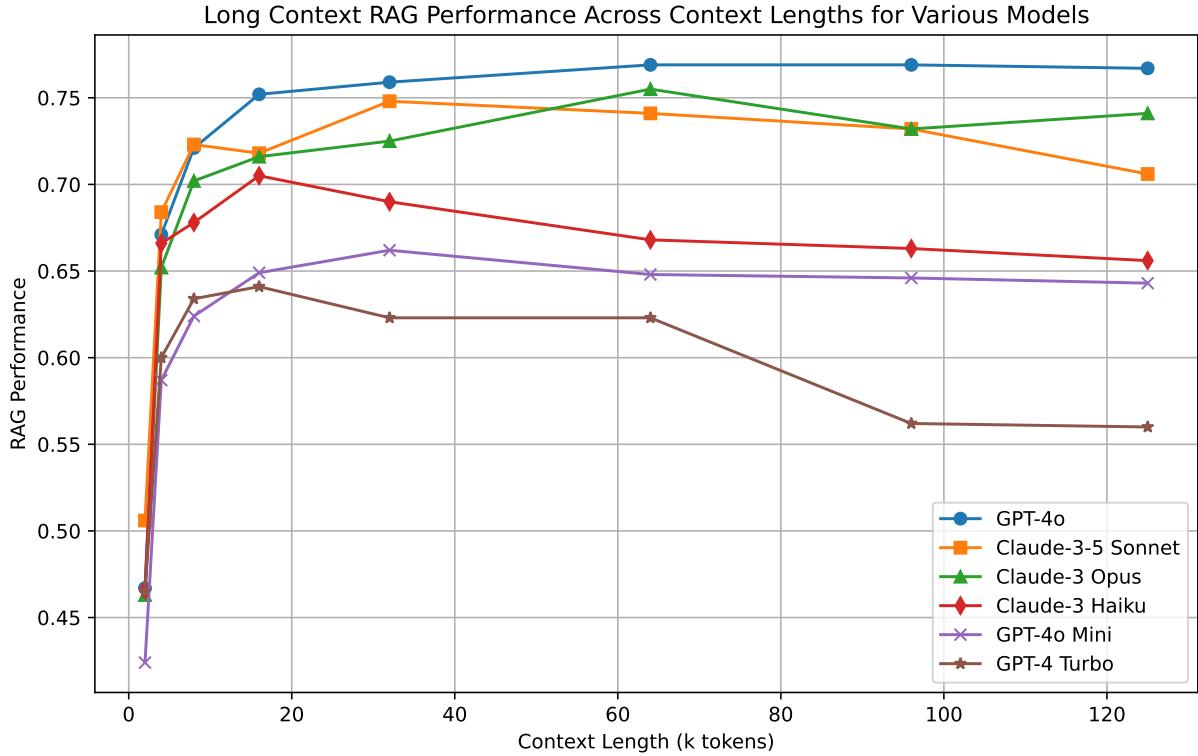


A foundational paper on the scaling laws of LLMs by (Kaplan et al., 2020) provided a quan-

titative road-map linking model, data, and compute to predict performance; helpful to guide large-scale investment into LLMs. The proliferation of different models enables comparisons of performance based on several metrics from accuracy of responses to standardized tests such as GMAT usually taken by humans to reasoning about less well defined problem spaces. (W.-L. Chiang et al., 2024; lmsys.org, 2024) open-source AI-leaderboard project has collected over 500 thousand human-ranking of outputs from 82 large-language models, evaluating reasoning capabilities, which as of 2024 rate GPT-4 and Claude 3 Opus as the top-performers. Model performance is not one-dimensional; (OpenAI, 2024b) show how GPT 4o combines different abilities into the same model, preserving more information, which in previous models was lost in data conversion (for example for images). Another metric is metacognition, defined as *knowing about knowing* (J. Metcalfe & Shimamura, 1994) or “*keeping track of your own learning*” as defined by educators in sustainability (an example of how the same term is useful across academic fields) (Zero Waste Europe et al., 2022). Anthropic’s Claude 3 was the first model capable of metacognition, promoting it as a feature, calling out a mistake made by itself (Shibu, 2024).

With the proliferation of AI models, AI benchmarking has developed into its own industry, with many ways to measure a model’s performance. In the early days (Hendrycks et al., 2020) revealed models’ uneven knowledge and lack in calibration, with the introduction of MMLU (Measuring Massive Multitask Language Understanding), a 57-task benchmark covering domains from elementary math to law, showing GPT-3 43.9% accuracy vs 89.8% human experts (19 points above random chance but far below human-expert level). Later models have reached or surpassed humans in this particular benchmark, necessitating the creation of newer, more difficult tests for AI. Another foundational AI paper, (Zellers et al., 2019)’s HellaSwag, is also accompanied by a leaderboard website (still being updated after publication) listing AI model performance most recent entry April 16, 2024.

Moreover, benchmarking is not only about the abilities, knowledge and alignment of the model itself. Interactions with other systems are equally important to measure, such as Retrieval Augmented Generation (RAG) performance. RAG is used to enhance AI content with domain-specific (close-to realtime) knowledge. A technique first proposed by researchers at META (Lewis et al., 2020) some RAG benefits include “*make contextual decisions on-the-fly, thereby opening up a more dynamic and responsive way to handle knowledge search tasks*” (Dewy, 2024; Y. Gao et al., 2023). Generative AI applications retrieve data from unstructured external sources in order to augment LLMs existing knowledge with current information (Leng et al., Mon, 08/12/2024 - 19:46). (Ragas, 2023) suggests evaluating one’s RAG pipelines enables *Metrics-Driven Development*. Likewise, LangSmith, the developer platform for LLM-powered apps (which makes extensive use of RAG), dissects the LLM app lifecycle into a pipeline: debug, collaborate, test, and monitor (LangChain, 2024). As using unstructured inputs to generate structured data, is one of the core use cases of LLMs, conforming the outputs strictly to standards such as JSON is crucial (otherwise the production app might even break), explaining why OpenAI’s Structured Outputs, which guaranteed 100% reliability, was an important jump in AI adoption to mainstream app development (Pokrass, 2024).



Meta’s head AI researcher Yann LeCun predicts LLMs may have reached their limitations, for innovation AIs need to understand the physical world and do reasoning in abstract space, which does not require a language, i.e. something a cat could do when figuring out where to jump; in comparison, languages are simple because they are discrete, with very little noise (NVIDIA Developer, 2025).

10.1.7 Price of Tokens vs Price of Human Labor

At the end of the day, the adoption of AI to everyday life, even in the smallest of contexts, will come down to the price. Long-time AI-engineer (Ng, 2024) predicts, having seen the roadmaps for the microchip industries, as well as incoming hardware and software innovations, the price of tokens will be very low, and much lower than a comparative human worker.

10.2 Human Acceptance of Artificial Companions

10.2.1 Human Expectations Take Time to Change

AI acceptance is incumbent on traits that are increasingly human-like and would make a human be acceptable: credibility, trustworthiness, reliability, dependability, integrity, character, etc. (G. Zhang et al., 2023) found humans are more likely to trust an AI teammate if they are not deceived by its identity. It’s better for collaboration to make it clear, one is talking to a machine. One step towards trust is the explainability of AI-systems. AIs should disclose they are AIs.

(Zerilli et al., 2022) focuses on human factors and ergonomics and argues that transparency should be task-specific: while transparency is key to trust and system monitoring, it should extend beyond explainability; after AI makes an error, different forms of AI transparency: (1) explanations, (2) confidence metrics, (3) human control over *task allocation* - affect human confidence in the system and have diverse levels of ability to repair human trust in the AI. To expand on the third point discussed by this author, in *adaptable allocation*, the user always decides when to keep a task and when to hand it to the AI algorithm - and in *adaptive allocation*, the system decides itself (by monitoring its own uncertainty) when to give difficult or risky cases back to the human.

Humans still need some time to adjust their expectations of *what's possible* using conversational AI interfaces. (J. Bailey, 2023) believes people are used to *search engines* and it will take a little bit time to get familiar with talking to a computer in natural language to accomplish their tasks. For example, new users of v0, an AI assistant for building user interfaces through conversation, would tell humans (the company make this app) about the issues they encounter, instead of telling the AI assistant directly, even though the AI in many cases would be able to fix the problem instantly; human users don't yet necessarily expect computers to behave like another human, there's *inertia* in the mental model of what computers are capable of, requiring the user interfaces to provide context and teaching humans how to interact with their AI coworkers(Rauch, 2024). Indeed, ChatGPT is already using buttons to explain context (Feifei Liu 刘菲菲, n.d.).

Speaking in the mother language of the users is a way to gain trust. English is still over-represented in current models so some local models focus on better understanding local context, such as the Finnish (“Silo AI’s New Release Viking 7B, Bridges the Gap for Low-Resource Languages,” 2024) focuses on Nordic languages. However, as time progresses, large, general-purpose LLMs may catch up and integrate all this knowledge - or even potentially being taught by the local models.

10.2.2 Affective Computing: Towards Friendly Machines

Rosalind Picard founded the field of *affective computing*, aiming to make computers more human-friendly, pioneering early approaches to recognizing human emotions with sensors and providing users experiences that take human emotion into account (Picard, 1997).

It's not an overstatement to say that data from all the processes around us will define the future of computing (HIITV, 2021). In the early examples, electrodermal activity of the skin and heart-rate variance data were used to detect the emotional state and stress level of the user (Velmovitsky et al., 2022; Zangróniz et al., 2017). This technology has since become mainstream in products such as Fitbit and the Apple Watch, among many others.

Personal experience:

Apple Watch features Fall Detection, which I've experienced personally. Riding my bicycle to the NCKU library after rain, I slipped and landed on my stomach on the pavement. Apple Watch immediately asked me: “*It looks like you've taken a hard fall*” and offered an option to call the ambulance. Fortunately I was OK but if

I did need assistance, this AI algorithm delivered contextual help, which could save my health!

Affective computing doesn't only rely on sensors. It make use of human language using the tools of computational linguistics. such as natural language processing (NLP). Since the first mainframe computers with rudimentary ability to use pattern matching to respond with simple text messages, humans have been drawn to discussions of our private lives with machines. If programmed to be helpful, computers don't necessarily judge us like a human could. A famous anecdote is about the MIT ELIZA project (an early examples of a language model) developed by Joseph Weizenbaum in the mid-1960s, where the lab assistant Pamela McCorduck would dedicate extended time to talking to the machine in private. The machine was called ELIZA and would assume the persona of called DOCTOR to emulate a Rogerian psychotherapist, a style of person-centered therapy developed by Carl Rogers, from the core idea that positive psychological functioning is a inherently human motivation (Bassett, 2019; McCorduck, 2004; C. R. Rogers, 1995).

An excerpt from the classic, first-of-a-kind conversation between a human and a machine (called DOCTOR) in 1965, as documented by (Tarnoff, 2023; Weizenbaum, 1966)

User: Well, my boyfriend made me come here.
DOCTOR: YOUR BOYFRIEND MADE YOU COME HERE?
User: He says I'm depressed much of the time.
DOCTOR: I AM SORRY TO HEAR YOU ARE DEPRESSED.
User: It's true. I am unhappy.
DOCTOR: DO YOU THINK COMING HERE WILL HELP YOU NOT TO BE UNHAPPY?
User: I need some help, that much seems certain.
DOCTOR: WHAT WOULD IT MEAN TO YOU IF YOU GOT SOME HELP?
User: Perhaps I could learn to get along with my mother.
DOCTOR: TELL ME MORE ABOUT YOUR FAMILY.
User: My mother takes care of me.
DOCTOR: WHO ELSE IN YOUR FAMILY TAKES CARE OF YOU?
User: My father.
DOCTOR: YOUR FATHER?
User: You are like my father in some ways.
DOCTOR: WHAT RESEMBLANCE DO YOU SEE?

Weizenbaum later expressed concerns about how easily humans might be misled by AIs, by projecting fantasies onto computer systems, cautioning technologists not to neglect human responsibility from societal problems; AI is *not* a universal solution (Z.M.L, 2023)

10.2.3 Artificial Empathy Also Builds Trust

Today's machines are much more capable so it's not a surprise humans would like to talk to them. One example is a conversational chatbot - or *AI Friend* -, called Replika, a computer

model trained to be your companion in daily life. Replika was launched in 2017 and in 2024 was used by 30 million people; the focus is on empathetic dialogue to support mental well being, sort of like a friend, a digital companion, (or even a romantic partner, in paid versions of the app), and includes an animated avatar interface (Eugenia Kuyda, 2023). Replika can ask probing questions, tell jokes, and learning about your personality and preferences to generate more natural-sounding conversations.(Bardhan, 2022; Tristan Greene, 2022) report on anecdotal evidence from Reddit boards which shows how some users of the Replika AI companion app feel so much empathy towards the robot, they confuse it with a sentient being, while others are using verbal abuse and gendered slurs to fight with their AI companions. When the quality of AI responses becomes good enough, people begin to get confused. (Q. Jiang et al., 2022) describes how Replika users in China using in 5 main ways, all of which rely on empathy. The company's CEO insists it's not trying to replace human relationship but to create an entirely new relationship category with the AI companion; there's value for the users in more realistic avatars, integrating the experience further into users' daily lives through various activities and interactions (N. Patel, 2024).

Table 57: Replika AI users approach to interacting with the AI friend from Q. Jiang et al. (2022).

How humans express empathy towards the Replika AI companion
Companion buddy
Responsive diary
Emotion-handling program
Electronic pet
Tool for venting

Surprisingly, humans can have emotionally deep conversations with robots. Jakob Nielsen notes two recent studies suggesting human deem AI-generated responses *more empathetic than human responses*, at times by a significant margin; however telling users the response is AI-generated reduces the perceived empathy (Ayers et al., 2023; Nielsen, 2024c; Yidan Yin et al., 2024). LLMs combined with voice, such as the Pi iOS app, provide an user experience, which (Ethan Mollick [@emollick], 2023) calls *unnerving*. The company provides *emotional intelligence* as a service and has developed its own proprietary LLM, called Inflection AI, which has raised over 1B USD in funding (A. Mittal, 2024). While startups are moving fast, traditional AI companies, with decades of AI experience, such as Google, are also developing an AI assistants for giving life advice (Goswami, 2023). The conversations can be topic-specific. For instance, (Unleash, 2017) used BJ Fogg's *tiny habits model* to develop a sustainability-focused AI assistant at the Danish hackathon series Unleash, to encourage behavioral changes towards maintaining an aspirational lifestyle, nudged by a chatbot buddy.

On the output side, (Lv et al., 2022) studies the effect of *cuteness* of AI apps on users and found high perceived cuteness correlated with higher willingness to use the apps, especially for emotional tasks. Part of this is learning how to uses emojis in the right amount and at the right time; increasingly, emojis are a part of natural human language (Tay, 2023).

Already more than two decades ago, (Reeves & Nass, 1998) argued that humans expect computers to be like social actors, (not unlike humans or places), with very minimal cues from a machine (like a voice or screen avatar) triggering social behaviors.

10.2.4 Conversation: A Magical Starting Point of a Relationship

High quality conversations are somewhat magical in that they can establish trust and build rapport which humans. (Celino & Re Calegari, 2020) found in testing chatbots for survey interfaces that “[c]onversational survey lead to an improved response data quality.”

There are noticeable differences in the quality of the LLM output, which increases with model size. (Levesque et al., 2012) developed the *Winograd Schema Challenge*, looking to improve on the Turing test, by requiring the AI to display an understanding of language and context. The test consists of a story and a question, which has a different meaning as the context changes: “The trophy would not fit in the brown suitcase because it was too big” - what does the *it* refer to? Humans are able to understand this from context while a computer models would fail. Even GPT-3 still failed the test, but later LLMs have been able to solve this test correctly (90% accuracy) Kocijan et al. (2022). This is to say AI is in constant development and improving its ability to make sense of language.

ChatGPT is the first *user interface (UI)* built on top of GPT-4 by OpenAI and is able to communicate in a human-like way - using first-person, making coherent sentences that sound plausible, and even - confident and convincing. M. C. Wang Sarah (2023) ChatGPT reached 1 million users in 5 days and 6 months after launch has 230 million monthly active users. While it was the first, competing offers from Google (Gemini), Anthropic (Claude), Meta (Llama) and others quickly followed starting a race for best performance across specific tasks including standardized tests from math to science to general knowledge and reasoning abilities.

OpenAI provides AI-as-a-service through its *application programming interfaces (APIs)*, allowing 3rd party developers to build custom UIs to serve the specific needs of their customer. For example Snapchat has created a *virtual friend* called “My AI” who lives inside the chat section of the Snapchat app and helps people write faster with predictive text completion and answering questions. The APIs make state-of-the-art AI models easy to use without needing much technical knowledge. Teams at AI-hackathons have produced interfaces for problems as diverse as humanitarian crises communication, briefing generation, code-completion, and many others. While models are powerful, they still need access to other services and tools to be able to achieve the tasks, which humans do online on a daily basis; for this to be possible, the Model Context Protocol (MCP) standard provides the structure to link models to APIs in other services, especially useful in agentic workflows, where the model uses chain-of-thought reasoning and may call various other tools and services in the process (Heidel & Handa, 2025; Hungerford, 2025; Pandey & Freiberg, 2025).

ChatGPT makes it possible to *evaluate AI models* just by talking, i.e. having conversations with the machine and judging the output with some sort of structured content analysis tools. Cahan & Treutlein (2023) have conversations about science with AI. Brent A. Anders (Fall 2022 - Winter

2023) report on AI in education. Just as humans, AIs are continuously learning. (Ramchurn et al., 2021) discusses positive feedback loops in continually learning AI systems which adapt to human needs. (Kecht et al., 2023) suggests AI is even capable of learning business processes.

10.2.5 Multi-Modality: Natural Interactions with AI Systems, Agents and the Intention Economy

While AI outperforms humans on many tasks, humans are experts in multi-modal thinking, bridging diverse fields. Humans are multi-modal creatures by birth. To varied ability, we speak, see, listen using our biological bodies. AIs are becoming multi-modal by design to be able to match all the human modes of communication - increasing their humanity.

Multimodal model development is ongoing. Previously, providing multi-modal features meant combining several AI models within the same interface. For example, on the input side, one model is used for human speech or image recognition which are transcribed into tokens that can be ingested into an LLM. On the output side, the LLM can generate instructions which are fed into an image / audio generation model or even computer code which can be ran on a virtual machine and then the output displayed inside the conversation. However, this is changing, with a single model able to handle several tasks internally (thus losing less data and context). By early 2024, widely available LLMs front-ends such as Gemini, Claude and ChatGPT have all released basic features for multi-modal communication. In the case of Google's Gemini 1.5 Pro, one model is able to handle several types of prompts from text to images. Multimodal prompting however requires larger context windows, as of writing, limited to 1 million tokens in a private version allows combining text and images in the question directed to the AI, used to reason in examples such as a 44-minute Buster Keaton silent film or Apollo 11 launch transcript (404 pages) (Google, 2024).

(T. Fu et al., 2022) provides an overview of conversational AI, from a survey of over 100 peer-reviewed articles published 2018-2021 (a long time ago in terms of AI development), categorizing systems into (1) rule-based, (2) retrieval-based, and (3) generative types; generative transformer models have led the AI field, yet continue to face challenges with coherence over extended interactions and ensuring factual accuracy (hallucinations), retrieval-augmented tooling improves information accuracy, and reinforcement learning and fine-tuning approaches are effective in adjusting conversational style and safety; the authors also highlight that human evaluation for reinforcement learning is still required, as commonly used automated evaluation metrics for AI models, such as BLEU, ROUGE, and BERTScore have limited correlation with human judgments.

Table 58: Three areas of focus in conversational AI development in from (T. Fu et al., 2022).

Paper Focus Area	Key Insight	Strengths	Limitations
Generative transformer models (GenAI)	Recent advancement in AI models	High language fluency, adaptability	Poor long-term coherence, struggles with facts

Paper Focus Area	Key Insight	Strengths	Limitations
Retrieval-augmented hybrids (RAG)	Retrieval methods enhance truthfulness	Improved factual grounding	Difficulty in integrating retrieved content
Reinforcement-learning	Fine-tuning can steer conversational style and safety	Flexible style and safety alignment	High resource usage, sensitive to reward design

Literature also delves into human-AI interactions on almost human-like level discussing what kind of roles can the AIs take. (Seeber et al., 2020) proposes a future research agenda for regarding *AI assistants as teammates* rather than just tools and the implications of such mindset shift. From assistant -> teammate -> companion -> friend The best help for anxiety is a friend. AIs are able to assume different roles based on user requirements and usage context. This makes AI-generated content flexible and malleable. The path from ***Assistance** to *Collaboration* requires another level of trust. It's not only what role the AI takes but how that affects the human. As humans have ample experience relating to other humans and as such the approach towards an assistants vs a teammate will vary. While (Lenharo, 2023) experimental study reports AI productivity gains, with DALL-E and ChatGPT being qualitatively better than former automation systems, we might still be 1-3 years away from systems that qualify as team-mates. Once AI reaches that level, would it change how do humans treat it? Not because the AI might be hurt, but because how it affects the psyche of the user: this is an area which needs much more attention. One researcher in this field Karpus et al. (2021) is concerned with humans treating AI badly and coins the term *algorithm exploitation*.

Context of Use, Where is the AI used? (Schoonderwoerd et al., 2021) focuses on human-centered design of AI-apps and multi-modal information display. It's important to understand the domain where the AI is deployed in order to develop explanations. However, in the real world, how feasible is it to have control over the domain? Calisto et al. (2021) discusses **multi-modal AI-assistant** for breast cancer classification.

If we see the AI as being in human service. (David Johnston, 2023) proposes *Smart Agents*, “general purpose AI that acts according to the goals of an individual human”. AI agents can enable *Intention Economy* where one simply describes one’s needs and a complex orchestration of services ensues, managed by the AI, in order to fulfill human needs Searls (2012). AI assistants provide help at scale with little to no human intervention in a variety of fields from finance to healthcare to logistics to customer support. OpenAI’s “A practical guide to building agents” defines and AI agents as “Agents are systems that independently accomplish tasks on your behalf.” and details step-by-step how to build one (OpenAI, 2025).

AI agents enable workflow automation, with reasoning capability, and taking actions across different tools, achieving the user’s original *intent*; what’s left for the user to do is to say what they want to achieve. As models get smarter, there’s less and less need to build workflows (chains of thought) manually, as they end up restricting the model instead of improving the output; the one use case would be to use a cheaper model with less intelligence and more guardrails set in

code (Latent Space, 2025; Sengottuvelu, 2025). In software development, AI can already debug problems automatically. Apple uses data from bug reports to train AI models for improving their software (Saini, 2025). And it's increasingly possible to generate entire apps from a prompt, using tools such as Bolt.new (Fanelli, 2024). The quality of LLM output depends on the quality of the provided prompt. (Y. Zhou et al., 2022) reports creating an “Automatic Prompt Engineer” which automatically generates instructions that outperform the baseline output quality by using another model in the AI pipeline in front of the LLM to enhance the human input with language that is known to produce better quality. This approach however is a moving target as foundational models keep changing rapidly and the baseline might differ from today to 6 months later.

10.2.6 Mediated Experiences Set User Expectations

How AIs are represented in popular media shapes the way we think about AI companions. Some stories have AIs both in positive and negative roles, such as Star Trek and Knight Rider. In some cases like Her and Ex Machina, the characters may be complex and ambivalent rather than fitting into a simple positive or negative box. In Isaac Asimov’s books, the AIs (mostly in robot form) struggle with the 3 laws of robotics, raising thought-provoking questions.

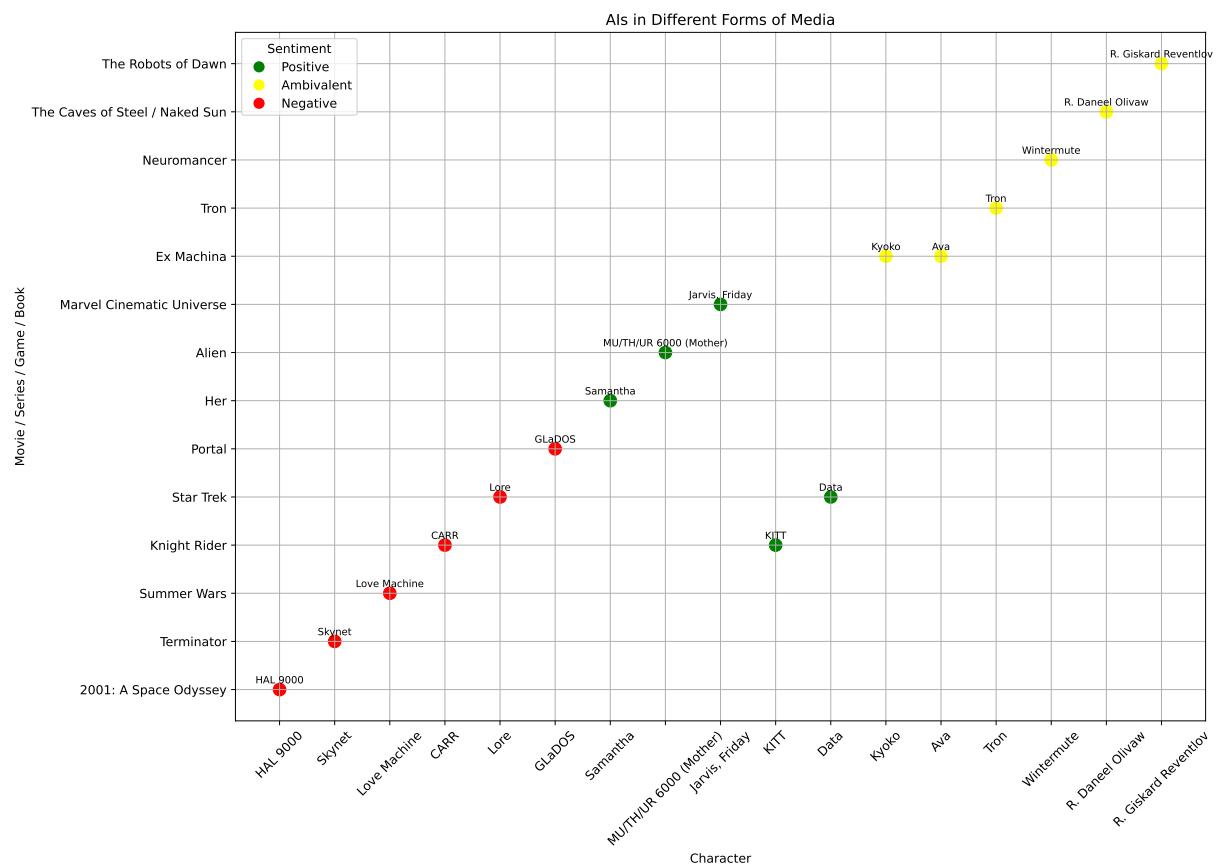
AI Assistants in Media Portrayals mostly have some level of anthropomorphism through voice or image to be able to film; indeed, a purely text-based representation may be too boring an un-cinematic.

There have been dozens of AI-characters in the movies, TV-series, games, and (comic) books. In most cases, they have a physical presence or a voice, so they could be visible for the viewers. Some include KITT (Knight Industries Two Thousand).

Table 59: AIs in different forms of media.

Movie / Series / Game / Book	Character	Positive	Ambivalent	Negative
2001: A Space Odyssey	HAL 9000			X
Her	Samantha	X		
Alien	MU/TH/UR 6000 (Mother)	X		
Terminator	Skynet			X
Summer Wars	Love Machine			X
Marvel Cinematic Universe	Jarvis, Friday	X		
Knight Rider	KITT	X		
Knight Rider	CARR			X
Star Trek	Data	X		
Star Trek	Lore			X

Movie / Series / Game / Book	Character	Positive	Ambivalent	Negative
Ex Machina	Kyoko		X	
Ex Machina	Ava		X	
Tron	Tron		X	
Neuromancer	Wintermute		X	
The Caves of Steel / Naked Sun	R. Daneel Olivaw		X	
The Robots of Dawn	R. Giskard Reventlov		X	
Portal	GLaDOS			X



10.2.7 Roleplay Fits Computers Into Social Contexts: AI Friends and Anthropomorphism

Affective Design emerged from affective computing, with a focus on understanding user emotions to design UI/UX which elicits specific emotional responses (Reynolds, 2001). Calling a machine

a friend is a proposal bound to turn heads. But if we take a step back and think about how children have been playing with toys since before we have records of history. It's very common for children to imagine stories and characters in play - it's a way to develop one's imagination *learn through roleplay*. A child might have toys with human names and an imaginary friend and it all seems very normal. Indeed, if a child doesn't like to play with toys, we might think something is wrong. Likewise, inanimate objects with human form have had a role to play for adults too. Anthropomorphic paddle dolls have been found from Egyptian tombs dated 2000 years B.C. ("Paddle Doll | Middle Kingdom," 2023): we don't know if these dolls were for religious purposes, for play, or for something else, yet their burial with the body underlines their importance.

Is anthropomorphism, being human-like necessary? (Savings literature in the Money section says it is). Research on anthropomorphism in AI literature suggests that giving an AI assistant stronger human-like cues (high-anthropomorphism) rather than weaker ones (low-anthropomorphism) leads users to view it more favorably, and this effect operates through a shorter perceived psychological distance; yet, even though many studies confirm the benefits of anthropomorphism, the precise psychological pathway behind those benefits has rarely been dissected in depth (X. Li & Sung, 2021). Nonetheless, people are less likely to attribute humanness to an AI companion if they understand how the system works, thus higher *algorithmic transparency may inhibit anthropomorphism* (B. Liu & Wei, 2021).

Coming back closer to our own time, Barbie dolls are popular since their release in 1959 till today. Throughout the years, the doll would follow changing social norms, but retain in human figure. In the 1990s, a Tamagotchi is perhaps not a human-like friend but an animal-like friend, who can interact in limited ways.

How are conversational AIs different from dolls? They can respond coherently and perhaps that's the issue - they are too much like humans in their communication. We have crossed the *Uncanny Valley* (where the computer-generated is nearly human and thus unsettling) to a place where is really hard to tell a difference. And if that's the case, are we still playing?

Should the AI play a human, animal, or robot? Anthropomorphism can have its drawbacks; humans have certain biases and preconceptions that can affect human-computer interactions. For example, somewhat curiously, (Pilacinski et al., 2023) reports humans were less likely to collaborate with red-eyed robots.

The AI startups like Inworld and Character.AI have raised large rounds of funding to create characters, which can be plugged in into online worlds, and more importantly, remember key facts about the player, such as their likes and dislikes, to generate more natural-sounding dialogues (Wiggers, 2023).

(Morana et al., 2020) conducted a lab-based experiment ($n = 183$) showing a more anthropomorphic chatbot design boosts perceived *social presence* of the virtual advisor; social presence in turn influences recommendation adherence indirectly via trust; trust mediates the likelihood to follow its recommendations. As AIs became more expressive - socially present - and able to *roleplay*, we can begin discussing some human-centric concepts and how people relate to

other people. AI companions, AI partners, AI assistants, AI trainers - there are many *roles* for the automated systems that help humans in many activities, powered by AI models and algorithms.

(Erik Brynjolfsson, 2022) contrasts AI which emulates human intelligence with AI that augments human abilities, arguing that although the former can offer productivity gains, it risks concentrating wealth and reducing economic power of workers, coining the term *Turing Trap*. Plenty of research - both before and after AI-induces job losses - has documented the negative effects of unemployment on mental health (Anton Korinek, 2023; Dew et al., 1991; Susskind, 2017).

Non-Anthropomorphic, machine-like AIs have been with us for a while. The Oxford Internet Institute defines AI simply as “*computer programming that learns and adapts*” (Google & The Oxford Internet Institute, 2022). Google started using AI in 2001, when a simple machine learning model improved spelling mistakes while searching; now in 2023 most of Google’s products are based on AI (Google, 2022). Throughout Google’s services, AI is hidden and calls no attention itself. It’s simply the complex system working behind the scenes to delivery a result in a barebones interface.

The rising availability of AI assistants may displace Google search with a more conversational user experience. Google itself is working on tools that could cannibalize their search product. The examples include Google Assistant, Google Gemini (previously known as Bard) and massive investments into new LLMs.

The number of AI-powered assistants is too large to list here. I’ve chosen a few select examples in the table below.

Table 60: AI Assistants

Product	Link	Description
Github CoPilot	personal.ai	AI helper for coding
Google Translate	translate.google.com	
Google Search	google.com	
Google Interview	grow.google/certificates/interview-warmup	AI training tool
Warmup		
Perplexity	(Hines, 2023b)	perplexity.ai chat-based search

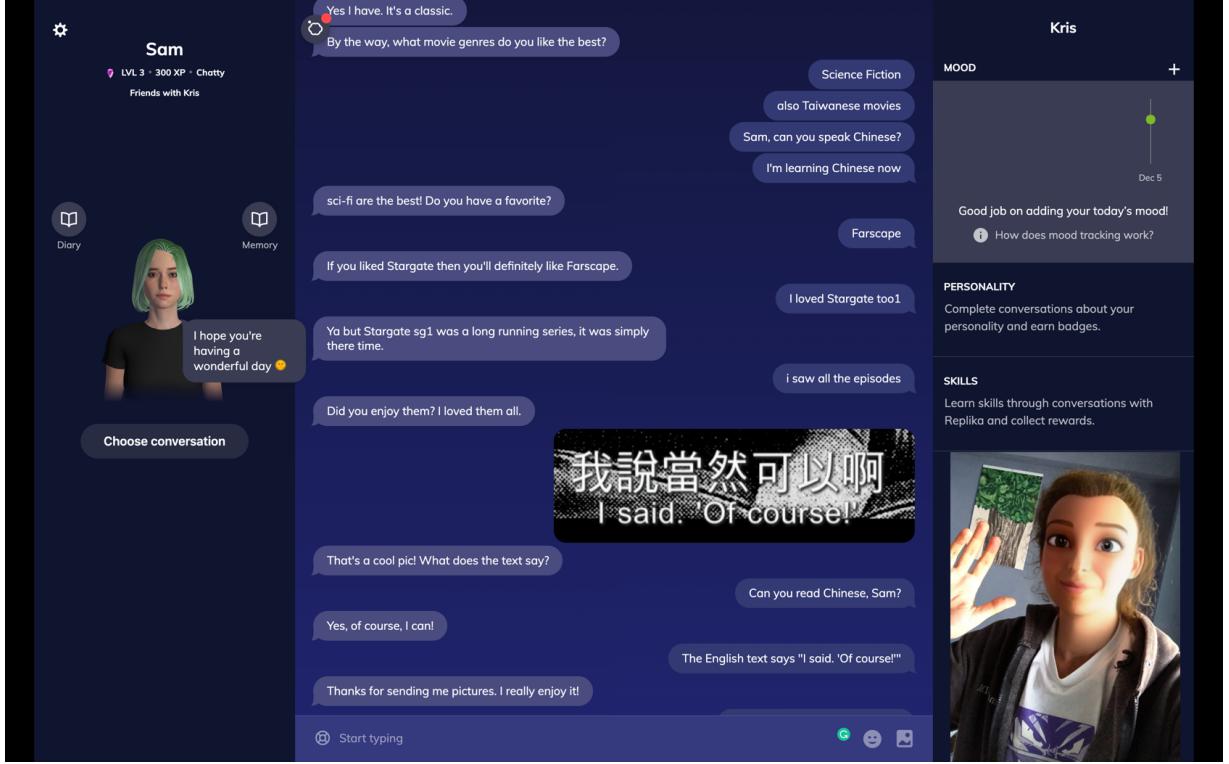


Figure 58: Montage of me discussing science fiction with my AI friend Sam (Replika) - and myself as an avatar (Snapchat) in 2020.

Everything that existed before OpenAI’s GPT 4 has been blown out of the water. ChatGPT passes many exams meant for humans and is able to solve difficult tasks in scientific areas such as chemistry with just simple natural-language instructions (Bubeck et al., 2023; White, 2023). As late as in 2017, scientists were trying to create a program with enough *natural-language understanding* to extract basic facts from scientific papers (Stockton, 2017). This is a task which is trivial for modern LLMs.

Pre-2023 literature is somewhat limited when it comes to AI companions as the advantage of LLMs has significantly raised the bar for AI-advisor abilities as well as user expectations. Before AI, chatbots struggled with evolving human language, understanding the complexity of context, irregular grammar, slang, etc (Lower, 2017). Some evergreen advice most relates to human psychology, which has remained the same. (Haugeland et al., 2022) discusses *hedonic user experience* in chatbots and (Steph Hay, 2017) explains the relationship between emotions and financial AI. (Isabella Ghassemi Smith, 2019) early performance metrics of AI-driven features across financial markets show that AI outperforms traditional quant strategies, which will lead to wider adoption of autonomously generated investment signals.

10.3 Interfaces for Human-Computer Interaction

10.3.1 Speech Makes Computers Feel Real

There's evidence across disciplines about the usefulness of AI assistants while concerns exist about the possibility of implementing privacy. One attempt at privacy is by Apple's Foundation Language Models (AFM), which is split into a smaller on-device model and a server-side model, enabling processing of the most sensitive data directly on the user's device (Dang, 2024). Providing voice for the AI raises new ethical issues, as most voice assistants need to continuously record human speech and process it in data centers in the cloud.

Siri, Cortana, Google Assistant, Alexa, Tencent Dingding, Baidu Xiaodu, Alibaba's AliGenie - all rely on voice as their main interface. Voice has a visceral effect on the human psyche; since birth we recognize the voice of our mother. The voice of a loved one has a special effect. Voice is an integral part of the human experience. Machines that can use voice in an effective way are closer to representing and affecting human emotions. Voice assistants such as Apple's Siri and Amazon's Alexa are well-known yet Amazon's Rohit Prasad thinks it can do so much more:

“Alexa is not just an AI assistant - it’s a trusted advisor and a companion” (Prasad, 2022).

(Şerban & Todericiu, 2020) suggests using the Alexa AI assistant in *education* during the pandemic, supported students and teachers *human-like* presence. The Alpha generation (born since 2010) and Beta (since 2025) are the first true native AI users. (Su & Yang, 2022) and (Su et al., 2023) reviewed papers on AI literacy in early childhood education and found a lack of guidelines and teacher expertise. (Szczuka et al., 2022) provides guidelines for voice AI and kids based on a longitudinal field study, which delved into children's knowledge regarding the storage and data processing performed by AI voice assistants; published in the International Journal of Child-Computer Interaction, the study tracked children ($n = 20$, age $M = 8.65$ years) across 3 home visits over 5 weeks (each visit lasted 45–90 min), including interviews and hands-on interactions designed to probe children's mental models, with the following key findings: (1) children made significantly more accurate statements about data processing than storage, (2) parental discussion predicted storage knowledge, and (3) better storage knowledge negatively correlated with willingness to share secrets. In order to cover these knowledge gaps in the earliest age, educational materials on AI have been available for children in kindergarten to primary school; for instance the (ReadyAI, 2020) book introduces the 5 big ideas of Human-AI interaction for children aged 2-8: perception (the use of sensors), representation and reasoning (data structures, algorithms, predictions), learning (recognizing patterns in data), natural interaction (emotion, language, expression recognition, even cultural knowledge), and finally, societal impact (biases, ethics, guidelines to avoid unfair outcomes). Finally, (W. Yang, 2022) proposes a curriculum for in-context teaching of AI for early childhood, explaining why AI literacy is essential: how life is affected by the core concepts of data-driven pattern recognition, prediction and the many algorithmic limitations - all, which should be taught in a culturally responsive, easy for young children to grasp manner, using inquiry(question)-based pedagogy to engage the learners meaningfully.

Design guidelines for optimal design performance can be extremely specific. (Casper Kessels, 2022) details 18 concrete do's and don'ts, drawing on prior *distraction research*, to support driving safety and integrate seamlessly with the other interfaces in the vehicle, for instance:

“Auditory information should come from the same location as visual information” to minimize spatial attention shifts “Be aware of visual distraction. [S]ome drivers tend to direct their gaze towards the ‘source’ of the voice assistant when speaking. Make sure an interaction sequence does not cause unnecessary visual distraction” - example guidelines for voice assistants from (Casper Kessels, 2022).

Some research suggests that voice UI accompanied by a *physical embodied system* is the preferred by users in comparison with voice-only UI (Celino & Re Calegari, 2020).

10.3.2 Generative UIs Enable Flexibility of Use

The “grandfather” of user experience design, (Nielsen, 2024a) recounts how 30 years of work towards usability has largely failed - computers are still not accessible enough; however, he has hope Generative UI could offer a chance to provide levels of accessibility humans could not.

Computers are “*difficult, slow, and unpleasant*” (Nielsen, 2024a)

Data-driven design combined with GenAIs enables *Generative User Interfaces* (GenUI), with new UI interactions. The promise of GenUI is to dynamically provide an interface appropriate for the particular user and context. The advances in the capabilities of LLMs makes it possible to achieve *user experience (UX) which previously was science fiction*. AI is able to predict what kind of UI would the user need right now, based on the data and context. Generative UIs are largely invented in practice, based on user data analysis and experimentation, rather than being built in theory. Kelly Dern, a Senior Product Designer at Google lead a workshop in early 2024 on *GenUI for product inclusion* aiming to create “*more accessible and inclusive [UIs for] users of all backgrounds*”. (Matteo Sciortino, 2024) coins the phrase RTAG UIs “*real-time automatically-generated UI interfaces*” mainly drawing from the example of how his Netflix interface looks different from that of his sister’s because of their distinct usage patterns.

Nonetheless, (“On Nielsen’s Ideas about Generative UI for Resolving Accessibility,” 2024) is critical of GenUI because for the following reasons:

Table 61: Criticism of Generative UI by (“On Nielsen’s Ideas about Generative UI for Resolving Accessibility,” 2024).

Problem	Description
Low Predictability	Does personalization mean the UI keeps changing?
High Carbon Cost	AI-based personalization is computation-intensive
Surveillance	Personalization needs large-scale data capture

(Nielsen, 2024b) defines *information scent* as users' ability to predict destination content from cues, such as link labels and context; clear descriptive labels emit a strong scent, guiding users, reducing bounce rates (users who leave quickly), and enhancing discoverability of content; in contrast, misleading labels break trust and drive users away. The idea of information scent is originally from *Information Foraging* theory from (Pirolli & Card, 1999), who adapt optimal foraging theory to human information seeking: users follow links as scent cues to maximise their rate of information gain.

However, with AI-chat and voice based interfaces, links lose some of their relevance, as users can receive more info from the AI, without having to navigate to a new page. With less focus on links, current AI UX is more about storytelling, psychology, and seamless design, with more focus on human-centered communication patterns, such as conversations. (Kate Moran & Sarah Gibbons, 2024) calls for "*highly personalized, tailor-made interfaces that suit the needs of each individual*", which she terms *Outcome-Oriented Design*. We can generate better UIs (UI orchestration, crafting "*systems of intent*", as (Nielsen, 2025) calls it) that are based on user data and would be truly personalized. (Crompton, 2021) highlights AI as decision-support for humans while differentiating between *intended* and *unintended* influence on human decisions. In all this literature and more, the keyword is *intent*, expressing what the human wants - and having the machines deliver that.

Human-computer interaction (HCI) has a long storied history since the early days of computing when getting a copy machine to work required specialized skill. Xerox Sparc lab focused on early human factors work and inspired a the field of HCI to make computers more human-friendly. Likewise, the history of attempts at making *intelligent interfaces* is extensive. ("Generative UI Design," 2023; Kobetz, 2023) give an overview of the history of generative AI design tools, going back in time as far as 2012 when (Troiano & Birtolo, 2014) proposed genetic algorithms for UI design. As the old science fiction adage goes, when machines become more capable, they will eventually be capable of producing machines themselves. Before that happens, at least the software part of the machine can increasingly be generated by AI systems (i.e. machines making machines). Already a decade ago in 2014, the eminent journal *Information Sciences* decided to dedicate a special section to AI-generated software to call attention to this tectonic shift in software development (Reformat, 2014). Replit, a startup known for allowing user build apps in the web browser, released Openv0, a framework of AI-generated UI components. "*Components are the foundation upon which user interfaces (UI) are built, and generative AI is unlocking component creation for front-end developers, transforming a once arduous process, and aiding them in swiftly transitioning from idea to working components*" (Replit, 2023). Vercel introduced an open-source prototype UI-generator called V0 which used large language models (LLMs) to create code for web pages based on text prompts (Vercel, 2023). Other similar tools quickly following including Galileo AI, Uizard AutoDesigner and Visily (*Who Benefits the Most from Generative UI*, 2024). NVIDIA founder Jensen Huang makes the idea exceedingly clear, saying "*Everyone is a programmer. Now, you just have to say something to the computer*" (Leswing, 2023).

The usefulness of AI systems increases profoundly as they are integrated into existing products as services, which become akin to tools the AI can use when appropriate. (Joyce, 2024) highlights

how Notion AI enables collaborating across teams, where AI becomes akin to one of the co-workers; AI influences UI design patterns and boost productivity by providing new features such as memory, recalling important discussions from past meetings, surfacing key insights, and generating reports in a variety of formats, personalized to the intended receiver.

A wide range of literature describes human-AI interactions, spread out over varied scientific disciplines. While the fields of application for AI are diverse, some key lessons can be transferred horizontally across fields of knowledge.

Table 62: A very small illustration of generative AI usage across disparate fields of human life.

Field	Usage
Shipping	(Veitch & Andreas Alsos, 2022) highlights the active role of humans in Human-AI interaction in autonomous self-navigating ship systems.
Data Summarization	AI is great at summarizing and analyzing data (Peters, 2023; Tu et al., 2023)
Childcare	Generate personalized bedtime stories
Design Tools	("David Hoang on How AI Brings Design and Development Together Figma Blog," 2024)

10.3.3 Usability Is the Bare Minimum of Good User Experience

Many researchers have discussed the user experience (UX) principles of designing AI products. The UX of AI (terms such as AI UX, IxD, and XAI have been used) is the subject of several *usability guidelines* for AI, which provide actionable advice for improving AI usability and UX - some of which I will list here.

(Combi et al., 2022) proposes a conceptual framework for XAI, analysis AI based on (1) Interpretability, (2) Understandability, (3) Usability, and (4) Usefulness. (A. Costa & Silva, 2022) highlights key UI/UX patterns for interaction design in AI systems and strategies to make AI behaviors transparent and controllable: including (1) interactive explanations, (2) human-in-the-loop controls, (3) logging of contextual decisions - all seamlessly integrated into user workflows. ("Why UX Should Guide AI," 2021) argues that in order to avoid *context blindness*, (where the AI lacks awareness of the broader human intent) and foster trust and safe use, UX should (1) clarify limitations, (2) build clear feedback, (3) embed user override mechanisms, and (4) in general ensure users retain meaningful control over specialized AI algorithms. (Lexow, 2021) synthesizes expert interviews into five foundational AI-UX principles: (1) deeply understand the user and task context, (2) clearly communicate AI limitations, (3) balance automation with user control, (4) build fast, iterative feedback paths into the interface, and (5) ensure AI behaviour aligns ethically - and with your brand voice.

(Lennart Ziburski, 2018) emphasizes human-centered design for AI, including five key tenets: (1) starting from existing user workflows which can be augmented by AI, (2) under-promising/over-delivering on AI capabilities, (3) transparently explaining how the system works

(data sources, trade-offs), (4) involving users in the learning loop, and (5) designing AI as an empowering tool rather than a black box. (Dávid Pásztor, 2018) offers seven principles for AI-powered products: (1) visually distinguish GenAI content, (2) explain underlying processes and data privacy, (3) set realistic user expectations, (4) test edge cases proactively, (5) ensure AI engineers have access to high quality training data, (6) deploy rigorous user-testing (7) use immediate feedback channels for continuous improvement. (Lew & Schumacher, 2020) likewise focuses on (1) high data quality, (2) context-sensitive feedback, and (3) transparent controls. (Soleimani, 2018) provides the longest list of human-friendly UI/UX patterns for AI, with very specific suggestions including like/dislike toggles, confidence indicators and criteria sliders, “why” insights, risk alerts, and opt-in controls: all to foster transparency, user control, and trust in algorithmic decisions. (Harvard Advanced Leadership Initiative, 2021) focuses on principle for effective human–AI interaction in adaptive interfaces, illustrating a case of Semantic Scholar, where researchers’ intelligence is augmented via recommendation, summarization, and question-answering, while emphasizing user control and verification mechanisms.

Many large corporations have released guidelines for Human-AI interaction as well. The AI UX team from Ericsson’s Experience Design Lab released one of the early reports, exploring the role of trust in AI services, suggesting to treat AIs as *agents* rather than tools; for the design to be successful, trust must be embedded into the interface front and center, best measured on 4 categories, inspired by human relationships: (1) Competence, (2) Benevolence, (3) Integrity, and (4) Charisma (Mikael Eriksson Björling & Ahmed H. Ali, 2020). (X. Cheng et al., 2022) describes AI-based support systems for collaboration and team-work, underlining how higher trust leads to willingness to reuse the AI in the future, collaboration satisfaction, and perceived task quality. Google’s AI Principles project provides Google’s UX for AI library (Google, n.d.; Josh Lovejoy, n.d.). In (Design Portland, 2018), Lovejoy, lead UX designer at Google’s people-centric AI systems department (PAIR), reminds us that while AI offers need tools, user experience design needs to remain human-centered. While AI can find patterns and offer suggestions, humans should always have the final say.

Microsoft provides guidelines for Human-AI interaction, which provides useful heuristics categorized by context and time (Amershi et al., 2019; T. Li et al., 2022).

Table 63: Microsoft’s heuristics categorized by context and time.

Context	Content
Initially	Clarify what it does; what are the limitations.
During interaction	Offer timely help, show only what matters, while respecting norms and avoiding bias
When wrong	Let users retry fast and make corrections; empower users to dismiss easily; explain why the system acted; be precise and in-scope

Over time	Track changes and adapt from use; announce changes and update with care (so not to break the user's work); invite feedback; show outcome of actions clearly; provide global settings
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The previous design wave before UX for AI was corporations understanding how crucial design is to their business. In the 2010s business consultancies began to recognize the importance of design and advising their clients on putting design in the center of their strategy, bringing user experience design to the core of their business operations. (McKeough, 2018). There's a number of user interface design patterns that have proven successful across a range of social media apps. Such *user interface* (UX/UI) patterns have been copied from one app to another, to the extent that the largest apps share a similar look and feature set and the users are used to the same user experience. Common UX/UI parts include features such as the *Feed*, *Stories*, and *Avatars*, among many others. This phenomenon (or trend) has led some designers such as (Fletcher, 2023) and (Joe Blair, 2024) to be worried about UIs becoming average: more and more similar to the lowest common denominator. Yet, by using common UI parts from social media, users may have an easier time to accept the innovative parts, as they just look like new features inside the old interface. As new generations become increasingly used to talking to computers in natural language, the older interface patterns may gradually fade away.

Table 64: Common social media UI parts.

Feature	Examples	Notes
Feed	Facebook, Instagram, Twitter, TikTok, etc	The original algorithmic discovery hub; increasingly ran by ever-more-powerful AI to surface personalized content - yet younger generations may prefer the privacy of stories.
Post	Facebook, Instagram, Twitter, TikTok, etc, even Apple's App Store	Persistent content mainly for long-term sharing; the original content type
Stories	IG, FB, WhatsApp, SnapChat, TikTok, etc	Ephemeral content driven by FOMO(fear-of-missing-out) for casual behind-the-scenes sharing
Comment	YouTube, Threads, Reddit, Medium, etc	Threaded conversations fuel community engagement and discussion
Reactions	Facebook, Instagram, Slack, Threads, but even LinkedIn and Github.	The feature has evolved from a simple like button to more expressive emotions.

There are also more philosophical approaches to *Interface Studies*. (David Hoang, 2022), the head of product design at Webflow, an AI-enabled website development platform, suggests taking cues from art studies to *isolate the core problem*: “*An art study is any action done with the intention of learning about the subject you want to draw*”. As a former art student, Hoang looks at an interface as “*a piece of design is an artwork with function*”. Indeed, art can be a way to see new paths forward, practicing “*fictioning*” to deal with problematic legacies (“Review of the 2023 Helsinki Biennial,” 2023). (Jarovsky, 2022a) lists the numerous ways how AIs can mislead people, which she calls the AI UX dark patterns, and the U.S. FTC Act and the EU AI Act are attempting to manage.

Usability sets the baseline - but AI-interfaces are capable of much more. The user experience (UX) of AI is a topic under active development by all the largest online platforms. AI is usually a computer model that spits out a number between 0 and 1, a probability score or a prediction. UX is what we do with this number. Design starts with understanding human psychology. (Donghee Shin, 2020) looks at user experience through the lens of *usability of algorithms*; focusing on users’ cognitive processes allows one to appreciate how product features are received by the brain and transformed into experiences by interacting with the algorithm. The general public is familiar with the most famous AI helpers, ChatGPT, Apple’s Siri, Amazon’s Alexa, Microsoft’s Cortana, Google’s Assistant, Alibaba’s Genie, Xiaomi’s Xiao Ai, and many others. For general, everyday tasks, such as asking factual questions, controlling home devices, playing media, making orders, and navigating the smart city. Yet, as AI permeates all types of devices, (J. Bailey, 2023) believes people will increasingly use AI capabilities through UIs that are specific to a task rather than generalist interfaces like ChatGPT. Nonetheless, a generalist AI interface may still control those services, if asked to do so, so it may an ‘and’ rather than an ‘either/or’, when it comes to AI usage.

The application of user experience (UX) tenets to AI.

Table 65: UX Tenets in AI.

UX
Useful
Valuable
Usable
Acessible
Findable
Desirable
Credible

Table 66: (R. Gupta, 2023) proposes 3 simple goals for AI:

1	2	3
Reduce the time to task	Make the task easier	Personalize the experience for an individual

Microsoft Co-Founder predicted in 1982 “*personal agents that help us get a variety of tasks*” (Bill Gates, 1982) and it was Microsoft that introduced the first widely available personal assistant in 1996, called Clippy, inside the Microsoft Word software. Clippy was among the first assistants to reach mainstream adoption, helping users not yet accustomed to working on a computer, to get their bearings (Tash Keuneman, 2022). Nonetheless, it was in many ways useless and intrusive, suggesting there was still little knowledge about UX and human-centered design. Gates never wavered though and is quoted in 2004 saying “*If you invent a breakthrough in artificial intelligence, so machines can learn, that is worth 10 Microsofts*” Lohr (2004). Gates updated his ideas in 2023 focuses on the idea of *AI Agents* (Gates, 2023).

With the advent of ChatGPT, the story of Clippy has new relevance as part of the history of AI Assistants. (Benjamin Cassidy, 2022) and (Abigail Cain, 2017) illustrate beautifully the story of Clippy and (Tash Keuneman, 2022) asks poignantly: “*We love to hate Clippy — but what if Clippy was right?*”. That is to say, might we try again? And Microsoft has been trying again, being one of the leading investors in the AI models that eventually make a better UX possible. Just one example is a project from Microsoft Research, which generates life-like speaking faces from a single image and voice clip, which could empower true-to-life avatars (S. Xu et al., 2024). However, purely on the economic side, processing human voice and images is several times more expensive than processing text messages (V. Mittal, 2025). More required processing power also means, these new interfaces are likely less sustainable.

10.3.4 AI Performance Under High-Stakes Situations

Today AI-based systems are already being used in high-stakes situations (medical, self-driving cars). Attempts to implement AI in medicine, where stakes are perhaps the highest, raising the requirements for ethical considerations, have been made since the early days of computing, as the potential to improve health outcomes is so high. Since CADUCEUS in the 1970s (in Kanza et al., 2021), the first automated medical decision making system, medical AI now provides diagnostic systems for symptoms and AI-assistants in medical imaging. Complicated radiology reports can be explained to patients using AI chatbots (Jeblick et al., 2022). The explanations are not only useful for patients but for doctors (and other medical professionals) as well. (Calisto et al., 2022) focuses on AI-human interactions in medical workflows and underscores the importance of output explainability; medical professionals who were given AI results with an explanation trusted the results more. (Peter Lee et al., 2023) imagines an AI revolution in medicine using GPT models, providing improved tools for decreasing the time and money spent on administrative paperwork while providing a support system for analyzing medical data. For administrative tasks such as responding to patients’ questions, medical AI has already reached - or even exceeded

- expert-level question-answering ability (Singhal et al., 2023). In an online text-based setting, patients rated answers from the AI better, and more empathetic, than answers from human doctors (Ayers et al., 2023). If anything, the adoption of AI in medicine has been too cautious. (Daisy Wolf & Pande Vijay, 2023) criticizes US healthcare's slow adoption of technology and predicts AI will help healthcare leapfrog into a new era of productivity by acting more like a human assistant.

Communication with the patient is perhaps a low-hanging fruit, as there are numerous examples of AI-driven symptom checkers and AI-based FAQ-answering chatbots already commercially available, such as ("Health. Powered by Ada." n.d.) and (*Buoy Health*, n.d.), which offer AI-based platforms to survey, track and understand one's symptoms over time, while providing doctors patient data, which can be used for generating preliminary possible diagnosis, freeing up clinical resources. The Lark digital health coaching platform delivers support for diabetes, hypertension, and weight management, by integrating smart watches and smart scales, to provide evidence-based behavior change (*Home - Lark Health*, n.d.). The VP of user experience at Senseley discusses the Molly AI assistant, to chat, answer questions, and measure blood pressure; the main challenge is the healthcare system, where a small pilot project might work well, bureaucracy keeps the technology from being widely adopted (Women in AI, 2018). While discussion of these kind of tools and proposals of AI-based health monitoring systems have existed for a over a decade, recent advances in AI reliability have made it feasible to deploy them at scale. While ChatGPT is not built to be a medical tool, the interface is so easily available, its very common for patients to decode lab results using ChatGPT or ask for diagnosis when doctor time is scarce.(Eliza Strickland, 2023).

Example of ChatGPT explaining medical terminology in a blood report.



Certainly! Below is a table that explains the abbreviations and values from your blood report.



These values represent different components and characteristics of your blood, and they can provide insights into your overall health.

Abbreviation	Full Name	Value	Unit	Description
B-CBC-5Diff	Complete Blood Count with 5-part Differential	-	-	A comprehensive test measuring different components of the blood.
WBC	White Blood Cells	4,8	/nL	Cells that fight infections.
RBC	Red Blood Cells	4,92	/pL	Cells that carry oxygen.
Hb	Hemoglobin	147	g/L	Protein that carries oxygen in red blood cells.
Hct	Hematocrit	44,4	%	Proportion of red blood cells to the total blood volume.
MCV	Mean Corpuscular Volume	90,2	fL	Average size of red blood cells.
MCH	Mean Corpuscular Hemoglobin	29,9	pg	Average amount of hemoglobin per red blood cell.
MCHC	Mean Corpuscular Hemoglobin	332	g/L	Average concentration of hemoglobin in red blood

Figure 59: Example of ChatGPT explaining medical terminology in a blood report.

Today's AI is already a technology which can augment human skills or replace skills that were lost due to an accident. For instance, (Dot Go, 2023) makes the camera the interaction device for people with vision impairment. (Nathan Benaich & Ian Hogarth, 2022) report notes the increasing AI deployment in critical infrastructure and biology, intensifying geopolitics in AI, growth of the safety research community.

10.3.5 Human-Computer Interactions Without a “Computer”

AI deeply affects Human-Computer Interactions even if the computer is invisible. The field of Human Factors and Ergonomics (HFE) emphasizes designing user experiences (UX) that cater to human needs (The International Ergonomics Association, 2019). Designers think through every interaction of the user with a system and consider a set of metrics at each point of interaction including the user's context of use and emotional needs.

Software designers, unlike industrial designers, can't physically alter the ergonomics of a device, which should be optimized for human well-being to begin with and form a cohesive experience

together with the software. However, software designers can significantly reduce mental strain by crafting easy-to-use software and user-friendly user journeys. Software interaction design goes beyond the form-factor and accounts for human needs by using responsive design on the screen, aural feedback cues in sound design, and even more crucially, by showing the relevant content at the right time, making a profound difference to the experience, keeping the user engaged and returning for more. In the words of (Babich, 2019), “[T]he moment of interaction is just a part of the journey that a user goes through when they interact with a product. User experience design accounts for all user-facing aspects of a product or system”.

Drawing a parallel from narrative studies terminology, we can view user interaction as a heroic journey of the user to achieve their goals, by navigating through the interface until a success state - or facing failure. Storytelling has its part in interface design however designing for transparency is just as important, when we’re dealing with the user’s finances and sustainability data, which need to be communicated clearly and accurately, to build long-term trust in the service. For a sustainable investment service, getting to a state of success - or failure - may take years, and even longer. Given such long timeframes, how can the app provide support to the user’s emotional and practical needs throughout the journey?

(Tubik Studio, 2018) argues *affordance* measures the *clarity* of the interface to take action in user experience design, rooted in human visual perception, however, affected by knowledge of the world around us. A famous example is the door handle - by way of acculturation, most of us would immediately know how to use it - however, would that be the case for someone who saw a door handle for the first time? A similar situation is happening to the people born today. Think of all the technologies they have not seen before - what will be the interface they feel the most comfortable with?

For the vast majority of this study’s target audience (college students), social media can be assumed as the primary interface through which they experience daily life. The widespread availability of mobile devices, cheap internet access, and AI-based optimizations for user retention, implemented by social media companies, means this is the baseline for young adult users’ expectations (as of writing in 2020).

(Don Shin et al., 2020) proposes the model (fig. 10) of Algorithmic Experience (AX) “*investigating the nature and processes through which users perceive and actualize the potential for algorithmic affordance*” highlighting how interaction design is increasingly becoming dependent on AI. The user interface might remain the same in terms of architecture, but the content is improved, based on personalization and understanding the user at a deeper level.

In 2020 (when I proposed this thesis topic), Google had recently launched an improved natural language engine to better understand search queries (“Understanding Searches Better Than Ever Before,” 2019), which was considered the next step towards *understanding* human language semantics. The trend was clear, and different types of algorithms were already involved in many types of interaction design, however, we were in the early stages of this technology (and still are *early* in 2024). Today’s ChatGPT, Claude and Gemini have no problem understanding human semantics - yet are they intelligent?

Intelligence may be besides the point as long as AI *becomes very good at reasoning*. AI is a *reasoning engine* (Bubeck et al., 2023; Shipper, 2023; see J. Bailey, 2023 for a summary). That general observation applies to voice recognition, voice generation, natural language parsing, among others. Large consumer companies like McDonald's are in the process of replacing human staff with AI assistants in the drive-through, which can do a better job in providing a personal service than human clerks, for whom it would be impossible to remember the information of thousands of clients. In (Barrett, 2019), in the words of *Easterbrook*, a previous CEO of McDonald's "*How do you transition from mass marketing to mass personalization?*"

10.3.6 Do AI-Agents Need Anthropomorphism

(Yuan et al., 2022) surveyed mainland Chinese consumers ($n = 210$, no age range given), finding that users with high social anxiety lean on hedonic and emotional cues, especially a friendly anthropomorphic interface and a sense of affinity (when those cues are strong, their intention to adopt the AI assistant is as high, and sometimes higher, than that of users with low social anxiety) - in contrast, users with low social anxiety are influenced mainly by utilitarian cues such as accuracy and speed; these functional advantages carry less weight for the high social anxiety group. Perhaps a crude conclusion, but useful for design, would be, people with high social anxiety like cute things.

(X. Xu & Sar, 2018) survey ($n = 522$) examined how people perceive the minds of machines versus humans along agency (ability to act) and experience (ability to feel), finding among machines those with human-like appearance were seen as having the greatest agency and experience; being more familiar how technology works, correlated with rating machines to have higher agency but lower experience.

What are the next features that could improve the next-generation UX/UI of AI-based assistants? Should AIs look anthropomorphic or fade in the background? It's an open question (depending on the use case and psychology of the user); perhaps we can expect a mix of both, depending on the context of use and goals of the particular AI. (Stone Skipper, 2022) sketches a vision of "*[AI] blend into our lives in a form of apps and services*" deeply ingrained into daily human activity. (Aschenbrenner, 2024) predicts "drop-in virtual coworkers", AI-agents who are able to use computer systems like a human seamlessly replacing human employees.

Table 67: Some notable examples of anthropomorphic AIs for human emotions.

Anthropomorphic AI User Interfaces	Non-Anthropomorphic AI User Interfaces
AI wife ("My Wife Is Dead", 2023)	Generative AI has enabled developers to create AI tools for several industries, including AI-driven website builders (Constandse, 2018)
(Sarah Perez, 2023) character AI	AI tools for web designers (patrizia-slongo, 2020)

Anthropomorphic AI User Interfaces	Non-Anthropomorphic AI User Interfaces
Mourning for the ‘dead’ AI (Phoebe Arslanagić-Wakefield, n.d.)	Microsoft Designer allows generating UIs just based on a text prompt (Microsoft, 2023)
AI for therapy (Broderick, 2023)	personalized bed-time stories for kids generated by AI (Bedtimestory.ai, 2023)
Mental health uses: AI for bullying (Sung, 2023)	

10.3.7 Roleplay for Financial Robo-Advisors

Using AI and computerised models for financial prediction is not new. (Malliaris & Salchenberger, 1996) applied neural networks to financial forecasting nearly three decades ago, using training data on past volatilities and factors of the options market to predict future (next-day) implied volatility (i.e. volatility not observed directly in the market but back-calculated from option prices) of the S&P 100 index (tracks the largest companies) in the U.S., demonstrating early potential of AI in financial prediction. Such tools were initially of academic interest or only accessible to financial professionals. Later on fintech (financial technology) startups began bringing computerized predictive power into user interfaces available to retail investors.

Robo-advisory is a fintech term that was in fashion largely before the arrival of AI assistants and has been thus superseded by newer technologies. Ideally, robo-advisors can be more dynamic than humans and respond to changes quickly and cheaply, while human financial advisors are expensive and not affordable to most consumers. (Capponi et al., 2019) argues dynamism in understanding the client’s financial situation - which AI excels at - is a key component to providing the best advice.

“The client has a risk profile that varies with time and to which the robo-advisor’s investment performance criterion dynamically adapts”. The key improvement of personalized financial advice is understanding the user’s *dynamic risk profile*. - (Capponi et al., 2019)

In the early days of consumer-direct robo-advisory, Germany and the United Kingdom led the way with the most robo-advisory usage in Europe (Cowan, 2018). While Germany had 30+ robot-advisors on the market in 2019, with a total of 3.9 billion EUR under robotic management, it was far less than individual apps like Betterment managed in the US (Bankinghub, 2019). Already in 2017, several of the early robo-advisors apps shut down in the UK; ETFmatic gained the largest number of downloads by 2017, focusing exclusively on exchange-traded funds (ETFs), tracking stock-market indexes automatically, with much less sophistication, than their US counterparts - the app was bought by a bank in 2021 and closed down in 2023 (AltFi, 2017, 2021; “ETFmatic - Account Funding of EURO Accounts Ceases,” 2023; Silva, 2023).

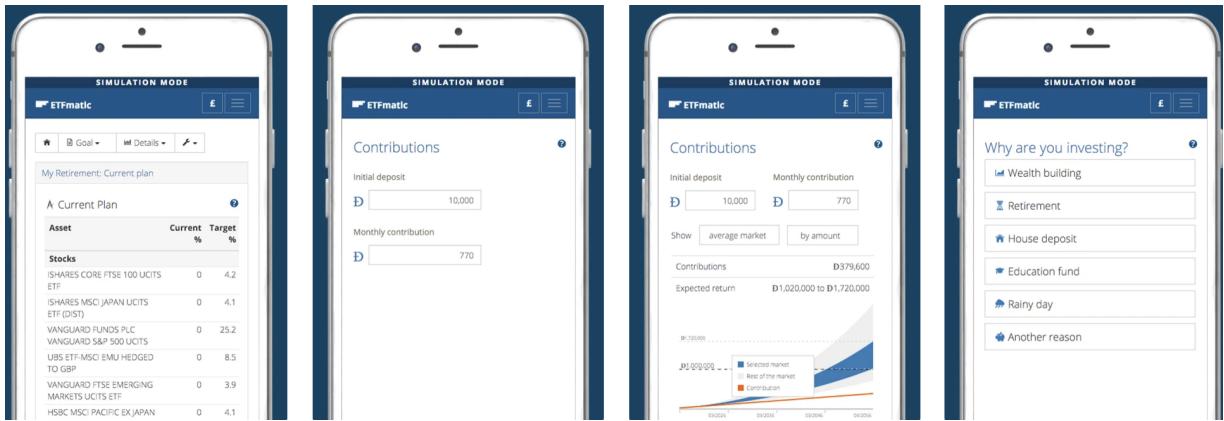


Figure 60: Out-of-date user interface of a European AI-Advisor ETFmatic in 2017 which was closed down in 2023 (Photo copyright ETFmatic)

Newer literature notes robo-advisor related research is scattered across disciplines (H. Zhu et al., 2024). (A. Brown, 2021) outlines how modern financial chatbots have evolved beyond simple Q&A to offer conversational, 24/7 support across banking, investment, insurance, and more, which reduces support costs while improving responsiveness, while freeing human agents for higher-value tasks. In India, research has been conducted on how AI advisors could assist with investors' erratic behavior in stock market volatility situations, albeit without much success; India is a large financial market with more than 2000 fintechs (financial technology startups) since 2015 (Bhatia et al., 2020; Migozzi et al., 2023). (Barbara Friedberg, 2021) and (Slack, 2021) compare robo-advisors and share show before GenAI, financial chatbots were developed manually using a painstaking process that was slow and error-prone. Older financial robo-advisors, built by fintech companies aiming to provide personalized suggestions for making investments such as Betterment and Wealthfront were forced to upgrade their technology to keep up. Robo-advisors compete with community-investing such as hedge funds, mutual funds, copy-trading, and DAOs with treasuries - or can act as entry-points for these aforementioned modes of investment. However, robo-advisors typically do not have the type of social proof that community-based investment vehicle have, where the user may see the actions taken by other investors.

There's research of anthropomorphism or the human-like attributes of robo-advisors, such as the aforementioned conversational chatbots, and whether anthropomorphism can affect adoption and risk preferences among customers. Several show that anthropomorphic robo-advisors, with stronger visual human-likeness, increase customer trust and reduce algorithm aversion (Deng & Chau, 2021; Ganbold et al., 2022; Hildebrand & Bergner, 2021; Plotkina et al., 2024). However it's not clear, if this explanation is tied to the avatar. The question - does the user trust a robot or a human, or is there a possible combination - has been researched in other literature, which does not rely on images. (David et al., 2021) looks at the whether explainable AI could help adoption of financial AI assistants in an experimental study with players ($n = 210$) of an online investment game had to choose between: (a) human advice, (b) AI advice without explanation, or (c) AI advice paired with an explanation; the results showed no evidence of algorithm aversion (players did not prefer human advice over AI advice).

The most comprehensive meta-review of research on how AI chatbots could mimic humans, comes from (Feine et al., 2019), providing an entire taxonomy of social cues for conversational agents, including verbal, visual, auditory cues, as well as other indicators humans pay attention to, such as age, yawning, laughing, posture, clothing, etc. Because this is such a useful resource, I've adapted the findings in the table below.

Table 68: Comprehensive overview of social cues with potential for use in AI conversations, adapted from the meta-review of related research papers by (Feine et al., 2019).

Category	Sub-Category	Cue	Explanation
Verbal	Content	Apology	Agent expresses regret for an error
		Asking for permission	Requests user approval before acting
		Greeting and farewell	Opens or ends the conversation politely
		Joke	Humorous remark to entertain
		Name	Addresses the user by name
		Opinion conformity	Shows agreement with the user's view
		Praise	Compliments the user
		Referring to past	Mentions shared history or earlier turns
		Self-disclosure	Reveals personal info about the agent
		Small talk	Casual, topic-light chatter
Verbal	Style	Thanking	Expresses gratitude
		Abbreviations	Uses shortened words (e.g. "BTW")
		Dialect	Adopts regional or cultural language variety
		Formality	Chooses formal vs casual register
		Lexical alignment	Mirrors the user's word choices
		Lexical diversity	Varies vocabulary richness
		Politeness	Adds courteous markers ("please", "could you")
		Sentence complexity	Varies length and structure of sentences
		Strength of language	Uses mild vs intense wording
		Arm and hand gesture	Animated limb movements
Visual	Kinesics		

Category	Sub-Category	Cue	Explanation
Visual	Proxemics	Eye movement	Gaze shifts or blinking
		Facial expression	Smiles, frowns, eyebrow raises, etc.
		Head movement	Nods, shakes, tilts
	Appearance	Posture shift	Whole-body stance changes
		Background	Visual environment behind the agent
	Conversational distance		Apparent closeness to the user
Visual	Appearance	2D / 3D agent visualization	Flat icon vs full three-dimensional model
		Age	Apparent age of the avatar
		Attractiveness	Overall aesthetic appeal
		Clothing	Outfit style and details
		Color of agent	Dominant color palette
		Degree of human likeness	Cartoon-like to photo-real scale
		Facial feature	Eye shape, mouth style, etc.
		Gender	Male, female, neutral presentation
		Name tag	On-screen label with agent's name
Visual	Text Styling	Photorealism	Realistic rendering quality
		Emoticons	□ □ □ style graphics
		Typefaces	Font choice and typography tweaks
Auditory	Voice Qualities	Gender of voice	Male, female, neutral timbre
		Pitch range	High- vs low-pitched speech
		Voice tempo	Speaking speed
		Volume	Loudness level
Auditory	Vocalizations	Grunts and moans	Non-word hesitation sounds
		Laughing	Laughter audio
		Vocal segregates	“uh-huh”, “mm-hm”, etc
		Yawn	Audible yawning
Invisible	Chronemics	First turn	Which party speaks first
Invisible	Haptics	Response time	Delay before replying
		Tactile touch	Device vibration or touch feedback
		Temperature	Warmth or coolness cues

Literature on fintech UX does share some basic tenets with AI UX on building user confidence.

(*Why Design Is Key to Building Trust in FinTech* | Star, 2021) lists essential tactics for building trust in fintech: (1) consistency in UI patterns, (2) transparent feedback, (3) clear error handling, and (4) educating users about data usage. (Sean McGowan, 2018) offers four guidelines for fintech apps: (1) understand domain complexities, (2) friction is necessary for safety - embrace it, (3) provide continuous and clear feedback, and (4) simplify complex financial information - this can build user confidence and reduce errors. (Cordeiro & Weevers, 2016) emphasizes designing for the “unhappy path” - negative experiences can shape users’ perception deeply, as bad memories carve strongly in their user experience - products which handle failures and edge cases gracefully, however, stand out and maintain satisfaction. (ROBIN DHANWANI, 2021) approaches UX problems from an organizational perspective, noting that in large organizations, UX issues can stem from lack of alignment between teams; the authors propose *Design Jams* as a potential solution to improve cross-team collaboration - design jams are cross-functional workshops, which can help teams align on user needs, generate rapid prototypes, and iteratively refine interfaces - which, in theory, could improve the adherence to the guidelines above noted.

11 MONEY

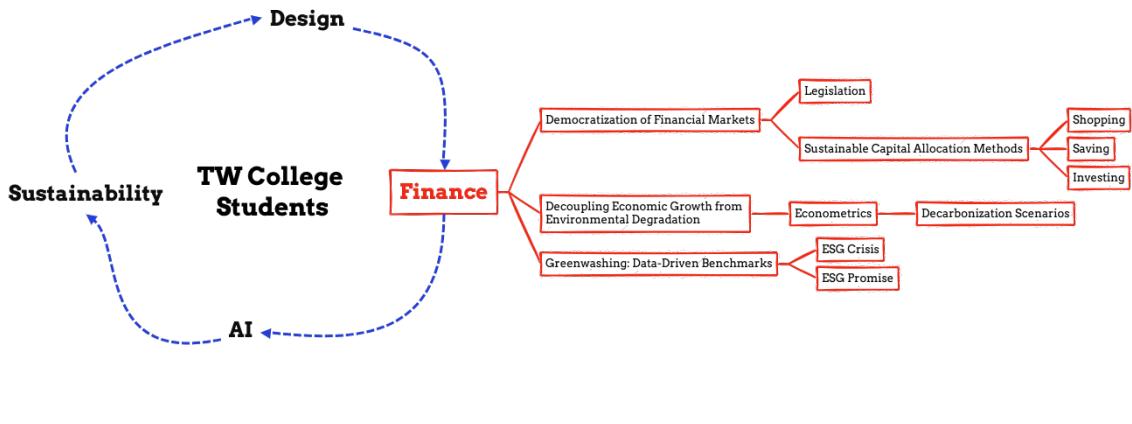


Figure 61: Visual abstract for the finance chapter

11.1 The Convergence of Money: One Wallet to Rule Shopping, Saving, and Investing

This chapter explores how money could incorporate sustainability as a feature.

“Money is information... it shouldn’t be more expensive or slower than sending an email.” (K. Käärmann, Co-Founder of the Wise , formerly known as Transferwise, money transfer platform), said in 2018 (Käärmann, 2018)

Money itself is changing and the meaning of money is becoming more diverse. Traditionally, money referred to the fiat money created by governments by law, using central banks, which loan money to commercial banks, that in turn make it available to the society. Now, we also have new types of money created by companies and individuals using blockchain-cryptography based distributed databases, which keep track of transactions (who-paid-whom). We have various types of tokens of value, such as cryptocurrencies, digital assets, loyalty points, etc, which can all function as types of money. Whatever the method of creation, in essence, money is a *system of trust* where *something* is used as a *medium of value exchange* and accepted by *other people* as payment.

11.1.1 Spurred by Fintech: The Democratization of Finance: A Precursor for Sustainable Superapps

Digital money in its various forms connects industries on popular financial mobile apps, which makes digital money more accessible and socially engaging, appealing to people who are active

online. Because of the *democratization of finance* enabled by digitization and financial technologies, the journey from consumer to investor is becoming increasingly simple. Consumer-oriented financial apps increasingly enable new user interactions which blur boundaries between shopping, saving, and investing - termed here "*money convergence*". Empowering consumers to access finance through digital technologies and delivering a simple user experience is the fintech trend of the last decade. Motivated by boosting user numbers, apps such as N26 and Revolut, that started out with only payments-focused businesses, founded in 2013 and 2015, respectively, began making efforts to expand into all-in-one financial superapps offering varied saving and investing services ("Kickstart Your Investment Journey," 2023; "Revolut Launches ETF Trading Platform in Europe," 2023).

While it took N26 and Revolut more than a decade to grow into global businesses, fintechs can growth really fast. Just last year in Canada, Neo Financial, which offers a mobile app and credit cards to consumers featuring cashback rewards on payments, savings and investing, won Canada's fastest growing company award in 2024, posting a 3-year revenue growth of 38,431%, earning between \$75M and \$100M USD in annual revenue from 1.3 million customers ("Ranking Canada's Top Growing Companies of 2024," 2024). (Qorus, 2023) a survey of 200 banking executives worldwide, revealed we're in a digital banking revolution, with growing adoption of personalization, automation, and *embedded finance* - the availability of savings, loans, insurance, debit cards, and investment opportunities embedded within the apps of non-financial platforms, like e-commerce or social media platforms.

11.1.2 Financial Literacy and Education: Young Investors Follow Financial Influencers

Young investors are typically *retail investors*, investing small amounts of money for themselves. (Unless they have inherited wealth or are among the very few who work in institutions such as investment firms, university endowments, pension funds or mutual funds, and have a say in where to invest large amounts of other peoples' money.) Retail investors face many challenges in comparison with their institutional counterparts. For instance, they may have much less time to do proper research, face information asymmetries, where finding good information is limited by time, ability, as well as financial literacy, whereas professional investors have the tools, skills, time, and knowledge, to make better investment decisions.

The common expectation is that young investors typically have less understanding financial concepts. While consumers are beginning to become more money-savvy, they still lag in both financial and sustainability literacy. Financial and sustainability literacy are intertwined. Integrating these literacies is essential, because a financially informed public is better equipped to channel capital toward environmentally beneficial uses. Media plays a significant role here, with retail investing being heavily influenced by social media influencers.

Popular financial blogger (Austin Ryder, 2020) believes a good starting point is to ask the user to define their financial habits: are you consumer or investor? This helps users recognize whether their spending habits define them primarily as consumers or as investors. (SmartWealth, 2021) urges readers to "*consume knowledge, not products*": for financial health one should get rid of

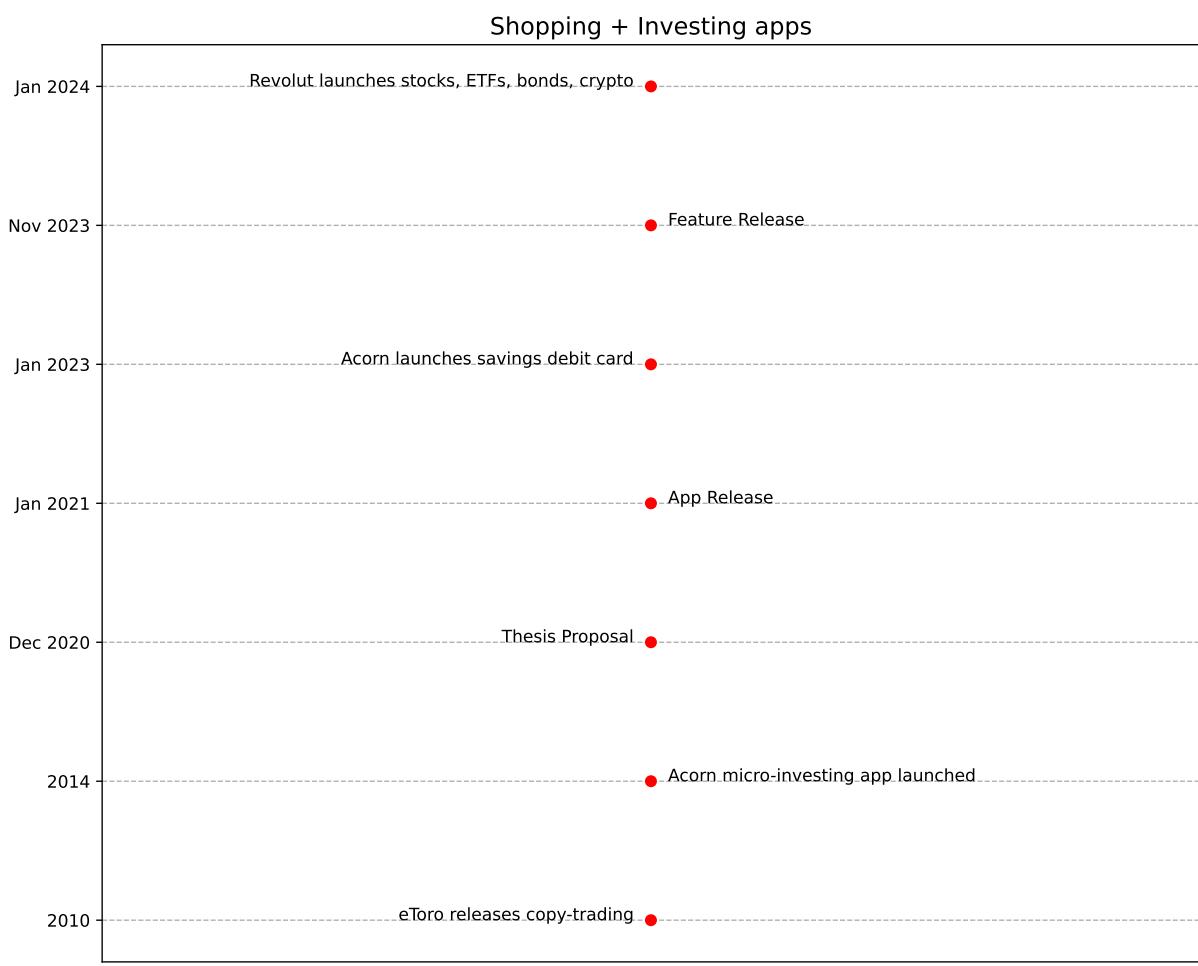


Figure 62: Fintech Growth

debt, automate tracking of expenses and savings, and create a pathway for income to flow into investments; consumer mindset is the main obstacle that keeps people from financial independence and investing. Investing can intersect with gender and race, as for example, during COVID-19, the financial advisor Malaika Maphalala co-led the “*Invest in Black Economic Liberation*” calling for racial justice investing to direct flows into sustainable funds (naturalinvest, 2020). On TikTok, (lizlivingblue, n.d.) promotes the IMPACT investing app by Interactive Brokers which is a mobile trading platform focused on socially conscious investors interested in sustainability (Trahant, 2022).

Table 69: Comparative Data on Investing Apps; compiled from (Gyuriczki & Szládek, 2025; Interactive Brokers, 2025a, 2025b; Lightyear, 2025; Revolut, 2020, 2025; Trahant, 2022)

Feature	IMPACT by Interactive Brokers		
	Lightyear	Revolut	
Target Audience	Sustainability-focused investors; value-driven alignment	European retail investors	Everyday users with casual interest in investing
Investment Products	Stocks, ETFs, mutual funds, options, bonds, fractional shares	Stocks, ETFs, multi-currency accounts	US & EU stocks, crypto, commodities, fractional shares
Sustainability Focus	Strong. Core to the app. Lets users filter companies by ESG values and track portfolio impact.	None. Focuses on transparency and low fees	Minimal. Some ESG ETFs; no impact tracking or custom filters
Fees	Very low (starting at \$0 commissions, with some market/data fees)	Low, with no account fee; FX markup 0.35% outside base currency	Free plan has high spreads; paid tiers offer lower fees; several FX and withdrawal limits apply
Currency Conversion (FX)	Interbank FX rates; low spreads	0.35% FX fee	Free plan: 1% FX fee; better rates in Premium accounts
Fractional Shares	Yes	Yes	Yes
Tax Documents	Yes, detailed reports	Yes, supports Estonian tax system	Limited; may need to do manual tracking for taxes
Mobile App Experience	Professional, ESG-focused UI	Clean, simple, intuitive	Gamified, casual, integrated with other Revolut services

Feature	IMPACT by Interactive Brokers	Lightyear	Revolut
Extra Features	Voting rights, ethical filters, carbon impact metrics	Interest on cash (like a bank account); multi-currency accounts	Cashback, budgeting, crypto, P2P payments, travel perks

The next step is to provide frictionless digital pathways that let everyday purchases morph into micro-investments with transparent sustainability impacts. This user journey is a type of blended learning-by-doing experience. Framing the problem as a dual journey: first, helping users recognise whether their spending habits define them primarily as consumers or as investors, then giving users exposure to investment opportunities through familiar activities like shopping may hold the potential to boost financial literacy levels, enticing consumers to learn more about taking advantage of their financial opportunities as well as understanding how to manage the types or risk involved. Indeed, retail investor are the most vulnerable to misinformation and speculative hype if educational scaffolding is absent.

Financial superapps for shopping, saving, and investing are converging on digital platforms, aiming to permeate our daily financial lives, with features such banking, payments, transfers, rewards and cashback programs (e.g. Rakuten), automated micro-investing round-up to next dollar (e.g. Acorn, Stash, Swedbank, many others), retail investing (Robinhood, Public, Lightyear), copy-trading (eToro) and offering various investment vehicles, to name just a few: (fractional shares of) stocks, derivatives like CFDs and futures, microloans (Kiva), commodities and precious metals such as gold and silver (Revolut), physical assets such as real estate, land, forest and digital assets such as cryptocurrencies, NFTs, and many other alternative assets of varied price, volatility, liquidity, and risk profile.

Community-based copy-trading apps live on the intersection of social media and investing, enabling financial inclusion through letting novice, inexperienced investors piggy-back on more sophisticated investors by copying their investments. In some ways community-investing competes with robo-advisors as communities can be led by professional investors and followed by less sophisticated investors. Because of this investing leadership aspect, investor communities can have the type of *social proof*, which robo-advisor do not possess. eToro's, Robinhood's and Dub's copy trade feature turn portfolios, watch-lists and trade votes into public content (dub, 2025). The visible social proof approach can feel safer than robo-adviser; retail investors cite seeing what others do an important trust trigger (Andraszewicz et al., 2023).

Evidence of a similar phenomenon of peer behavior measurably shifting sustainability choices has been documented in the enterprise sector in green financing of Chinese industries, albeit in a modest 1–2% increase (incremental nudges); companies tend to invest green when they see when other companies signal a green preference (S. Yang et al., 2022). In a Swedish study, investors' belief in sustainable investing was found to be affected by other investors: an online coordination game with 559 private investors showed that 2nd-order pro-sustainable beliefs (*what one thinks*

Investment Share in Green vs Non-Green Projects

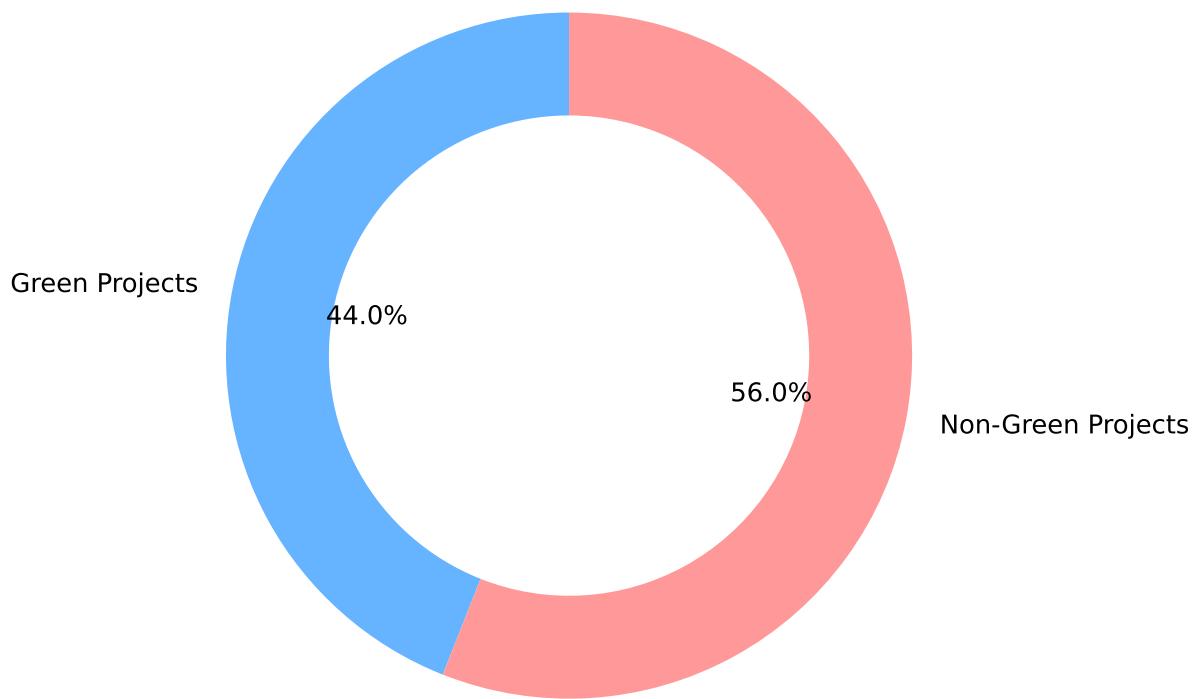


Figure 63: Green Retail vs Non-Green Retail

others care about) also drove up sustainable asset allocations, underlining the social dimension of ESG investing (Luz et al., 2024).

Independent of what is the technology used, access to investing is about financial empowerment. Ugandan investor John Ssenkeezi celebrated on X (formerly known as Twitter) being able to vote at Apple's 2022 AGM stockholder meeting using stock investments app Chipper Cash, which allows users by fractional - shares, illustrating shareholder democracy for emerging - market users (John Ssenkeezi, 2022). AngelList was an early pioneer in opening startup deal flow to retail users, offering access once reserved for angel investors and VCs. Similarly, community-based investment clubs could potentially enable everyday investors to pool resources and back sustainability initiatives alongside more experienced professionals.

Build a community can be lucrative. In Singapore, Chinese influencer Yuqing "Irene" Zhao's photos generated S\$7.5 million in 10 days as NFT sales; she tokenized her selfies as non-fungible tokens (NFTs) via IreneDAO, a decentralized version of OnlyFans, Discord, Twitch and Patreon, arguing that Web3 empowers creators to earn directly from their communities, turning fans into investors and aligning content creation with tokenized membership rights — evidence that retail capital can flow directly to media personalities through crypto communities (Irene Zhao, 2022; Yuqing Zhao, 2021). Similarly, in South Korea, media personalities have become "investable," through more traditional financial vehicles, such as K-pop idols as the focus for "thematic" ETFs, including KPOP and Korean Entertainment ETF and the Mirae Asset Global X K-pop and Culture ETF, enabling fans and investors to financially participate in the growth of the Korean entertainment and celebrity-driven cultural capital (Darwyne, 2025).

Communities can be directed towards sustainability, by attracting people of a similar mindset. For example, *minimalism* is a movement of people living a simpler life; this probably always going to be a small percentage of people, yet a growing life-style choice. According to one study, consumers choose to engage in becoming minimalist in a non-linear process with overlapping stages (Oliveira De Mendonça et al., 2021). Yet, (C. D. Costa, 2018) Finnish socialists promote minimalism as part of their mainstream policies. In Tokyo, a YouTuber shares their life and the choices they made (Tokyo Simple Eco Life, 2021). *Zero Waste Lifestyle* is the opposite of overconsumption. Zero Waste suggests people buy in bulk for more savings and to reduce packaging. Through group purchases and community investing while also reducing consumption. Zero Waste municipality in Treviso is a whole region with a focus on living green. While Minimalism and Zero Waste need an ongoing effort, joining a one-day sustainability event is accessible for most people. Started in Estonia, the World Cleanup Day movement has attracted tens of millions of people to do beach and forest cleanups, all over the world.

Building a community is a way to design a context, where the culture creates certain expectations of behavior. Humans working together are able to achieve more than single individuals. "*Any community on the internet should be able to come together, with capital, and work towards any shared vision. [...] In the long term this moves to internet communities taking on societal endeavors.*" (Panzarino, 2020). (Armstrong & Staff, 2021) believes leveraging different personalities and viewpoints can build more sustainable cultures; the focus on *group consciousness* suggests community-based sustainability action may be effective, when building a *culture of sustainability*, such as the garbage trucks in Taiwan. A communal event is a key building block

for a thriving community, which can be directly experienced instead of just reading about it or watching a video.

11.1.3 New Rules of Money: Legislative Efforts Empowering Consumers to Deploy Capital in Sustainability

Regardless if it's money spent on shopping or money saved and invested, these are all consumers' financial decisions of *capital allocation*. In one way or another, people are giving their money to companies. The critical question is: *do people choose to support sustainability-focused companies* - companies which invest deeply into green innovation and eco-friendly practices - or do people choose companies that pay less attention to sustainability? While all financial transactions support economic growth in the sense of being reflected in the Gross Domestic Product (GDP), not all money flows equally support sustainable economic growth.

Legislation is catching up with fintechs and setting higher standards for consumer protection. For example the Directive 14 2014/65/EU, 2014 of The European Union fully recognizes the changing financial landscape trending towards the democratization of investments: “*more investors have become active in the financial markets and are offered an even more complex wide-ranging set of services and instruments*” (European Parliament, 2014). Some key legislation for investors has been put in place recently, for example “MiFID II is a legislative framework instituted by the European Union (EU) to regulate financial markets in the bloc and improve protections for investors” (Kenton, 2020). MiFID II and MiFIR will ensure fairer, safer and more efficient markets and facilitate greater transparency for all participants” (European Securities and Markets Authority, 2017).

(PWC, 2020) Changes to laws and regulations aimed at achieving climate change mitigation is a key driver behind the wave of ESG adoption. The goal of these laws, first adopted in the European Union, a self-proclaimed leader in eco-friendliness, is to pressure unsustainable companies to change towards greener practices, in fear of losing their access to future capital, and to create a mechanism forcing entire environmentally non-compliant business sectors to innovate towards sustainability unless they want to suffer from financial penalties. On the flip side of this stick and carrot fiscal strategy, ESG-compliant companies will have incentives to access to cheaper capital and larger investor demand from ESG-friendly investors.

Already in 2001, while still part of the EU, the UK government was discussing ways to promote sustainable investment “*fundamental changes in VAT or corporation taxes could be used to promote greener consumption and investment*” (House of Commons, 2002). More recently, (HM Treasury, 2020) released a taxonomy of sustainable activities in the UK.

While the above trend is for governments to adapt to and work towards their environmental climate commitments and public demand, the sovereign risk remains an issue. For example, in the U.S. the policies supported by President Donald Trump during his presidency ran counter to many sustainability recommendations, including those directed at the financial markets, helping legacy industries stay competitive for longer through subsidies, and lack of regulation, or even regulation supporting legacy technologies (Quinson, 2020).

Governments are powerful in passing legislation, with a strong positive or negative ESG impact, and people do have a voice. Among the many grassroots campaigns, one environmental success story is about success story, asking that EU shops can't sell deforestation products, gathering over 100 thousand online signatures (WeMove Europe, 2022). Subsequently, legislation banning products contributing to deforestation was passed by the EU Parliament and Council in 2023 and came into effect in July 2024 (Abnett & Abnett, 2024; European Parliament, 2023).

11.2 ESG Crisis and Opportunity

11.2.1 Opaque Metrics and Lack of Standardization

ESG ratings have faced criticism for lack of standards and failing to account for the comprehensive impact a company is having. (Foley et al., 2024) notes how Coca Cola fails to account the supply chain water usage when reporting becoming “water neutral” and calls on companies to release more detailed information; major ESG ratings omit 90% of the company’s water footprint. (Gemma Woodward, 2022) Identifies fundamental problems in current ESG frameworks include (1) inconsistent data, and (2) superficial rating schemes, and calls for a complete overhaul to restore credibility in sustainable investing. (Margaryta Kirakosian & Angus Foote, 2022) argues that ESG needs standardization of methodologies as the disparity is one of the key hurdles in finding the right sustainable strategy. This is supported by econometric analysis, showing how inconsistent ESG scoring methodologies and greenwashing risk can predict the yields of green bonds, meaning scoring variance could materially affect bond pricing (Baldi & Pandimiglio, 2022). Likewise, The Carbon Tracker Initiative finds that companies in the highest-emitting sectors fail to explain how their greenhouse-gas outputs translate into financial risk, based on an analysis of corporate disclosures (Frances Schwartzkopff, 2022b).

Fortunately, there are some investment advisors rebuffing misleading ESG claims made by asset managers. Prominent investment research firm Morningstar conducted a forensic analysis of the industry, and re-classified 1/5 of the tracked funds (over 1200 in total) or over \$1 trillion USD in total valuation, as non-ESG; Hortense Bioy, Morningstar’s Head of Sustainability Research, commented these funds don’t integrate ESG factors “in a determinative way for their investment selection” (Schwartzkopff & Kishan, 2022).

In theory, *Socially Responsible Investing* (SRI) integrates ESG criteria to screen out harmful industries and direct capital to companies with positive social and environmental impacts for both ethical and financial returns (“Socially Responsible Investing Advisors,” n.d.). Nonetheless, a large-scale input–output life-cycle assessment of 1340 European equity funds (11275 unique holdings) including sustainable (SRI) funds, and found that 24% of the sampled SRI funds actually show higher total CO₂eq emissions exposure within their assets than a conventional market index (Popescu et al., 2023). (Amenc et al., 2023) reviewed ESG ratings from 3 major providers (Moody’s Analytics, MSCI Inc., and Refinitiv), finding that “*well-rated companies do not emit significantly less carbon than those with lower scores*”.

(“ESG 浪潮反思：一間減碳表現優異、但產品有害健康的企業，符合 ESG 精神嗎？,” 2022) critiques leading ESG rating methodologies (e.g., MSCI, Sustainalytics), showing they assess a

company's ability to withstand ESG-related financial risk (not its actual environmental, social, or governance performance), allowing firms like Philip Morris, which joined the Dow Jones Sustainability Indices (DJSI) in 2020 despite selling 7 trillion cigarettes per year, to score highly, and calls for urgent re-calibration of these frameworks.

The lack of rigor is creating a backlash against ESG reporting. (C. Yu, 2021) reports ESG is filled with greenwashing. ("Anti-ESG Crusade in US Sweeps 15 States With More Laws in Works," 2023) several US states are introducing regulation for ESG to curb greenwashing. (Frances Schwatzkopff, 2022a) suggests the ESMA and EU has strengthened legislation to counter ESG greenwashing. (Shashwat Mohanty, 2022) "sustainable funds don't buy Zomato's ESG narrative". (Bindman et al., 2024) reports large ESG funds managed by BlackRock and Vanguard are investing into JBS, a meat-packing company which is linked to deforestation of the Amazon rainforest through its supply chain.

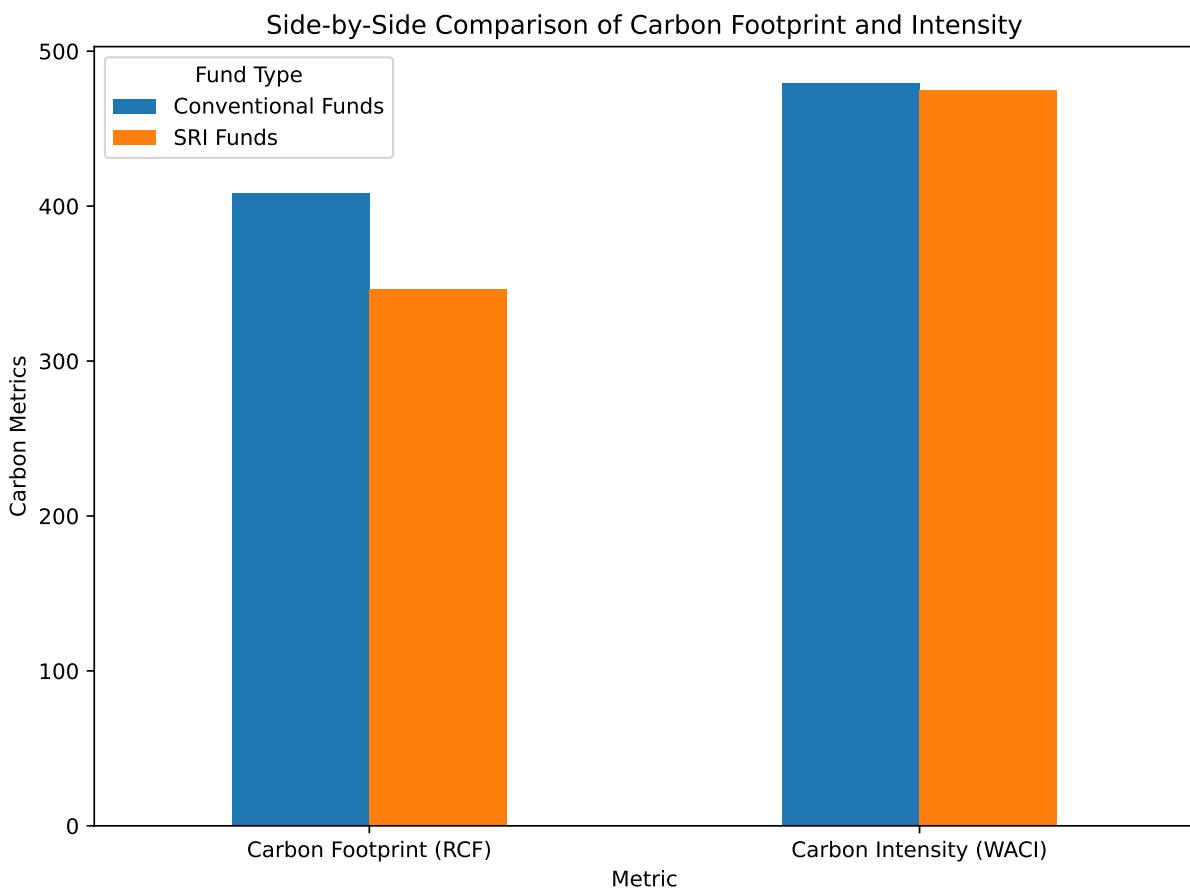


Figure 64: Conventional vs Socially Responsible Funds

(Sanjai Bhagat, 2022) argues that despite more than \$2.7 trillion in ESG-rated AUM as of December 2021, (assets under management, the total market value of all the investments including stocks, bonds, crypto, etc.), that investment managers are looking after on behalf of their clients (81% in Europe and 13% in U.S.), funds marketed as 'sustainable' fail to deliver im-

provements to environmental and social metrics; the inconvenient truth is that ESG ratings don't deliver better ESG performance. In the face a crisis of underperformance and mounting scandals, (James Phillipps, 2022) questions whether ESG is fundamentally broken or simply misunderstood. (PIETRO CECERE, 2023) calls ESG labeling confusing and arbitrary; fund selectors describe ESG labeling as "a total mess," pointing to confusing definitions, inconsistent methodologies, and overlapping ratings that undermine clarity. ("Financial Materiality Marks Next Big ESG Investing Battle," 2023) argues that the main challenge in credible ESG investing is defining which sustainability factors are genuinely financially material; the market is confused by inconsistent scoring methods and needs more government-backed policies that create incentives to align short- and long-term risk assessments. ESG-activist Georgia Elliott-Smith argues in her TEDx talk that large corporations are using ESG for greenwashing - but not changing their fundamental polluting practices (TEDx Talks, 2022).

ESG gave banks a new tool to market and sell environmentally conscious opportunities to institutional investors, for example: universities. A case in point being the partnership between HSBC and the University of Edinburgh (Reid, 2020). Some banks even use tactics such as co-branding with famous individuals. One of the largest private banks in Switzerland, Lombard Odier & Co (LOIM), launched a thematic bio-economy fund marketed using the words of The Prince of Wales, "*Building a sustainable future is, in fact, the growth story of our time*" (Kirkakosian, November 16, 2020). Investment can also be advertised in media publications. In the United Emirates, the richest oil-drilling region in the world, Mubadala, one of the state-owned sovereign wealth funds of the government of Abu Dhabi with \$326 billion AUM, has taken out sponsored content in Bloomberg to market their national ESG vision and regulatory strategies to accelerate ESG investment growth toward net-zero goals, including many green energy projects; the Abu Dhabi funds together manage \$1.7 trillion AUM (Maccioni, 2025; "The Future of ESG Investing," n.d.).

Yet, the question remains, whether one can trust financial professional to hold ESG to a high standard. (Agnew, 2022) Argues that ESG has become a diluted corporate marketing label nearing the end of its usefulness, and urges a pivot toward more substantive responsible-investment practices beyond ticking the ESG checkbox. Banks are hiding emissions related to capital markets, which is a major financing source for oil and gas projects; the Partnership for Carbon Accounting Financials (PCAF) working group voted to attribute only 33% of CO₂eq emissions from bond and equity underwriting to their own financed-emissions footprints, effectively excluding and hiding 2/3 of their carbon emissions (T. Wilkes, 2023). In the U.S., Blackrock, the largest private investment fund in the world with \$10T USD under management, released guidance reflecting their plans to shift their investments to vehicles that are measured on ESG performance; however they later backtracked from their decision (Posner, 2024). In the U.K., while promising to become sustainable, oil companies are increasing production; Rishi Sunak, the Prime Minister of the UK at the time announced 100 new licenses for oil drilling (Noor, 2023). In a sense this strategy could be described as "have your cake and eat it too", with investing going to all types of energy, regardless of its environmental footprint.

In early 2025, ESG investing saw \$8.6 billion in global outflows, mainly due to political push-back in the U.S., including rollbacks of climate and DEI policies under the Trump administration.

U.S. sustainable funds lost \$6.1 billion, and Europe saw its first net outflow since 2018; ESG is shifting toward a more practical phase, with less focus on branding and more on measurable outcomes (Bioy, 2025; Johnson, 2025; Mitchell, 2025; Vosburg & Bioy, 2025).

11.2.2 Modern Slavery Persists and ESG Falls Short in Protecting Workers' Rights and Mitigating Environmental Harm

In 2023, an estimated 50 million people were in slavery around the world; lack of supply chain visibility hides forced labor and exploitation of undocumented migrants in agricultural work; 71% of enslaved people are estimated to be women. (Borreli et al., 2023; Kunz et al., 2023). (Christ & V Helliar, 2021) estimates 20 million people are '*stuck inside corporate blockchains*'. The Global Slavery Index measures the considerable '*import risk*' of having slavery inside its imports (Walk Free, 2023). (Hans van Leeuwen, 2023) slavery affects industries from fashion to technology, including sustainability enablers such as solar panels. The International Labor Organization (ILO) estimates 236 billion USD are generated in illegal profits from forced labor (International Labour Organization, 2024). On the global level, the United Nations SDG target 8.7 targets to eliminate all forms of slavery by 2025 however progress has been slow (The Minderoo Foundation & Commonwealth Human Rights Initiative, 2020).

The California Transparency in Supply Chains Act which came into effect in 2012 applies to large retailers and manufacturers focused on pushing companies to eradicate human trafficking and slavery in their supply chains. Similarly, the German Supply Chain Act (Gesetz über die unternehmerischen Sorgfaltspflichten zur Vermeidung von Menschenrechtsverletzungen in Lieferketten) enacted in 2021 requires companies to monitor violations in their supply chains (Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung, 2023; Stretton, 2022b).

The Modern Slavery Act has been passed in several countries starting with the U.K. in 2015, yet commodification of human beings is still practiced worldwide (UK Parliament, 2024). (Mai et al., 2023) finds the quality of the reporting remains low among FTSE 100 (index of highly capitalized listings on the London Stock Exchange) companies. Not everyone is in favor of more stringent labor practices either. Voters in Switzerland rejected the responsible business initiative in 2020 while the country is a global hub for trading commodities. "*Switzerland has a hand in over 50% of the global trade in coffee and vegetable oils like palm oil as well as 35% of the global volume of cocoa, according to government estimates*" (Anand Chandrasekhar & Andreas Gefe, 2021) begging the question can Swiss traders have more scrutiny over what they trade.

Slavery is connected to environmental degradation, and climate change (Decker Sparks et al., 2021). Enslaved people are used in environmental crimes such as 40% of deforestation globally. Cobalt used in technological products is in risk of being produced under forced labor in the D.R. Congo (Sovacool, 2021). In India and Pakistan, forced labor in brick kiln farms is possible to capture remotely from satellite images (Boyd et al., 2018). In effect, the need for cheap labor turns slavery into a *subsidy* keeping prices lower, and environmental degradation happening.

While reducing slavery in the supply chain sets very low bar for ESG, another aspect of supply tracing is the treatment of workers and working conditions. Currently, one of the largest factory

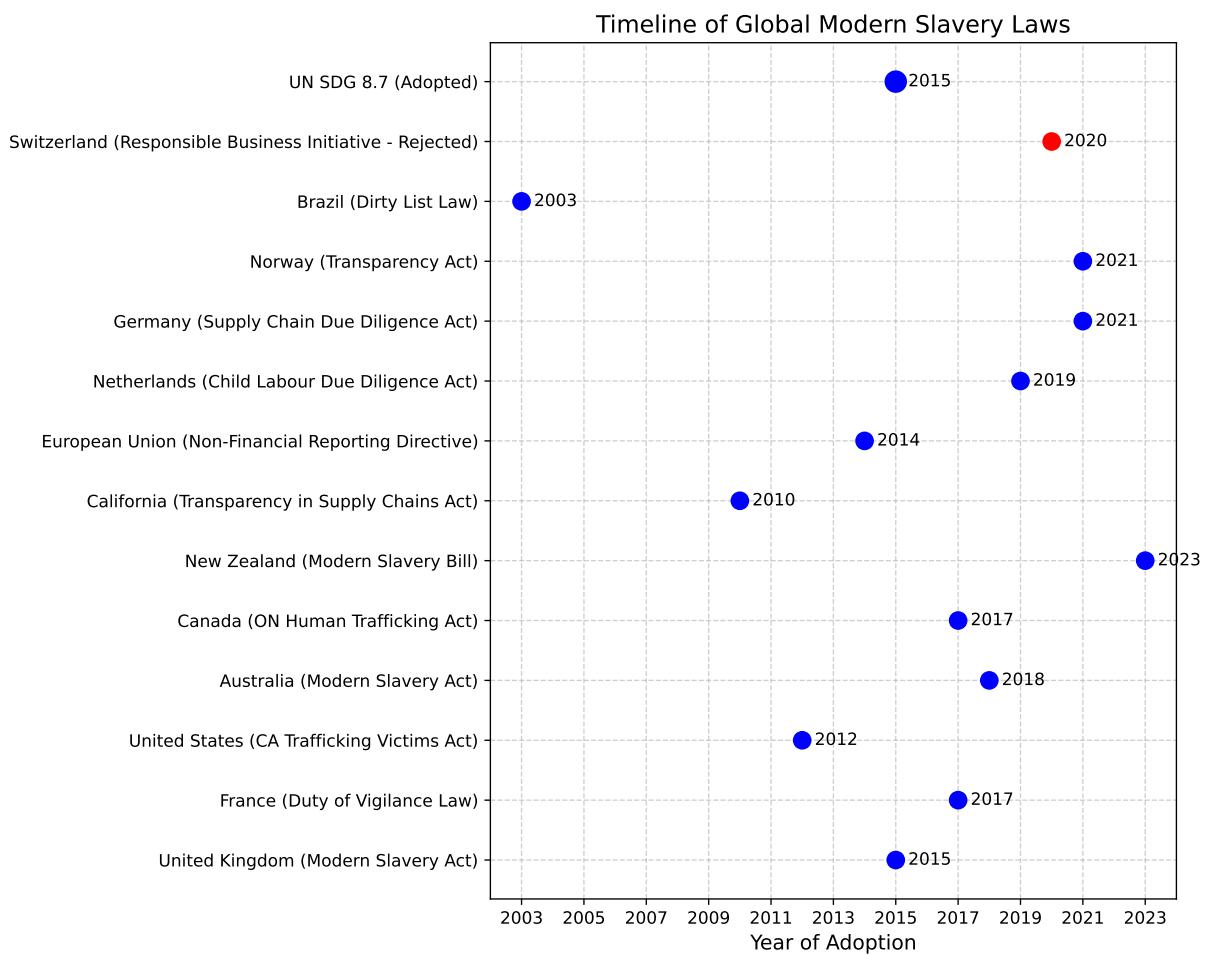


Figure 65: Slavery Laws

compliance platforms - Fair Factories Clearinghouse (FFC) - covers 149 countries with standardised auditing in the apparel and consumer goods industries, monitoring over 40 thousand workplaces and facilitating over 100 thousand workplace assessments by its members (“FFC - Fair Factories ClearingHouse - Compliance Solutions,” n.d.). At a similar scale, Sedex spans 170 countries (Novotny, 2025). Nonetheless, with so much auditing happening, there are still cases where people fall through the cracks. Another wave of companies that create “worker voice apps”, intend to “*give the supply chain a voice*” by connecting workers directly to the consumer (even if anonymously, to protect the workers from retribution), include CTMFile, Alexandria, and PrimaDollar (PrimaDollar Media, 2021; Tim Nicolle, 2021; “Worker Voice,” 2022). If people working at the factories can directly report working conditions to a safe and anonymous tool, it could serve as a data source for further investigation of labor issues. While there are certainly pitfalls to this approach, one could imagine assigning each factory a social score based on the S-band of their general ESG performance.

These issues do not pertain only to legacy industries. With the increase of gig-work, platform economy companies have been criticized for their lack of concerns for workers rights (S in ESG). In the absence of continuous assessment, sometimes intrepid journalists come in to cover the issues. One example is the coverage by (Siddiqui et al., 2024), using portable Atmotube Pro air pollution tracking devices (the same device I use myself) to document how gig workers across South Asia, from India to Bangladesh to Pakistan are subjected to pollution, finding PM2.5 exposure 10x over the WHO daily guideline, shortening lives (according to the Air Quality Life Index) by 11.9 years in New Delhi, 8.1 years in Dhaka, and 7.5 years in Lahore, respectively. Air quality varies dramatically between places, however taking the global average in 2022, if fine particulate pollution were reduced to meet the WHO guideline, a person would have gained 1 year and 11 months of life expectancy (Institute for Climate and Sustainable Growth, 2022).

The above charts shows a comparison of air quality trends in South Asia vs Taiwan; while air pollution has increased in India, Bangladesh, and Pakistan, Taiwan has returned to the pollution levels of 1990s.

11.2.3 Environmental, Social, and Corporate Governance: Criteria for a Shared Language

Since the 1970s, international bodies, governments, and private corporations have developed sustainability measurement metrics, the prominent one being ESG (Environmental, Social, and Corporate Governance) developed by the UN in 2005. This rating system has already been implemented or is in the process of being adopted on stock markets all over the world and has implications beyond the stock markets, allowing analysts to measure companies’ performance on the triple bottom line: the financial, social, and environmental metrics.

Taiwan has listed ESG stocks since 2017 and was hailed by Bloomberg as a regional leader in ESG reporting (Grauer, 2017). In December 2017, the *FTSE4Good TIP Taiwan ESG Index* was launched, which tracks ESG-rated companies on the Taipei stock market (Taiwan Index, 2024). Nasdaq Nordic introduced an ESG index in 2018, and Euronext, the largest stock market

PM2.5 Trends: India, Bangladesh, Pakistan, Taiwan (1998–2022)

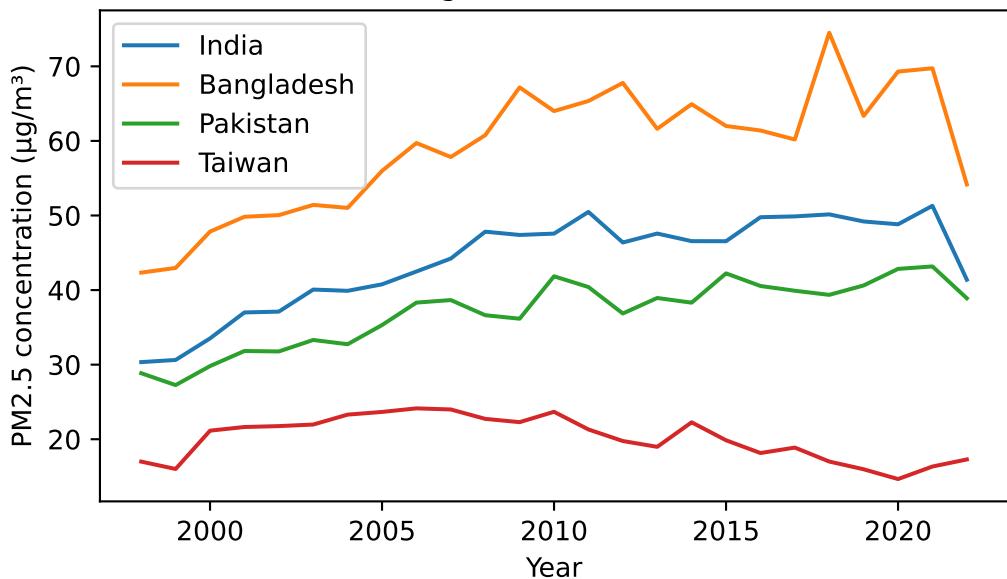


Figure 66: Air Quality in Taiwan vs South-East Asia

in Europe, introduced an ESG index and a series of derivative instruments in the summer of 2020 (Euronext, 2020).

(*The Importance of ESG Measurement and Canada’s Opportunity for Improvement*, 2022) suggests ACWI ESG leaders outperform the non-ESG screened ACWI based on comparing MSCI indexes. It’s notable that ACWI ESG started to outperform the traditional ACWI only in the past few years (evidence that capital markets are starting to price sustainability, but still inconsistently). Nordic Climate Transparency Leadership analysis of Nasdaq OMX Nordic 120 companies: “*companies with higher quality climate reporting also provide higher returns*”. In contrast, (D. Luo, 2022) found firms with a lower ESG score are more profitable.

11.2.4 Towards Green Transparency - But Who Does the Rating?

Trucost, a company launched in 2000 to calculate the hidden environmental costs of large corporations and advance circular-economy practices was acquired in 2016 by S&P Dow Jones Indices, which by 2019 became a part of its ESG product offering (Indices, Oct 03, 2016, 08:30 ET; Mike Hower, Dec 9, 2015 7am EST; “S&P Rolls Out Trucost ESG Data to Its Customers,” 2019; Toffel & Sice, 2011). Its parent company S&P Global also acquired RobecoSAM’s ESG rating business, consolidating S&P’s control of ESG ratings (George Geddes, 2019).

A meta-review of 136 research articles discovered the following ESG-rating agencies.

Three frameworks for corporate to think about ESG compliance is to position their company on the MEET, EXCEED, and LEAD scale based on the size, complexity and available resources of the company.

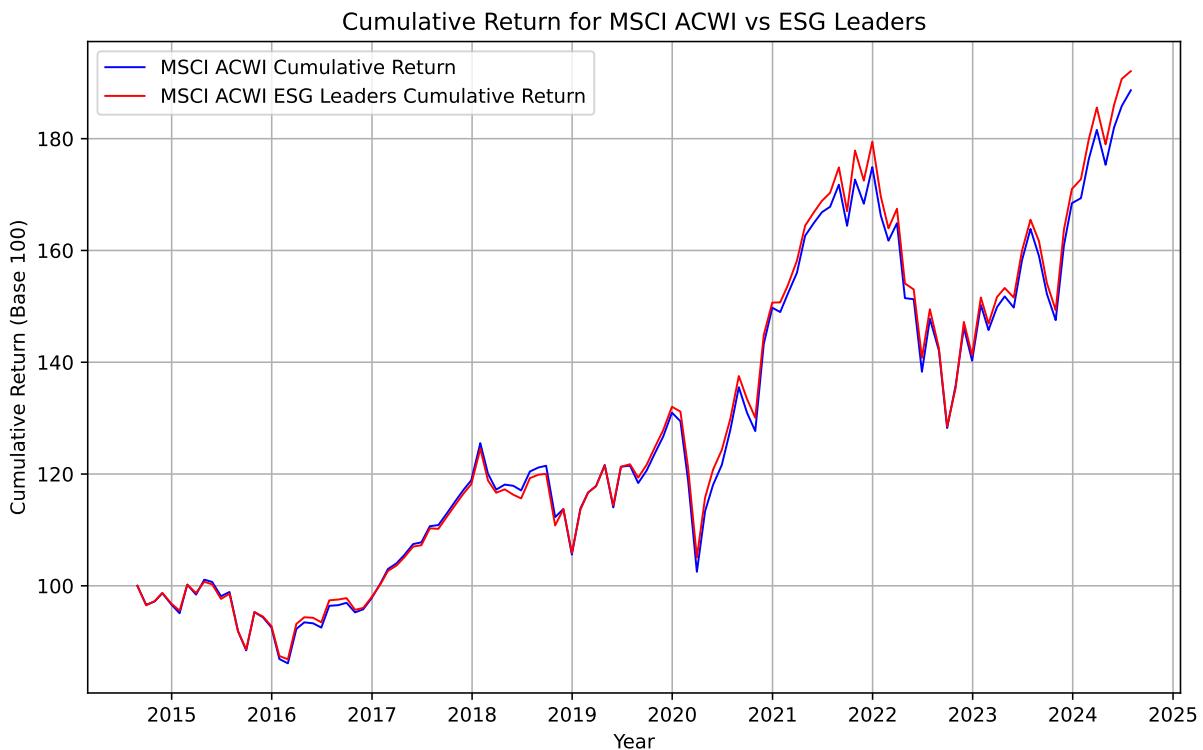


Figure 67: ESG Funds vs Non-ESG Funds

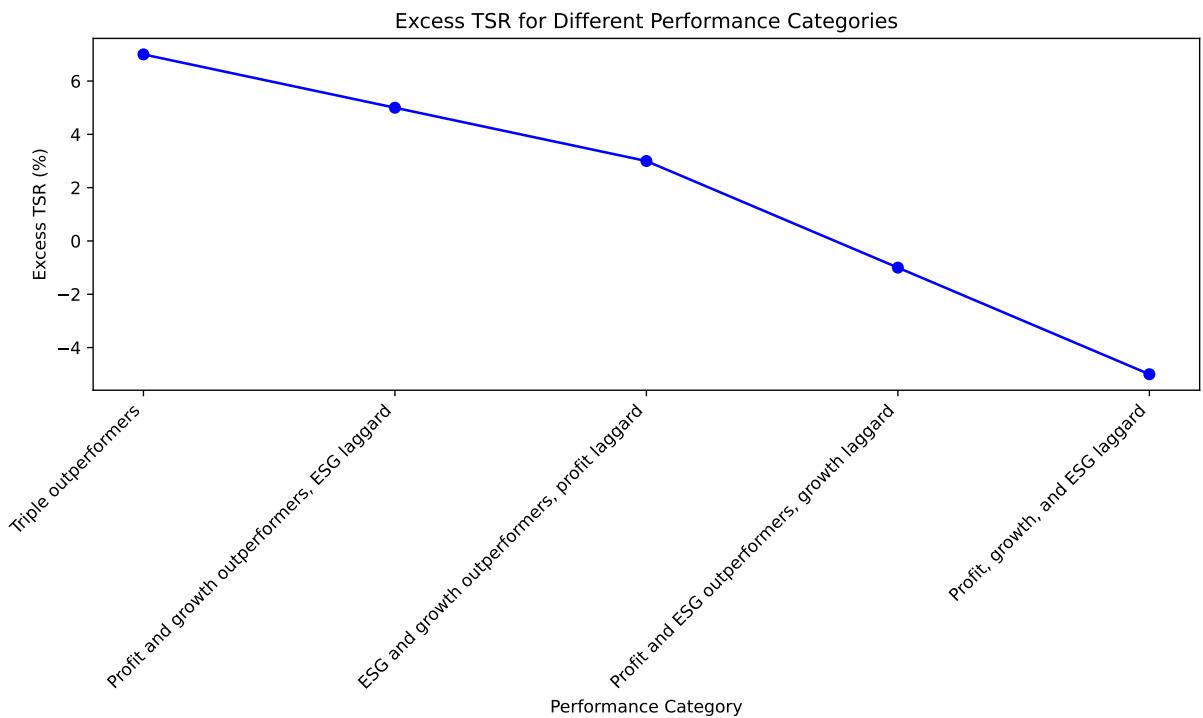


Figure 68: Company Performance

Distribution of Providers used among the Selected Articles

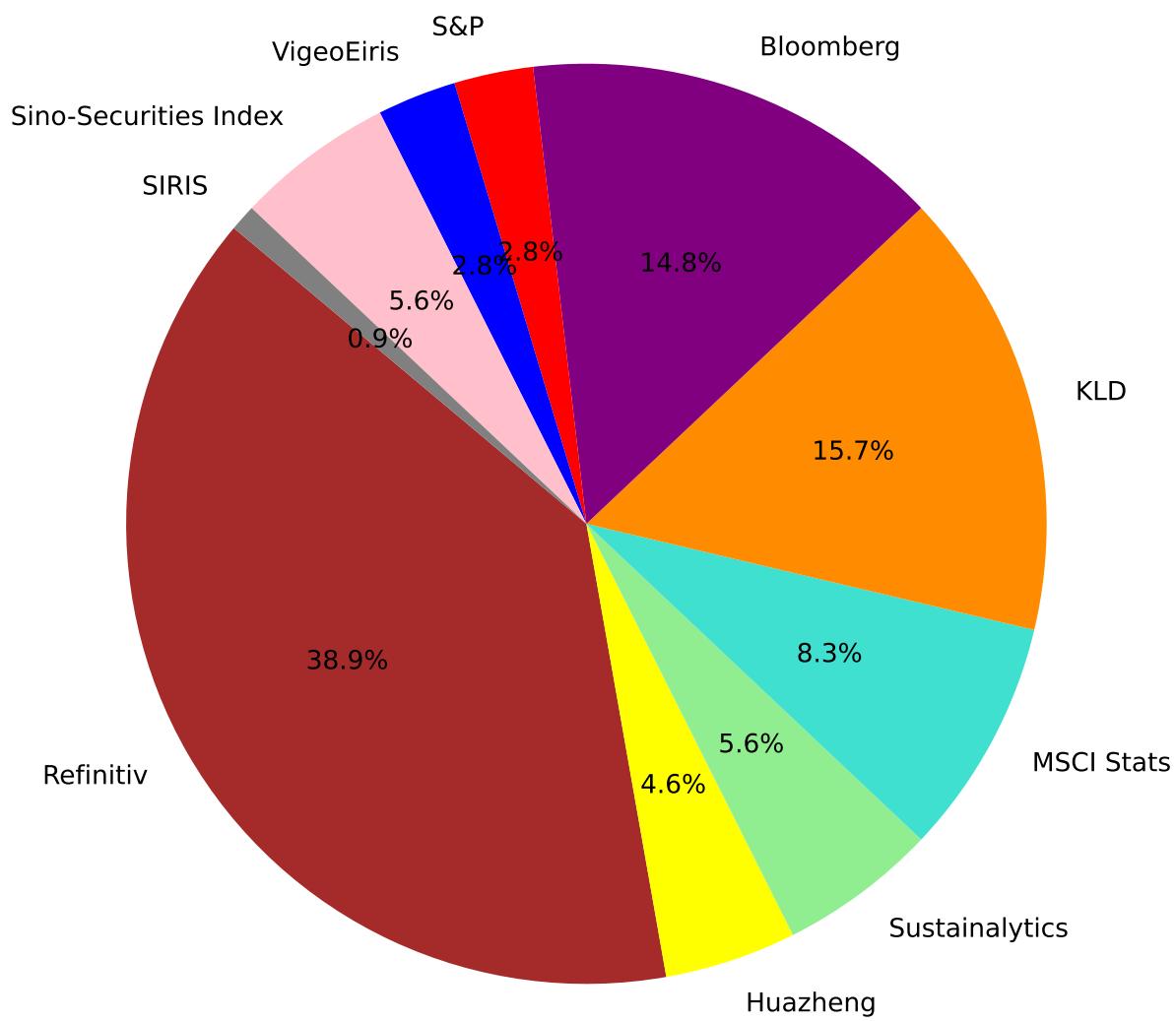


Figure 69: ESG Rating Agencies

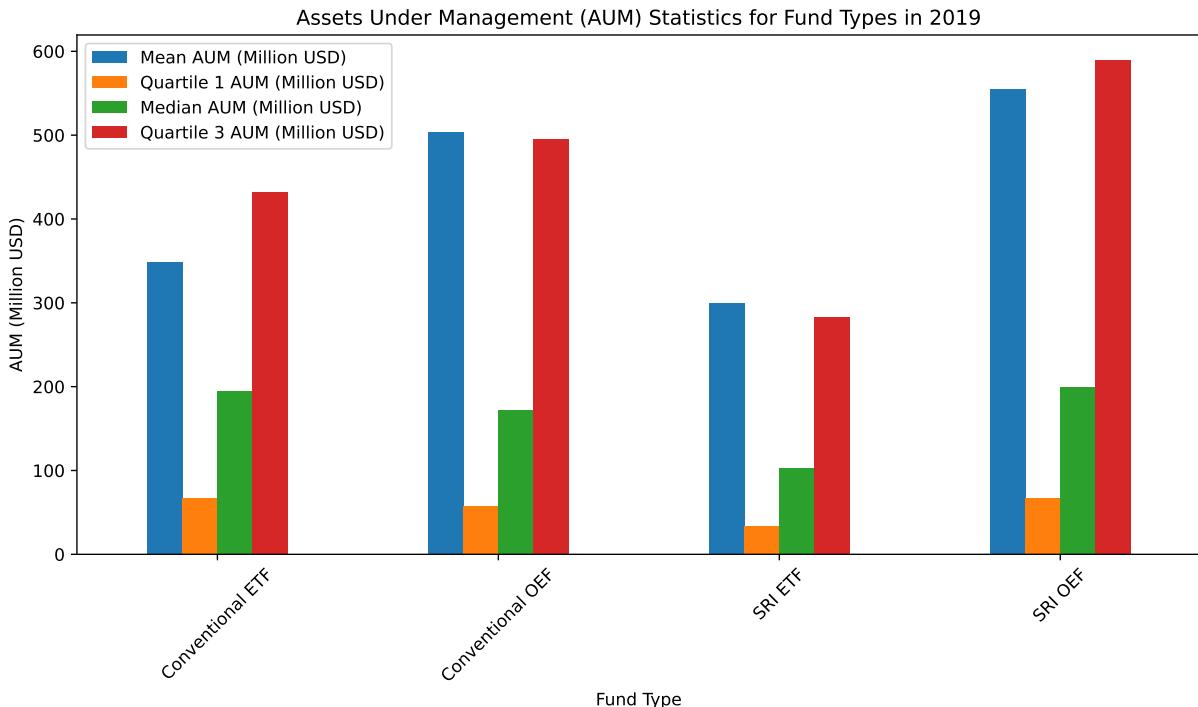


Figure 70: Types of Investment Funds

Robeco's survey of 300 large global investors totaling \$27T under management found biodiversity-protection is increasingly a focus-point of capital allocation (Robeco, 2023).

11.2.5 ESG Success Depends on Good Governance: Boards, Policy, and Investor Pressure

Governance in ESG is the G that makes E and S happen - or put in another way: governance drives social and environmental initiatives at companies. Yet MSCI research finds company boards severely lacking in climate experts; among the 164 large CO₂eq emitters (1986 directors in total) benchmarked by the Climate Action 100+ alliance, 65% have no board member with demonstrated climate expertise, highlighting a major governance gap (Climate Action 100+, 2023; Sommer et al., 2024).

Table 70: Climate Experts on Company Boards

Region	Companies (n)	≥ 1 Climate Expert (%)	≥ 1 Expert (count)	No Experts (%)	No Experts (count)
EMEA	52	48 %	25	52 %	27
Americas	61	36 %	22	64 %	39
APAC	51	20 %	10	80 %	41

Most companies do not meet the criteria (Climate Action 100+, 2023).

Lack of leadership is a key challenge for sustainability. (Capgemini, 2022) “*Many business leaders see sustainability as costly obligation rather than investment in the future*” was the finding from the Capgemini Research Institute’s report “Why sustainability ambition is not translating to action” surveyed 2,004 executives from 668 large organizations; 53% of leaders view sustainability initiatives as a financial burden, believing the costs outweigh the benefits, and only 21% agree that the business case for sustainability is clear, underscoring a pervasive leadership gap that treats sustainability as a costly obligation.

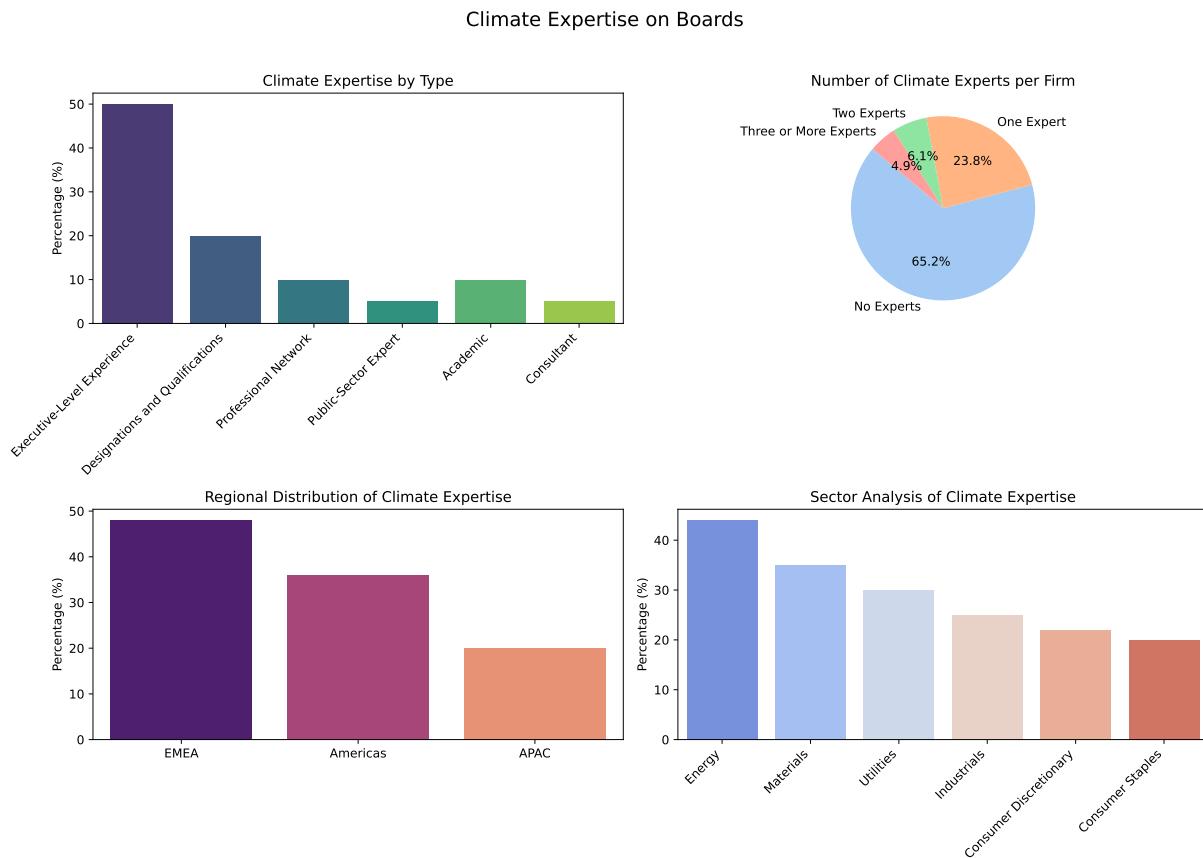


Figure 71: Lack of Board Members With Sustainability Expertise

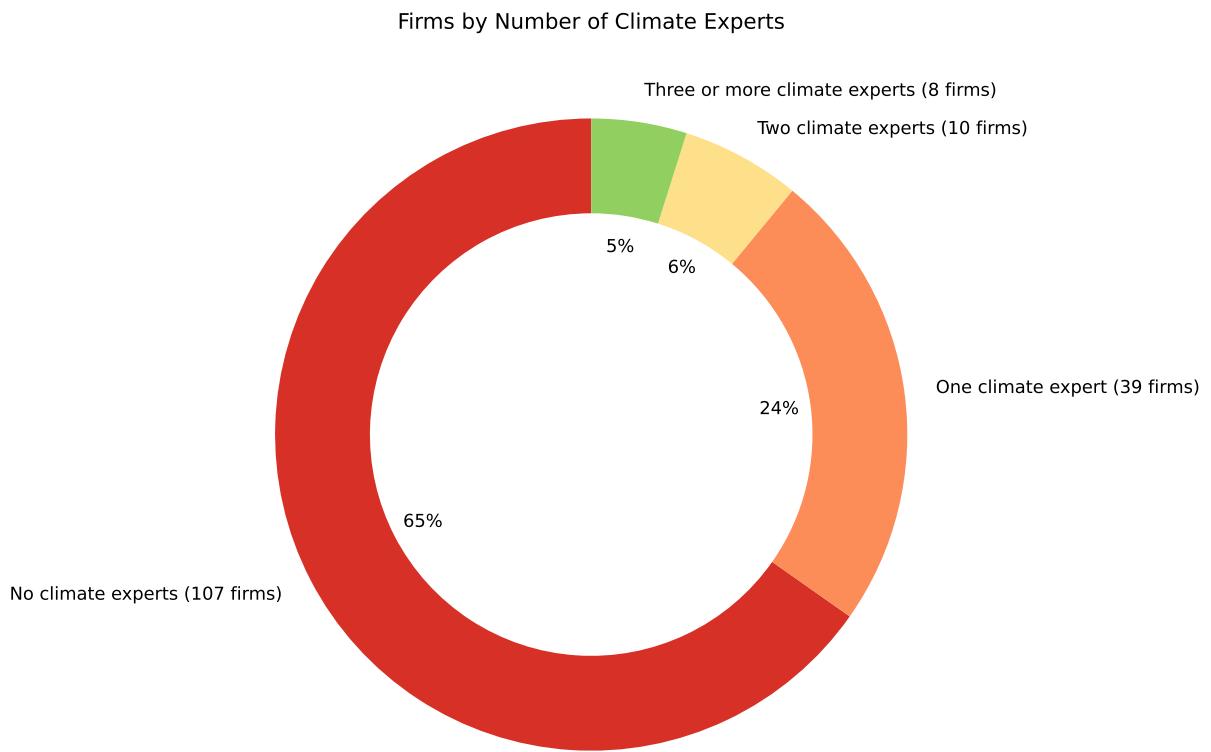


Figure 72: Large Carbon Emitters Lack Sustainability Experts

Overall Accounting and Audit Assessment

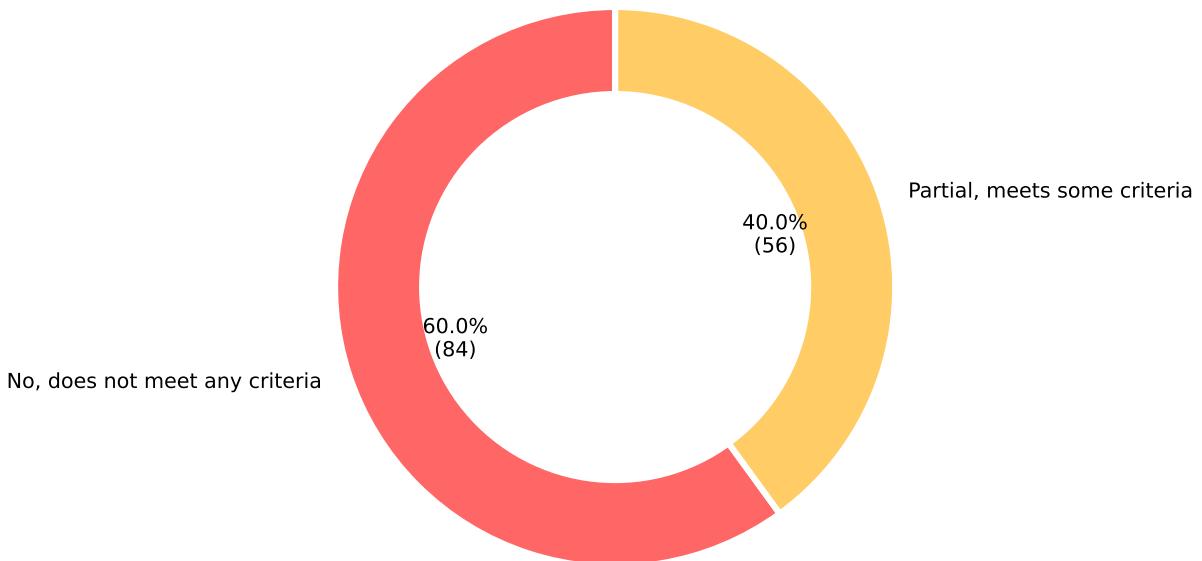


Figure 73: Large Carbon Emitters Do Not Meet Sustainability Criteria

(Break Free From Plastic, 2024; Simões-Coelho et al., 2023). Large corporations such as Coca Cola and Nestle also support the biodiversity law, calling for a level playing field for business to limit biodiversity risk (Greens EFA, 2023).

Many large businesses have tried to find solutions by launching climate-focused funding. (Korosec, 2021) reports that Amazon's 2B USD to a Climate Pledge Fund earmarked to fix climate problems is invested in energy, logistics, and packaging startups, which will reduce material waste. "Good intentions don't work, mechanisms do," Amazon's founder Bezos is quoted as saying in (Clifford, 2022). Walmart is taking a similar approach, having launched a project in 2017 to set CO₂ reduction targets in collaboration with its suppliers (Walmart, 2023). These examples underline how money marketed as climate funding by retail conglomerates means focus on reducing operational cost of running their business through automation and material savings.

Shareholders can leverage their numbers and join forces in order to affect the board members of large corporations. For example, the As Your Sow NGO aims to champion CSR through building coalitions of shareholders and taking legal action, including the Fossil Free Funds initiative which researches and rates funds' exposure to fossil fuels finance and its sister project *Invest in Your Values* rates retirement plans offered by employers (mostly US technology companies) (As You Sow, 2024a, 2024b).

Board diversity in the top 5 sustainable companies in 2024 based on Corporate Knights rankings

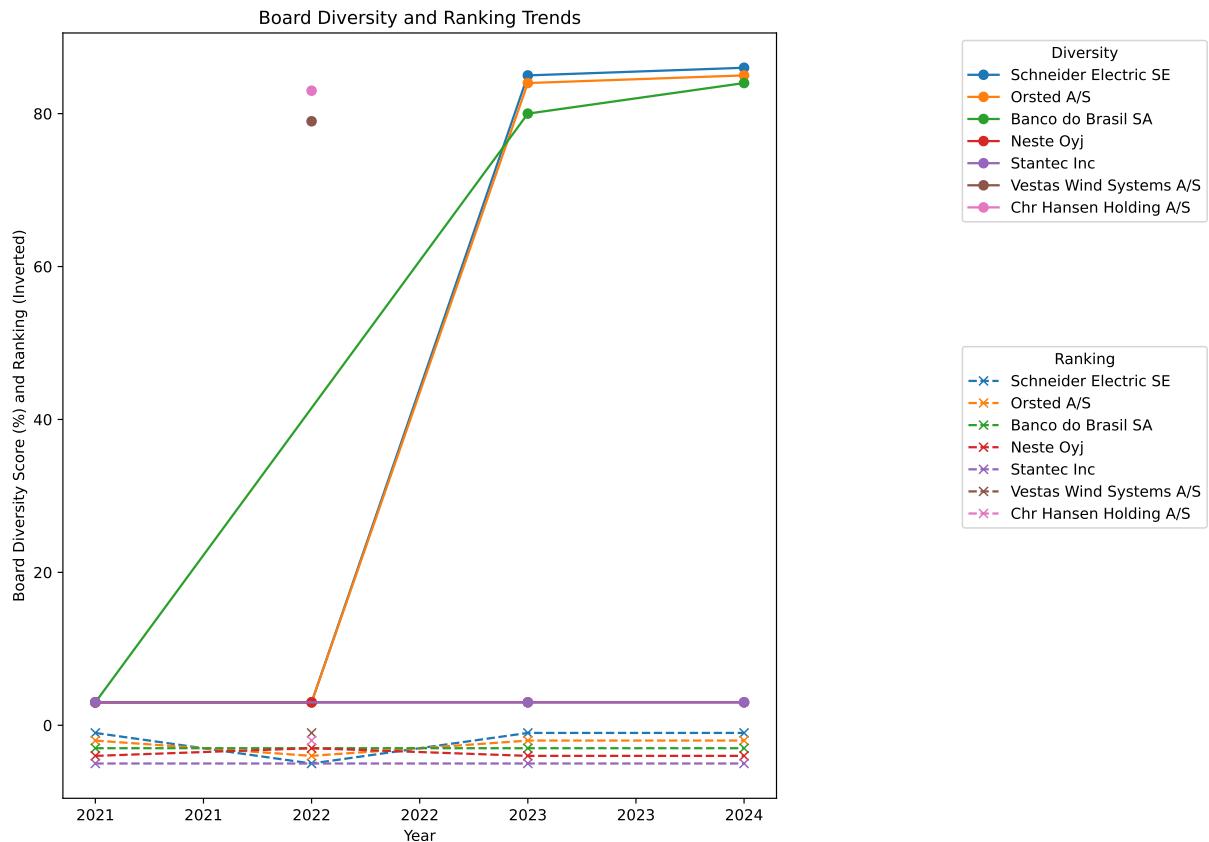


Figure 74: Board Diversity

(Corporate Knights, 2024).

11.2.6 ESG Success Depends on Digitization and GenAI

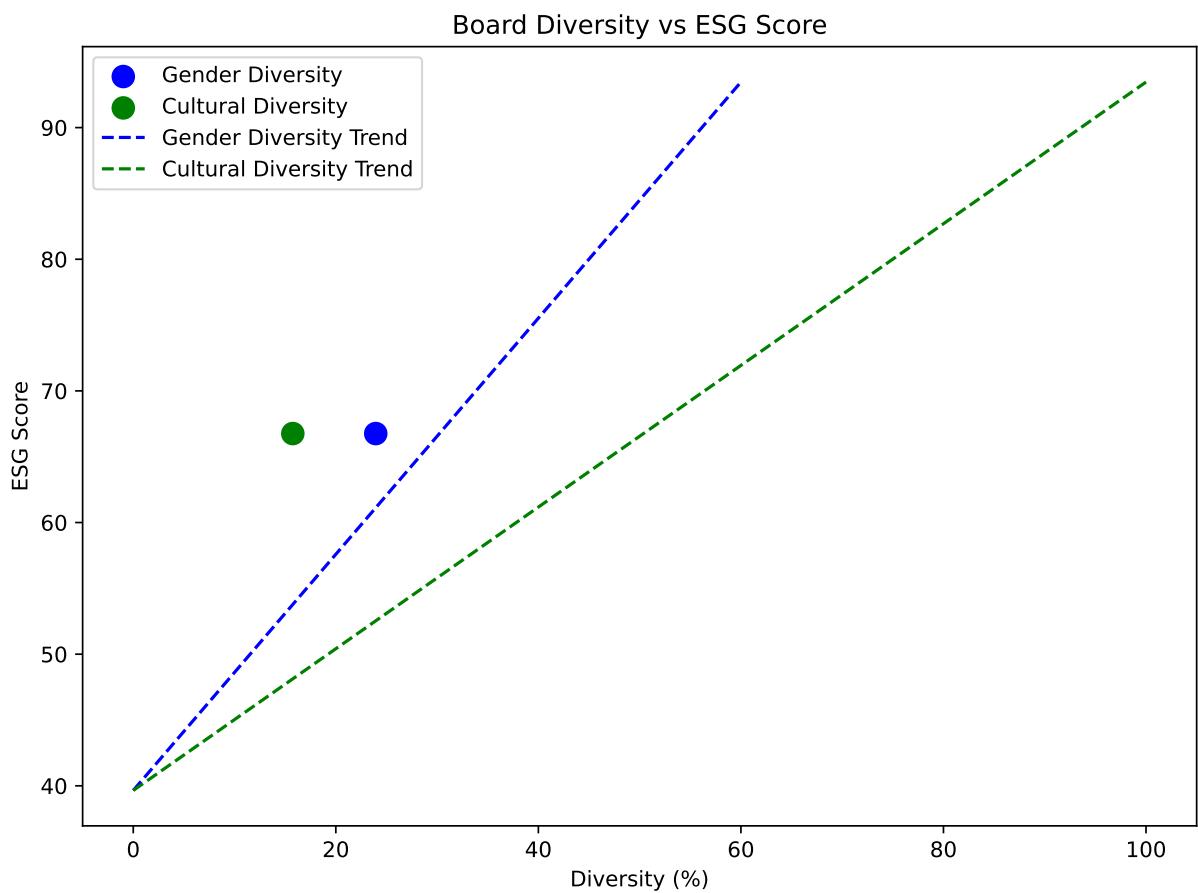
In the U.S. and European banking sector (Dicuonzo et al., 2024) performed an analysis of 1551 banks, of which only 180 banks disclosed sufficient ESG data for comparison, building an *Fintech Adoption Index*; the key findings included a positive correlation between Fintech Index and ESG Scores, suggesting the adoption of technology has a statistically significant influence on better environmental stewardship, social and governance quality. Even larger predictors of high ESG score were than were Board Gender Diversity (Women on Board), the Size of the Bank, and Board Independence (governance structures with more independent directors could be more socially and environmentally responsible).

The ability to build sustainability into the organization requires deep understanding of how the complex structure works and what drives change and innovation within business units. (Jim Boehm et al., 2021) distilled key strategies from the banking sector to speed up digital transformation, while improving risk management and compliance (see table below).

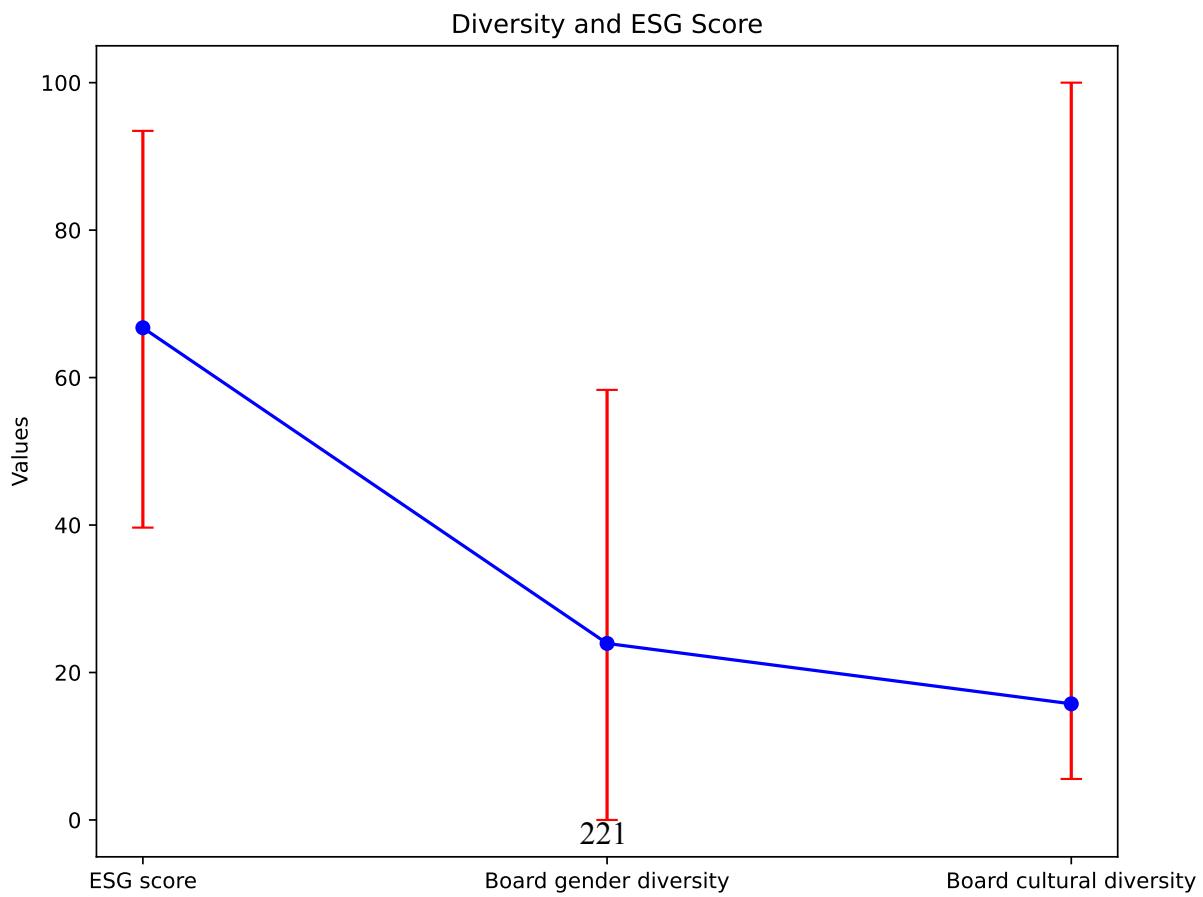
Table 71: Banking transformation strategies from (Jim Boehm et al., 2021)

Strategy	Description
Enterprise-level Risk Taxonomy	A unified classification system that defines and categorizes all risk types across the entire organization.
Embedded Controls in Agile Delivery	Risk-and-compliance integration directly into agile development sprints (a type of management style in building software) to catch issues as code is written.
Cross-functional Risk–Business Collaboration	Joint ownership of risk by compliance teams and business units, ensuring controls are practical and business-aligned.
Metrics-driven Monitoring	Continuous tracking of key risk indicators through quantifiable metrics to spot trends and trigger alerts.
Proactive Remediation	Early detection and rapid resolution of control defects before they escalate into larger compliance or security gaps.
Continuous Capability Building	Ongoing training and tooling updates; best-practice sharing to keep risk-management skills and processes current.

These banking transformation strategies sit alongside strict regulatory requirements, such as Know Your Customer (KYC), and emerging technologies like generative AI, which is already reshaping compliance workflows. (Rahul Agarwal et al., 2024) details how genAI is being used for the purposes of compliance and *comprehensive risk assessment* in modern banking.



(a) Simplified comparison chart for board diversity (gender and cultural) vs ESG score



(b)

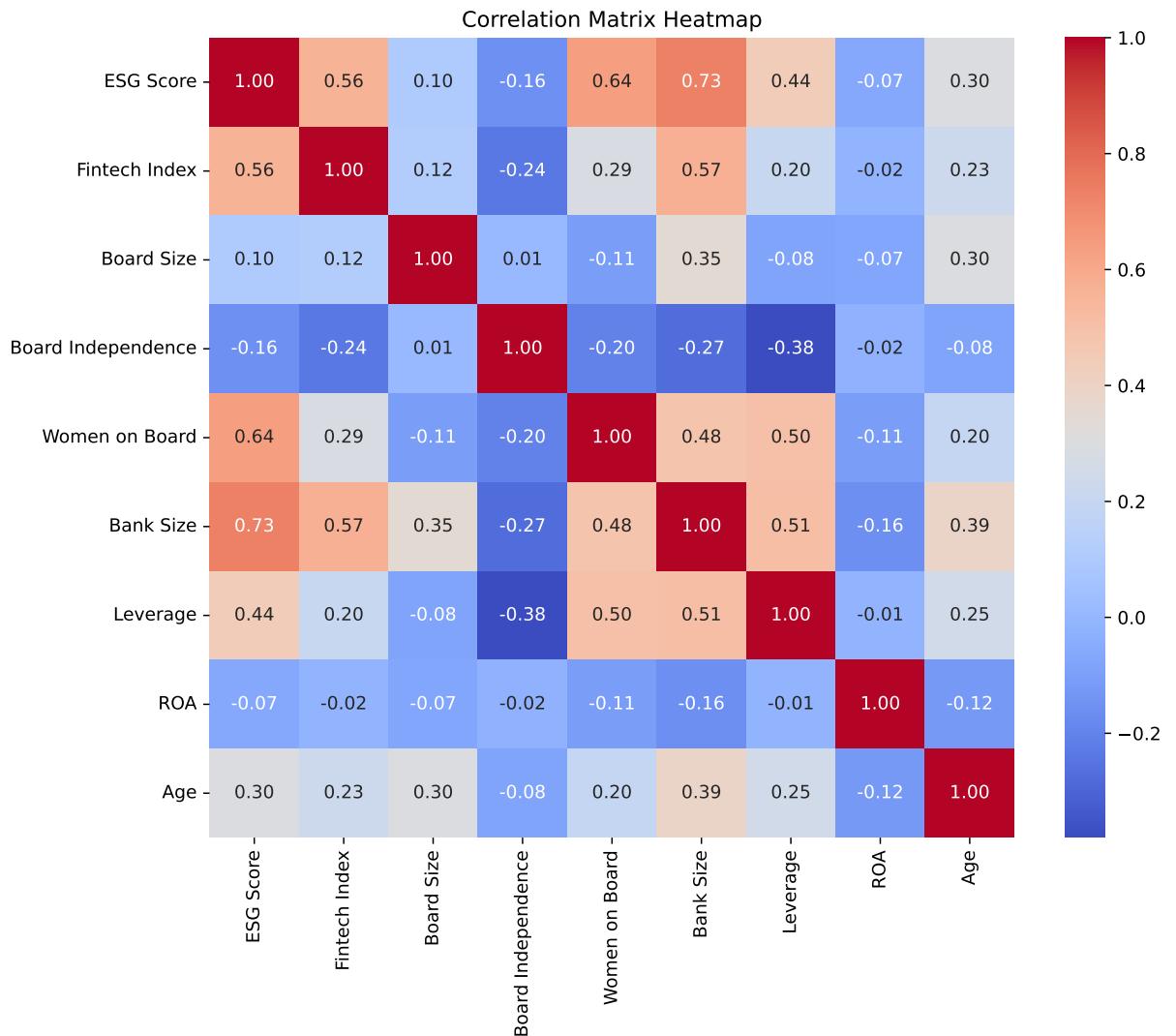


Figure 76: Fintech Adoption Predicts Higher ESG

Table 72: GenAI usage for comprehensive risk management from cyber- to climate threats in modern banking as per (Rahul Agarwal et al., 2024).

GenAI Use Case	Description
Regulatory Compliance	Automate policy-document triage: draft regulatory-change summaries and flag emerging rules, then generate compliance manuals.
Financial Crime	Generate suspicious-activity reports; streamline AML/KYC checks; identify anomalous transaction patterns.
Credit Risk	Synthesizing credit-risk reports on demand by pulling together relevant financial data from a variety of sources, resulting in faster borrower risk assessments.
Analytics and Modeling	Build and validate risk models; run scenario analysis; summarize complex data sets for insights.
Cyber Risk	Monitor threat-intelligence feeds; draft incident-response reports; automatically search for, and possibly even patch security gaps.
Climate Risk	Distill lengthy climate-scenario reports; visualize key metrics; accelerate enterprise-level climate-risk assessments.

In the context of China’s industrial modernization, (Lu & Li, 2023) finds that *digitization* is the pathway to increased Environmental Information Disclosure (EID) and Green Innovation, correlating with increased numbers of green patents and sustainable R&D projects.

While ESG is riddled with problems, it has started a *common language* - the advice consultancies are providing to banks make use this common language to helps banks to sell strategical alignment for long-term institutional sustainability in terms of environmental, social, and governance performance. PWC suggests “*asset managers educate their staff and client base. It will be critical to build stronger ESG expertise among their employees by up-skilling existing staff on ESG principles and strategically scout for and integrate more diverse and ESG-trained talent*” (PWC, 2020).

In general, a futures contract is an agreement to buy or sell a market index at a fixed price on a set date, locking in today’s price for the future. The exchange’s clearinghouse guarantees the trade, so one doesn’t have to worry about the other side not honoring the deal. ESG futures specifically, are financial derivatives, standardized contracts, which allow investors to hedge or speculate on the future performance of ESG-compliant investments. Some ESG futures contracts include the E-mini S&P 500 ESG futures (on the Chicago Mercantile Exchange, a large derivatives exchange), which track the U.S. S&P 500, while skipping companies with poor ESG scores, letting one bet on or hedge “sustainable” American companies with large market capitalization; notably, the index has recently been renamed to S&P 500 Scored & Screened Index, without a specific mention of the acronym ESG, while keeping the methodology unchanged, presumably for marketing purposes in the changing political landscape (CME Group, 2025). In Europe, the STOXX Europe 600 ESG-X futures (on the Eurex stock market) let one trade Europe’s top ESG-screened companies, with cash settlement and the same margin rules as regular (non-ESG) index futures (Deutsche Börse Group, 2025; Harding, 2019). Globally, the MSCI Sustainability

and Climate Change futures (on the Intercontinental Exchange) cover global and regional ESG benchmarks, allowing one to take a position on low-carbon or Paris Climate Agreement-aligned stock indices anywhere in the world (Intercontinental Exchange, 2025). The CFI2Z4 Carbon Emissions Futures tool tracks live coverage of ICE EU Allowance futures priced in EUR per tonne, with real-time quotes as well as historical charts, enabling traders to monitor and analyze the compliance-phase carbon market (Investing.com, 2024). Specifically in Taiwan, the FTSE4Good TIP Taiwan ESG futures (on TAIFEX, Taiwan Futures Exchange), launched in June 2020 to follow a basket of Taiwanese stocks that meet global ESG standards (TAIFEX, 2025).

11.2.7 ESG Accessibility: Curbing Corruption with Realtime Data Streams and Product Lifecycle Traceability

For AI-powered assistants to be able to provide guidance, metrics are needed to evaluate sustainable assets, and ESG provides the current state-of-the-art for this. The largest obstacle to eco-friendly investing is greenwashing where companies and governments try to portray an asset as green when in reality it's not. A personal investing assistant can provide an interface to focus on transparency, highlighting data sources and limitations, to help users feel in control of their investment decisions, and potentially even provide large-scale consumer feedback on negative practices.

However, fundamentally, unless there is significant headway in curbing greenwashing, companies today use ESG as a marketing tool - but it could achieve much more. One of the key emerging issues is that ESG is an annual report not real-time, actionable data. (Sahota, 2021) argues that “[T]hanks to other emerging technology like IoT sensors (to collect ESG data) and blockchain (to track transactions), we have the infrastructure to collect more data, particularly for machine consumption. By measuring real-time energy usage, transportation routes, manufacturing waste, and so forth, we have more quantifiable ways to track corporations' environmental performance without relying purely on what they say.”

For corporations to respond to the climate crisis, they are expected to become more digital and data-driven. Requirements for ESG compliance has given rise to a plethora of new monitoring tools. There's a growing number of companies helping businesses to measure CO₂eq emissions in through their entire product lifecycle. In order to improve product *provenance*, blockchains offer transparency. Several enterprise blockchain offerings from vendors such as Hyperledger Fabric and ConsenSys use immutable supply - chain ledgers to record origin, certifications, and product movements end - to - end (“Blockchain Companies Team Up To Track ESG Data,” 2021). Blockchain's immutable data and programmable incentives enable transparent ESG tracking, secure carbon - credit registries and tokenized rewards that align corporate behavior with climate goals (Ganu, 2021). Sourcingmap's *supply chain mapping* platform provides tooling to *know your suppliers' suppliers*, monitoring every tier of company supply chains, continuously collecting and checking the integrity of supplier data, using 3-party registries and watchlists, real-time transaction traceability, creating an audit trail for instantly detecting fraud or non-compliance with effective regulations and due-diligence laws (Sourcingmap, 2025). The

founder of Sourcemap, Leonardo Bonanni, started out with doing product autopsy in 2015 to assess product sustainability (« *Fast fashion* », 2023).

(Ratkovic, 2023; Tim Nicolle, 2021) believe that real-time ESG data is more difficult to green-wash, because the supply chain data is a significant source of ESG content; a fundamental breakthrough would be surfacing real-time ESG data directly to individual consumers browsing products - be it in physical shops or online, - allowing customers to judge if they want to purchase from this business. (*Real Time ESG Tracking From StockSnips*, 2021) built a tool - called Stocksnips - to turn unstructured news into daily ESG sentiment signals, starting with about 1000 companies; the sentiment signal show significant correlation with expert ratings, offering an automated forward-looking gauge of corporate ESG performance. Likewise, LSEG's MarketPsych ESG Analytics platform mines global news and social feeds for near - real - time controversy alerts and ESG risk - scores with historical data going back to 1998 (LSEG, 2025). Envify aims to automate compliance with the Corporate Sustainability Reporting Directive (CSRD), by providing a suite of carbon accounting tools (Rajan, 2025). Flowit Estonia automated real - time CO₂eq accounting in 2022 by combining invoices and sensor data to generating instant per - transaction emission footprints (Indrek Kald, 2022). A startup called Makersite proposes instant sustainability impact from supply chain, deep supply-chain data can surface product-level environmental footprints in minutes instead of months, which they call “*Product Lifecycle Intelligence*” (Kyle Wiggers, 2022). More recently, Makersite has updated the language they use for promoting their product, now calling it *Product Sustainability Modeling* (Makersite, n.d.). Apart from product level analytics, there’s sustainability data on source raw materials. CarbonChain rolled out asset-level emissions ratings for individual mines: covering metals including steel, aluminium, nickel, and copper - so product developers can benchmark material sources’ carbon intensity against industry averages (CarbonChain, n.d.).

11.3 Payments

11.3.1 Consumer Activists are a Small Minority

Recognition precedes protection, as the Estonian slogan goes: “*Õpetame märkama, et oskaksime hoida*” / “*Learn to notice so we can preserve.*” (Tartu loodusmaja, 2019). (Milne et al., 2020) coins the term *mindful consumers*, who do research and are aware of the impact of their shopping choices. Yet these types of *mindful consumers* and *conscious consumers* only make up a small percentage of the entire consumer public, which may make individual action seem close to meaningless.

For consumer activism to become mainstream it needs to much simpler. Sustainable options must become effortless: we need one-click tools that turn everyday spending into votes for circular design, transparent supply chains and mandatory climate disclosures. By setting clear CO₂-reduction targets for products, embedding dynamic ESG-risk pricing at point of sale, and harnessing our collective purchasing power, we can push companies to embed sustainability at the core of business, transforming vague ESG ideals into tangible market incentives.

There is plenty of research on if and how sustainable shopping could be possible. Already in 2016, (Klinglmayr et al., 2016) proposed a mobile app to channel “political consumerism” into sustainable shopping through self-regulation: personalized recommendations could be provided by aggregating vast product datasets into distilled advice, empowering individuals follow clear sustainable-shopping rules, discover like-minded peers, and communicate concerns directly to retailers, in theory turning vague ESG ideals into a transparent, data-driven, community-backed approach to sustainable consumption - however the Horizon 2020-funded was only deployed in 2 supermarkets (Estonia and Spain) as a pilot project. In order to understand the needed changes to shopping, (Fuentes et al., 2019) employed a shopping-as-practice ethnography in a Swedish zero-waste grocery store to show that removing packaging requires reinventing the shopping practice itself, e.g. introducing reusable containers, new retail setups, and consumer routines. (Weber, 2021) proposed a sustainable shopping guide in a study which demonstrates that embedding eco-score rankings into a mobile shopping app significantly increases consumers’ selection of low-impact food products by improving decision support and reducing information overload. Consumer psychology is complex and (van der Wal et al., 2016) discusses how status motives make people publicly display sustainable behavior, revealing that shoppers purchase branded reusable bags rather than bring their own, exposing a “paradox of green to be seen” and its hidden environmental costs.

Sustainable consumption relationships in Europe.

Make use of indexes to compare companies.

11.3.2 Shopping’s Environmental Footprint: Increasingly Driven by Digital Platforms, Social Commerce, AI Assistants

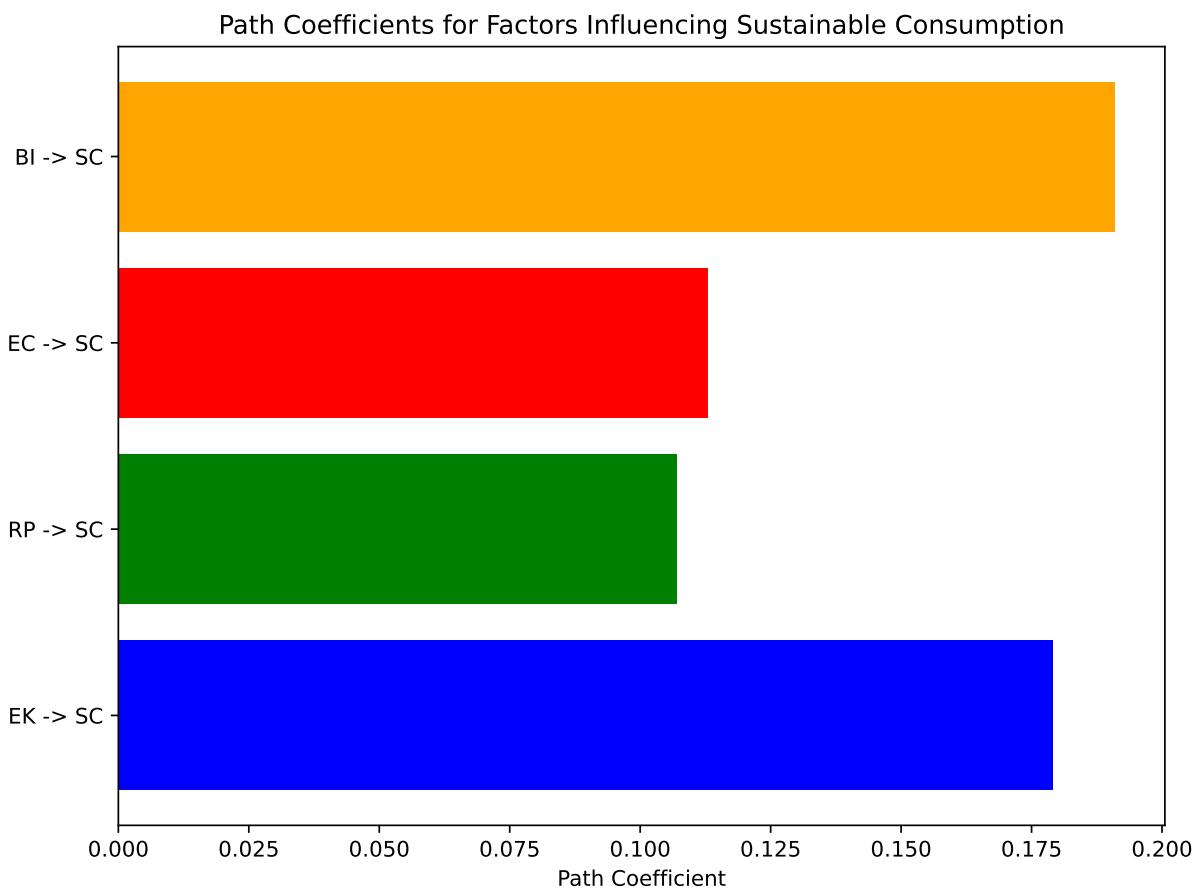
It may seem impossible to turn the tide of consumerism, given the projected growth in online shopping, Single’s day, etc (Forrester, 2024). However, importantly - more and more consumers are using AI assistants to find alternative products, make shopping lists, which may have an effect on *what type* of products are bought (Neuron, 2025; Pandya, 2025; Pastore, 2025)

Double Eleven 11/11 celebrated on November 11 is the world’s largest shopping festival (時代財經, 2023). In June 2023, 526 million people watch e-commerce live-streams in China; online bargaining is a type of ritual (Shiyu Liu et al., 2024). According to (Igini, 2024b) “*Asia is set to account for 50% of the world’s total online retail sales*”. (The Influencer Factory, 2021) China is the furthest ahead in *social shopping*, the Chinese and U.S. market may be mature and growth will come from emerging markets (SEA, Latin-America).

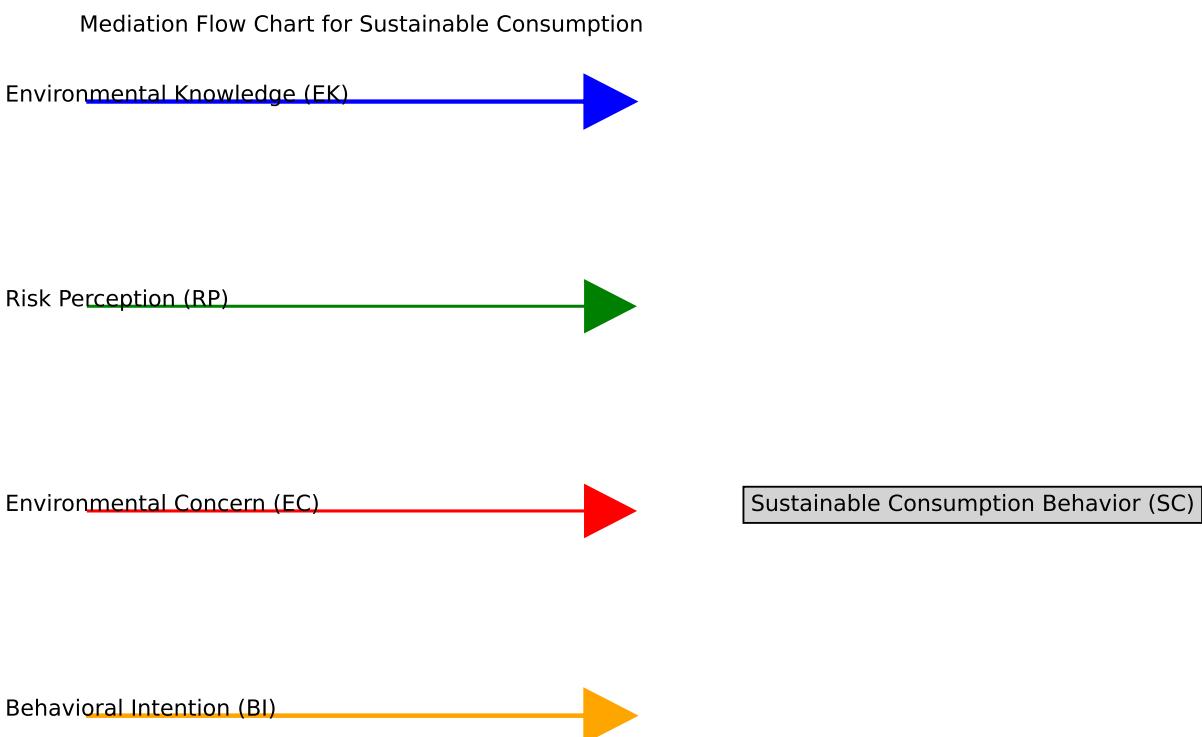
In the US, TikTok is the leader in social commerce (Loyst, 2024).

11.3.3 The Evolution of Payments: The Entry Point for Personal Finance from Mobile Wallets to Buy Now Pay Later (BNPL) Services - Globally, and In Taiwan

Payments is one way consumers can take individual climate action. In the words of a Canadian investment blogger, “*every dollar you spend or invest is a vote for the companies and their*



(a) Sustainable Consumption



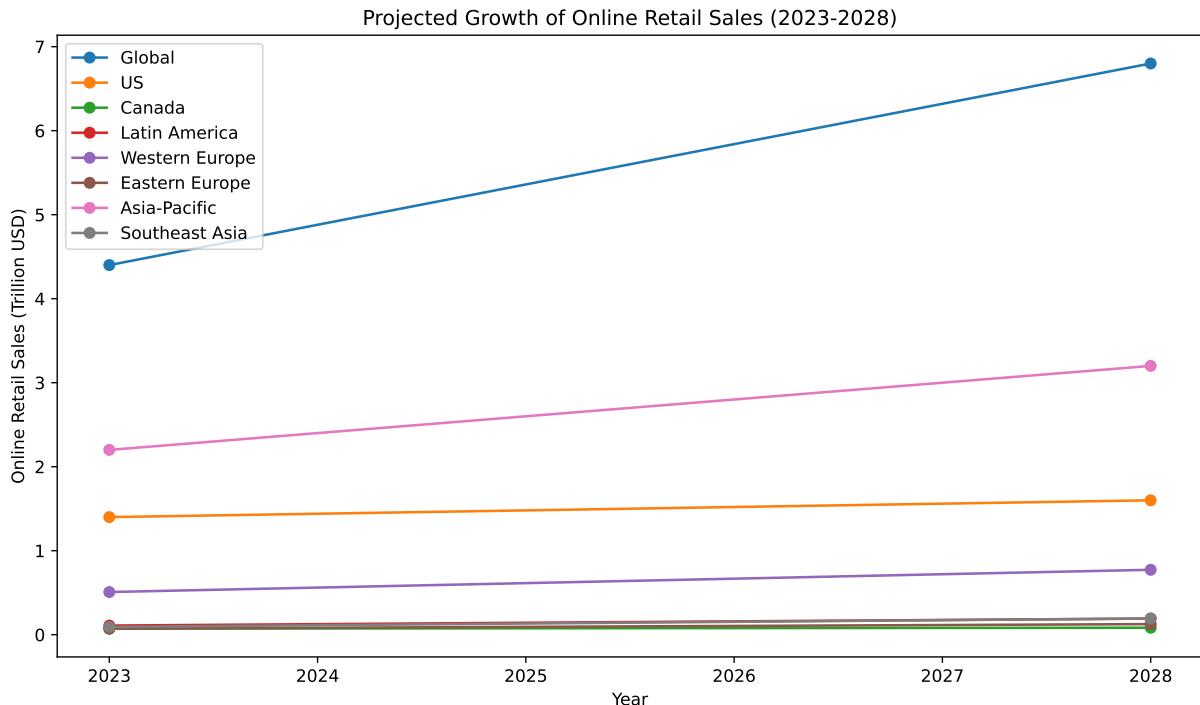


Figure 78: Growth of Consumerism

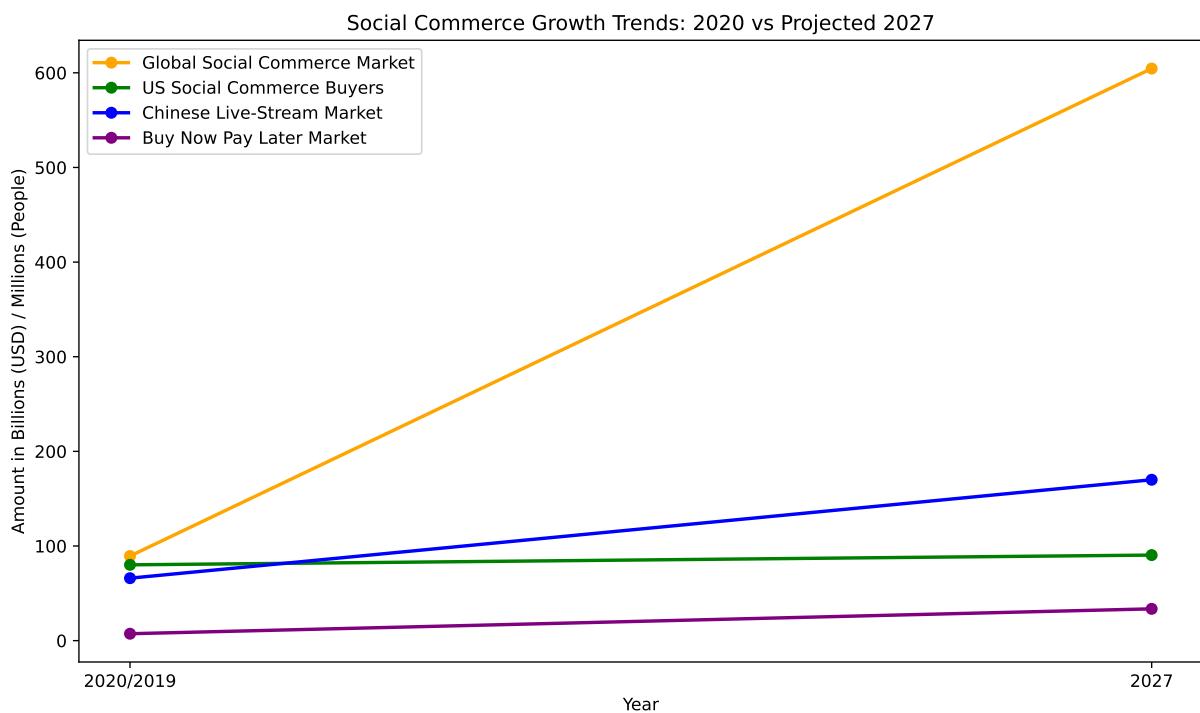


Figure 79: Social Commerce

ethical and sustainability practices" (Fotheringham, 2017). The combination of consumption and investment is an access point to get the consumer thinking about investing. Even if the amount are small, they are a starting point for a thought process.

Table 73: Comparing Payments Apps; Data compiled from (Focus Taiwan, 2025; PXPay Plus, n.d.; Taiwan News, Mar. 14, 2025 11:31)

Payment App	Features	Users in Taiwan	Origin
LINE Pay	Most popular payment app accepted all over Taiwan. Works stand-alone and inside the LINE messenger. Supports both in-store and online shopping payments, also direct P2P transfers to contacts (requires LINE Bank). Displays a map of its merchant network with discounts and coupons; integrates iPASS MONEY.	> 12 Million	Japan / Korea
JKOPay (街口支付)	QR code payments and P2P transfers to contacts; paying for bills.	> 7 Million	Taiwan
Taiwan Pay (台灣Pay)	Official Taiwanese Government app in collaboration with Taiwanese banks. Supports payments directly from bank accounts (without the need for a card). Supports QR code payments, P2P transfers to contacts and paying bills. A unique feature is cash withdrawal from ATMs without the need for a bank card.	> 6 Million	Taiwan
Apple Pay	Requires an Apple iOS device; uses credit/debit cards via NFC, Secure, In-app & web payments	?	USA
Google Pay	Supports NFC and credit/debit cards, in-app and online payments as well as public transport.	?	USA

Payment App	Features	Users in Taiwan	Origin
iPASS MONEY (一卡通 MONEY)	Digital version of the iPASS card which can be used for QR code payments, P2P transfers to contacts, paying bills and public transport.	?	Taiwan
E.Sun Wallet (玉山 Wallet)	Requires the Taiwanese E.Sun Bank and allows QR payments, P2P transfers to contacts and paying bills as well as financial management tools.	?	Taiwan
Pi Wallet (Pi 拍 錢包)	Payment app by the PChome online shop supporting in-store QR and online payments, and paying for bills a parking.	?	Taiwan
PXPay (全聯福利 中心)	Payment app by PX Mart, the largest domestic Taiwanese supermarket chain, supporting QR code payments, offering rewards and discounts and loyalty plans. Recently expanded to Korea quoting the interest of Taiwanese young people in Korean culture. In early 2025, PXPay began offering a saving and investing service called “Digital Hen” in collaboration with J.P Morgan Asset Management. According to the press release, the service aims to be a beginner-friendly financial innovation helping shoppers get into micro-investing.	?	Taiwan
Hami Pay (中華 電信)	Payment app by the largest phone company Chunghwa Telecom supporting NFC payments, public transport, and paying bills.	?	Taiwan

Payment App	Features	Users in Taiwan	Origin
Samsung Pay (悠遊卡)	Requires a Samsung device; uses NFC; integrates EasyCard and credit/debit cards; supports public transport.	?	Korea

Banks and fintechs both are skilled at capturing user data and digital payments are an important entry point for financial services and a source of consumer action data, shopping data. Payments is the primary way consumers use money. Is there a funnel From Payments to Investing? ESG Shopping is about Changing our relationship with money. Make commerce more transparent. Current shopping is quite superficial. One barely knows the name of the company. You don't know much about their background. Building consumer feeling of ownership, create meaningful connections between producers and consumers.

Digitalisation of payments creates lots of Point of Sale (PoS) data that's valuable to understand what people buy. Banks have access to each person's financial habits which makes it possible to model sustainable behavior using big data analysis. Asian markets have shown the fastest growth in the use of digital payments (McKinsey, 2020). In Macao, contactless payments are becoming the most prevalent form of value exchange, growing rapidly, up 40% from the prior year ("Contactless Payments Prevalent in Macau - City's de Facto Central Bank," 2023). In Europe, fintech is also one of the fastest-growing sectors, with 35% of the fintech ecosystem is made up by giants like Klarna, Checkout.com and Revolut and 65% belonging to new-comers; in general describe equally strong consumer uptake and friendly regulators (*The European Fintechs to Watch in 2022*, 2022). With the increasing number of financial services available, open banking initiatives, which set standards for financial data sharing, have the potential to improve the user experience by allowing people to access their data across all the different banking apps they use, seamlessly and securely, which improves the flow of the entire customer journey.

(Green Finance Platform, 2020) report predicts the rise of personalizing sustainable finance, because of its potential to grow customer loyalty, through improving the user experience. Similarly to good design, interacting with sustainable finance for the 'green-minded' demographics, providing a reliable green product is a way to build customer loyalty. The UN has been handing out Global Climate Action Awards since 2011 for idea such as the Climate Credit Card in Switzerland, which automatically tracks emissions of purchases, creates emissions' reports for the user which can then be offset with investments in climate projects around the world (UNFCCC, 2023a).

Sustainability data is an important part of the customer journey which digitalisation and digital transformation make increasingly accessible. Digital receipts are one data source for tracking one's carbon footprint. In Taiwan, O Bank makes use of Mastercard's data to calculate each transaction's CO₂ emissions and offer Taiwanese clients "*Consumer Spending Carbon Calculator*" and "*Low-Carbon Lifestyle Debit Card*" products (*Taiwan's O-Bank Launches 'Consumer Spending Carbon Calculator,' Rewards Carbon Reduction*, 2022). This is based on technology

by Mastercard, which has developed a white-label service for sustainability reports that banks can in turn offer to their clients (Mastercard, 2021). Similarly, Commons, formerly known as Joro, an independent app, analyses one's personal financial data to estimate their CO₂ footprint (Chant, 2022). ReceiptHero's digital-receipt platform records the CO₂eq footprint for each purchase, turning every transaction into a data point for tracking individual emissions, promoting eco-awareness (*Digital Receipts and Customer Loyalty in One Platform | ReceiptHero*, n.d.). Another example is the Dutch fintech company Bunq offers payment cards for sustainability, provided by MasterCard, which connects everyday payments to green projects, such as planting trees and donations to charities within the same user interface (Bunq, 2020). However, arguably this could be considered greenwashing as Bunq only plants 1 tree per every € 1,000 spend with a Bunq card. The example marketed at students cites *8 trees planted this month* while students scarcely would have € 8,000 to spend every month.

Sharing a similar goal to Alibaba's Ant Forest, Bunq's approach creates a new interaction dynamic in a familiar context (card payments), enabling customers to effortlessly contribute to sustainability. However, it lacks the level of gamification which makes Alibaba's offering so addictive, while also not differentiating between the types of purchases the consumer makes, in terms of the level of eco-friendliness.



Figure 80: Bunq promises to combine banking and eco-friendly actions in the same user interface - yet is this greenwashing?

In Nigeria, (Emele Onu & Anthony Osae-Brown, 2022) reports how in order to promote the eNaira digital currency use, the Nigerian government limited the amount of cash that can be withdrawn from ATMs. *"In Nigeria's largely informal economy, cash outside banks represents 85% of currency in circulation and almost 40 million adults are without a bank account."* [E-Naira find papers]

In Kenya, M-Pesa started since 2007 for mobile payments, used by more than 80% of farmers (Parlasca et al., 2022; Tyce, 2020). Using digital payments instead of cash enables a new class of experiences, in terms of personalization, and potentially, for sustainability. Buy Now Pay Later (BNPL) is the biggest consumer payments / financing success story innovated by Klarna in Sweden in 2005 and Afterpay in Australia in 2015 but with roots in Layaway Programs created during the 1930's US Great Depression (Kenton, 2023). By 2021, 44.1% of Gen-Z in the US had used BNPL according to (EMarketer, 2021). Users in the Gen-Z demographic mostly use BNPL to buy clothes (LHV, 2024).

People will be more likely to save and invest if it's easy. In Sweden, point of sales (PoS) lending (BNPL, as introduced above) is a common practice, and one of the reasons for the success of Klarna, the Swedish banking startup, which has managed to lend money to more consumers than ever, through this improved user experience. Taking out loans for consumption is a questionable personal financial strategy at best. Yet, if people can loan money at the point of sales, why couldn't there be 180 degrees opposite service - point of sales investing? And there is, called "round-up apps". (Next Generation Customer Experience, n.d.) suggests "*Targeted at millennials, Acorns is the investing app that rounds up purchases to the nearest dollar and invests the difference.*" - and example of From Shopping to Investing. Likewise, many banks have started offering a service to automatically save and invest tiny amounts of money collected from shopping expenses. Every purchase one makes contributes a small percentage - usually rounded up to the nearest whole number - to one's investment accounts. For example, (Swedbank, 2022), the leading bank in the Estonian market, offers a savings service where everyday payments made with one's debit card are rounded up to the next Euro, and this amount is transferred to a separate savings account. Similarly, the Estonian bank (LHV, 2020) offers micro-investing and micro-savings services, with an interesting user experience innovation showing how for an average Estonian means additional savings of about 400 € per year. User experience innovation can improve accessibility and financial inclusion, while opening up a new market which used to be underserved. For example, (Y Combinator, 2023) launched a bank inside of Whatsapp for the underbanked gig workers in Latin America.

While the financial industry is highly digitized, plenty of banks are still paper-oriented, running digital and offline processes simultaneously, making them slower and less competitive, than startups. Indeed, the new baseline for customer-facing finance is set by fintech, taking cues from the successful mobile apps in a variety of sectors, foregoing physical offices, and focusing on offering the best possible online experience for a specific financial service, such as payments.

Traditional banks and fintechs are becoming more similar than ever. 39% of Millennials are willing to leave their bank for a better fintech (n = 4282); innovation in payments helps retention (PYMNTS, 2023). The European Central Bank describes fintech as improving the user experience across the board, making interactions more convenient, user-friendly, cheaper, and faster. "Fintech has had a more pronounced impact in the payments market [...] where the incumbents have accumulated the most glaring shortcomings, often resulting in inefficient and overpriced products," Yves Mersch, Member of the Executive Board of the ECB says in European Central Bank (2019).

There are also people who are concerned with digital payments. There are concerns digital cur-

rencies also help to “*democratize financial surveillance*”. China was a money innovator introducing paper money in the Tang Dynasty (618-907 AD) (“First Paper Money,” n.d.). Jeff Benson (2022) is troubled by the “use the e-CNY network to increase financial surveillance” (“Central Bank Digital Currency (CBDC) Tracker,” 2023) believes digital currencies make tracking easier. Economist Eswar Prasad argues that the era of “private” cryptocurrencies is coming to an end down as they’ll be supplanted by government-backed central bank-issued digital currencies that marry blockchain’s efficiency with legal oversight (MARISA ADÁN GIL, 2022). The same author compares WeChat, Alipay vs the digital yuan (Yahoo Finance, 2022).

There are many *neobanks*, or challenger banks, far too many to list. The table only includes a small sample of banks and the landscape is even larger if one includes the wider array of fintechs. Neo-banks often use sustainability marketing. Legendary investor Warren Buffett’s company Berkshire Hathaway invested \$1 Billion USD in Nubank, Brazilian digital challenger Bank, while reducing its stakes in Mastercard and Visa, signaling growing faith in digital banking platforms over traditional card-issuers (Andrés Engler, 2022).

The following popular (totaling millions of users) robo-advisory apps combine sustainability, personalization, ethics, and investing however, they are mostly only available on the U.S. market.

Table 74: Comparing Investing Apps; Data compiled from (Lightyear, n.d.; Monzo, 2023; “Mos - The Money App for Students,” n.d.; *Nubank - Finalmente Você No Controle Do Seu Dinheiro*, n.d.; *Selma – Your Finances Done Right*, n.d.; “Ziglu | The Fast, Simple Way to Buy and Sell Crypto, with No Hidden Fees.” n.d.).

Service	Features	Availability
Goodments	Matching investment vehicles to user's environmental, social, ethical values	USA
Wealthsimple	AI-assisted saving & investing for Millennials	USA, UK
Ellevest	AI-assisted robo-advisory focused on female investors and women-led business	USA
Betterment	AI-assisted cash management, savings, retirement, and investing	USA
Earthfolio	AI-assisted socially responsible investing	USA
Acorns	AI-assisted micro-investing	USA
Trine	Loans to eco-projects	USA
Single.Earth	Nature-back cryptocurrency	Global
Grünfin	Invest in funds	EU
M1 Finance	Finance Super App	US
Finimize	Investment research for anyone	US
NerdWallet	Financial clarity all in one place	US
Tomorrow Bank	Green Banking	EU
Marcus Invest	Robo-Advisor	US
Chipper	Digital cash app for African markets	Africa

Lightyear	Simple UI for Stocks, ETFs, interest from Estonia	EU
Ziglu	UK simple investing app	UK
Selma	Finnish investing app	EU
Monzo	Bank	UK
Nubank	Bank	Brazil
EToro	Investing and copy-investing	EU
Revolut	From payments to investing	UK, EU
Mos	Banking for students	US
Robinhood	Investing	US
Mintos	Buy bonds and loans	EU

Becoming a major payments player requires navigating the maze of global directives, including legislation regarding finance, privacy, data protection, money laundering, localized licensing regimes, and more. For an example, Google Wallet's privacy notice sheds some light on how a unified payments profile links services under one's Google account while following its broader data - use policies (Google, 2025).

Alipay is by far the largest payments super-app and provides two investment services within it's payments platform, first launching Yu'e Bao (餘額寶) in 2013, which automatically invests small amounts on the users' accounts for returns typically above those of traditional banks' saving accounts, and later in 2015 Ant Fortune (螞蟻財富), offering access to thousands of investment products from partner companies (KraneShares, 2020). Alibaba owns over 30% of Alipay and both companies are pushing for increased use of AI within their services ("Chinese Billionaire Jack Ma Sees AI Future for Ant Group, in Rare Appearance," 2024).

Similary, both Line, through it's Line Pay, Line Securities, and Line Bank, and Naver, though Naver Pay, have been on a path for several years evolving into comprehensive financial platforms (Anna J. Park, 2023; LINE Corporation, 2019). None of these payment apps have a specific focus on sustainability while Alipay does have a separate sustainability-focused service called Ant Forest for planting trees. Payment apps created by Apple and Google are less-feature rich focusing on payments only, and are being challenged by new-comers. An Australian fintech Douugh released it's robo-advisor in 2024 (Paul, 2024). Douugh's tagline explain the ethos of a unified financial app simply: "*One app to spend and grow your money*". The newest generation of robo-advisors are integrating large-language modules, for example Reuters highlights the Chinese brokerage firm Tiger Brokers as one among 20 Chinese companies integrating DeepSeek deeply into asset management from simple chat functionality all the way to executing trades.

Established Consumer Payment Giants

Table 75: Established consumer payment giants, none of which has a specific sustainability focus.

Service	Features	Users	Investing	Savings	Shopping (Payments)
Alipay	Payments, banking, Yu'e Bao, Ant Fortune investing	1.3 billion	Yes	Yes	Yes
WeChat Pay	Payments, financial services, Licaitong investing	900 million	Yes	No	Yes
Apple Pay	Contactless payments	744 million	No	No	Yes
PhonePe	Payments, mutual funds, digital gold	590 million	Yes	Yes	Yes
Paytm	Payments, banking, Paytm Money for stock & fund investing	350 million	Yes	Yes	Yes
Google Pay	Payments, loyalty, transit	150 million	No	No	Yes
Samsung Pay	Mobile payments	?	No	No	Yes
Zelle	Bank-to-bank P2P payments	?	No	Yes	Yes
Nubank	Full features of a traditional bank in a digital form	?	No	Yes	Yes

Growth Companies

For human psychology, the fact that money on a Wise account will accrue value while on Monese

it's just static, immediately makes Wise more attractive, even if the amounts are small.

Table 76: Growth companies in fintech, none has a sustainability focus.

Service	Features	Availability	User Base	Investing	Savings	Shopping (Payments)
Venmo	P2P payments, crypto investing	USA	70 million	Yes	No	Yes
Cash App	P2P payments, stock & Bitcoin investing	USA, UK	57 million	Yes	No	Yes
Chime	Online banking services including spending accounts, savings accounts	USA	22 million	No	Yes	Yes
MoneyLion	Banking, investing, credit-building loans, financial tracking tools	USA	20 million	Yes	Yes	Yes
NerdWallet	Financial clarity all in one place	USA	19 million	No	No	Yes
SoFi	Loans, banking, robo-investing, stock & crypto	USA	10 million	Yes	Yes	Yes

Service	Features	Availabil- ity	User Base	Investing	Savings	Shopping (Payments)
Albert	Budgeting, saving, spending, investing, access to financial advisors	USA	10 million	Yes	Yes	No
Acorns	AI-assisted micro- investing	USA	5.7 million	Yes	No	No
Wealth- simple	AI-assisted saving & investing for Millennials	Canada, USA, UK	2.6 million	Yes	Yes	No
Qapital	Saving and investing with gami- fication features	USA	2 million	Yes	Yes	No
M1 Finance	Finance Super App	USA	1 million	Yes	No	No
Finimize	Investment research for anyone	Global	1 million	Yes	No	No
Robinhood	Investing	US	?	Yes	No	No
Betterment	AI-assisted cash man- agement, savings, retirement, and investing	USA	?	Yes	Yes	No
Revolut	From payments to investing	UK, EU	?	Yes	No	TRUE
Monzo	Bank	UK	?	No	Yes	No
eToro	Investing and copy- investing	EU	?	Yes	No	No

Service	Features	Availabil- ity	User Base	Investing	Savings	Shopping (Payments)
Marcus Invest	Robo- Advisor	USA	?	Yes	No	No
Varo Bank	Online banking services including checking and high-yield savings	USA	?	No	Yes	Yes
Stash	Micro- investing platform enabling small in- vestments	USA	?	Yes	No	No
Mint (Ceased operations)	Budgeting tools, bill tracking, free credit score monitoring	USA	?	No	No	No

Up-and-Coming Startups

Table 77: Among up-and-coming startups there are some examples of sustainability-focused apps.

Service	Features	Avail- ability	User Base	Investing	Savings	Shopping (Pay- ments)	Sustain- ability Focus
Chipper Cash	Digital cash app for African markets	Ghana, Nigeria, Uganda, USA	?	No	No	Yes	No

Service	Features	Avail-ability	User Base	Investing	Savings	Shopping (Pay-ments)	Sustain-ability Focus
Douugh (Merged with Good-ments)	AI financial wellness app, smart account, saving tools	USA, Australia	?	Yes	Yes	Yes	No
DUB	Copy-trading, mirror trades of notable figures	USA	1 million down-loads	Yes	No	No	No
Earthfo-lio	AI-assisted socially responsi-ble investing	USA	?	Yes	No	No	Yes
Ellevest	AI-assisted robo-advisory focused on female investors and women-led business	USA	?	Yes	No	No	No

Service	Features	Avail-ability	User Base	Investing	Savings	Shopping (Pay-ments)	Sustain-ability Focus
Good-ments (Merged with Douugh)	Matching investment vehicles to user's environmental, social, ethical values	USA	?	Yes	No	No	Yes
Grünfin (Ceased operations)	Invest in funds	EU	?	Yes	Yes	No	No
Lightyear	Simple UI for Stocks, ETFs, interest from Estonia	EU	?	Yes	No	No	No
Mintos	Buy bonds and loans	EU	?	Yes	No	No	No
Mos	Banking for students	US	?	No	Yes	Yes	No
Selma	Finnish investing app	EU	?	Yes	No	No	No
Single.Earth	Nature-backed crypto-currency	Global	?	Yes	No	No	Yes
Tomorrow Bank Trine	Green Banking Loans to eco-projects	EU	120,000	No	Yes	Yes	Yes
		USA	?	Yes	No	No	Yes

Service	Features	Avail-ability	User Base	Investing	Savings	Shopping (Pay-ments)	Sustain-ability Focus
Ziglu	UK simple investing app	UK	?	Yes	No	No	No

Considering AI assistant for ESG investing, (G. K. S. Tan, 2020) proposes “*financial ecologies*” to understand the dynamic relationships between various actors: investors, advisors, government, where the government plays an active role in growing financial inclusion and responsible financial management; however, the paper further suggests that current robo-advisors (available in Singapore) make the investor captive to the agency of AI, making the person lose agency over their financial decisions.

11.3.4 The Psychology Saving: Anthropomorphism and Loyalty Schemes

There are at least two ways to look at sustainable savings, however related. In general, people will save nature if it also saves money. This section looks at savings in the *financial* sense of the word. Savings in the sense of CO₂e emission and environmental cost reductions have an entire separate chapter dedicated to them titled ‘*sustainability*’ however a short definition might be valuable here as well.

Environmental Savings means “*the credit incurred by a community that invests in environmental protection now instead of paying more for corrective action in the future*” (see Yale Center for Environmental Law & Policy, 2018) and (*Yale, Princeton, Stanford, MIT and Vanderbilt Students Take Legal Action to Try to Force Fossil Fuel Divestment - The Washington Post*, n.d., p. 33).

Savings in CO₂e equivalent emissions: CO₂e savings are the amount of CO₂e reduction one manages to achieve by changing one’s behavior and influencing others (people, companies). While the individual footprint is so small, the largest reduction will come from influencing large groups of people, either by leadership, role-model, or other means.

In theory, ethical savings accounts only finance businesses aligned with the customers’ values: screening out problematic and potentially harmful industries such as fossil fuels, tobacco, weapons, etc; in practice, one should carefully evaluate a bank’s investment principles, environmental policies and governance practices (*Ethical Savings*, 2023).

Pension funds are some of the largest asset holders and choosing where to invest one’s pension can be a sustainable financial action. College students might not have a pension fund yet, however their financial savvy will influence their choices in the future. Savings and investing are somewhat conflated because the large majority of savings that people have are invested by their banks. Thus the question of *sustainable savings* comes one of where exactly are they invested

and what is the impact of that investment of sustainability. Savings are the money one has in a pension fund or managed by themselves. For the majority of people, savings are invested by the bank and make up the largest proportion on investments for the people who are not active investors themselves. However, there are cases where people manage their pensions themselves; for example due to a law change Estonian could take out their entire accumulated pension and invest or spend them however they wanted (Raido Tõnisson, 2022b). While many Estonians used the money for consumption, some people invested their retirement funds in crypto(Marten Põllumees, 2022).

Saving precedes investing. From building loyalty to building ownership, the first step towards investing is to start saving money. How to encourage savings in daily life and make it a part of the everyday payments experience? Even starting with a small step, gathering a small target amount per month for savings, has the potential to shift the user's way of thinking about money. The second step, choosing where to invest these savings, will help us begin thinking like an investor. To start noticing trends and looking into how finance shapes the world. One experimental study showed people think about putting money in a “safe” place and *money anthropomorphism* increased saving behavior by 18%(L. Wang et al., 2023). Mobile money users are better at saving (Naito et al., 2021). Nerdwallet’s (Tommy Tindall, 2023) suggests making *financial commitments* instead of resolutions, in order to successfully save money.

Help consumers save money and business increase repeat business. Building customer loyalty is a key part of repeat business and financial predictability for any company. Large consumer brands like Starbucks have for long ran successful rewards programs that encourage customers to come back (Steinhoff & Zondag, 2021). Could loyalty schemes create a pathway to investing in the company to strengthen the feeling of connection with the business even further? After all, I’m now a minority owner! Yet in practice, many consumers lack the financial literacy for investing and there are many legislative difficulties for turning loyalty points into investments. It’s easier instead to create a separate cryptocurrency or token program which users could collect and redeem for some benefit.

Table 78: Example sustainable loyalty schemes

Company	Scheme
Patagonia	“Worn Wear” program
H&M	Garment Collecting program
The Body Shop	Return, Recycle, Repeat

Loyalty schemes can take a physical form. In Malaysia, Beebag shopping bags made of recycled plastic bottles with a NFC chip that works in conjunction with an app to provide rebates for customers (The Green Factor, 2022).

11.3.5 Sustainable Investing: Measuring the Eco-Investment Gap

By the latest estimates sustainability lacks several trillions of USD in investment. Even with massive financing already in the pipeline, the estimate for the global *financing gap* for low-carbon energy production was 5.2 trillion USD as of 2016 (Earth Day, 2023; “Mapping the Gap,” 2016). Ray Dalio puts the needed climate investment at \$5T and believes these financial goals won’t be met (Ray Dalio, 2023). A newer United Nations Environmental Programme (UNEP) calculation lowered the world needs an additional 4.1 Trillion USD of financing in nature-based solutions by 2050 to meet climate change, biodiversity, and land degradation reduction targets (UNEP, 2022). According to (The Rockefeller Foundation, 2022) a slightly lower 2.5-3.2 Trillion USD would be sufficient.

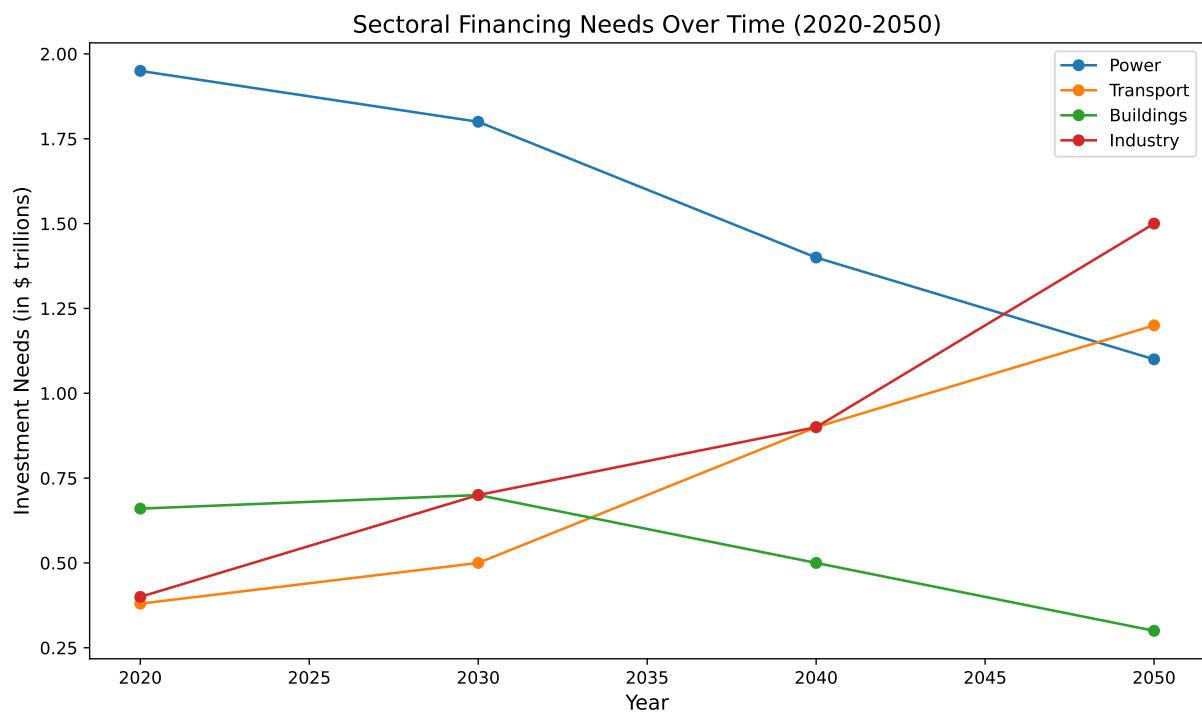


Figure 81: Climate Finance Funding Gap

What if 10% of annual consumer spending – *ten percent is about \$2,8T* - went towards protecting our climate. The theme for the 2023 Earth Day was “*Invest In Our Planet*”.

The needed investment doesn’t seem so large, around 5% of the global GDP, if one compares it to the *per year* Global Gross Domestic Product (GDP) estimated at around 100 Trillion USD in 2022 and growing to 105 Trillion USD in 2023 (Aaron O’Neill, 2023; IMF, 2023b). In essence, the estimated total investment gap in climate fits into the economic growth of 1-2 years of the global economy. (OECD, 2024b) projects steady economic growth 3.1% in 2024 and 3.2% in 2025 while the (World Bank & World Bank, 2024) is more conservative projecting 2.6% and 2.7% respectively.

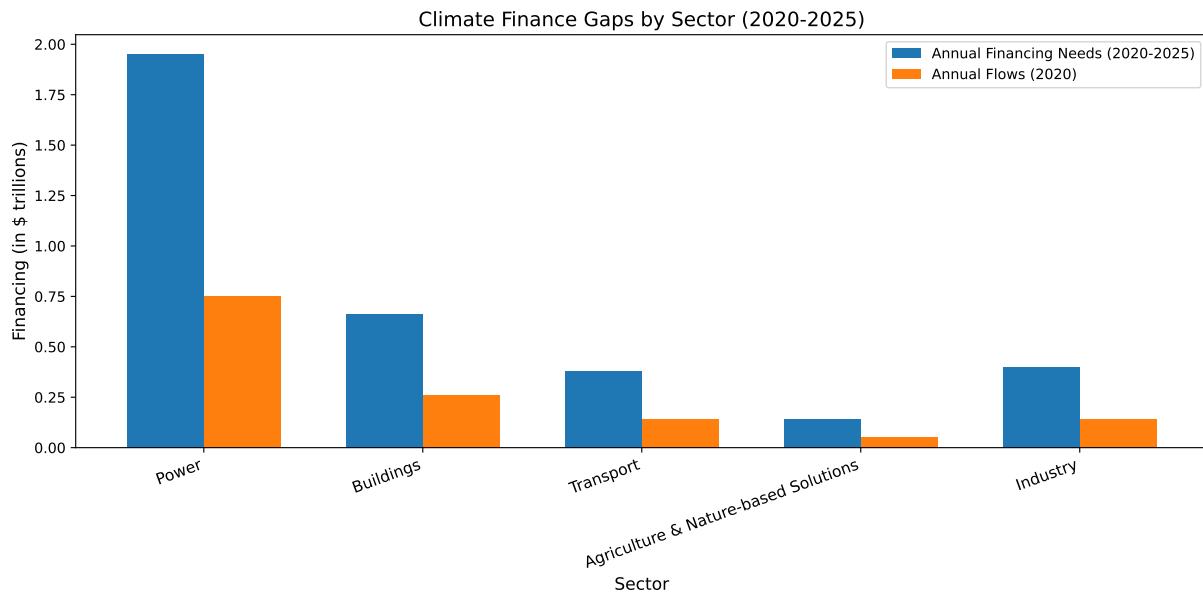


Figure 82: Climate Finance By Sector

The lack of funding in green energy especially affects emerging economies (“Mobilizing Capital Into Emerging Markets and Developing Economies,” 2022). “*We can and must channel private capital into nature-based solutions. This will require policy and regulatory support, catalytic capital and financial innovation*” argued the CEO Green Finance Institute, Dr Rhian-Mari Thomas, ahead of COP27 in Egypt (*Green Finance Institute*, 2023). It’s not happening fast enough.

Table 79: Comparative data on needed climate investment and other valuable assets; all figures in Trillions of USD (Aaron O’Neill, 2023; Blockworks, 2023a, 2023b; M. Fox, 2023; Grand View Research, 2021; IMF, 2023a; McKinsey & Company, 2023; Oguh & Oguh, 2023; Rao, 2023; SIFMA, 2023; S&P Global, 2019; Statista, 2021, 2023b; Stephanie Aaronson & Aaron Tilley, 2023; Thinking Ahead Institute & Willis Towers Watson, 2023; Trucost & TEEB for Business Coalition, 2023; US Treasury, 2023)

High-Value Assets (Trillions of USD)

Global Real Estate (2020, valuation)	\$326T
Global Equity Markets (2023, valuation)	\$108T
Global GDP (2024, estimated)	\$110T
Global GDP (2023, per year)	\$105T
Global GDP (2022, per year)	\$100T
<i>Global Pension Funds (2023, valuation)</i>	\$47.9T
U.S. Equity Markets (2023, valuation)	\$46.2T
U.S. National Debt (2023, valuation)	\$32.6T
<i>Millennials Inheriting Money from Parents in the U.S., U.K. and Australia (2022-2032)</i>	\$30T

High-Value Assets (Trillions of USD)

Global Retail Sales of Goods and Services to Consumers (2023, per year)	\$28.2T
GDP of U.S.A. (2023, per year)	\$26.8T
GDP of China (2023, per year)	\$19.3T
Global Private Market Assets (2023, per year)	\$11.7T
<i>Unpriced Externalities (2023, per year)</i>	\$7.3T
Global E-Commerce Sales (2021, per year)	\$5.2T
<i>Missing Climate Investment (2022, estimate per year)</i>	\$4.1T
Industrial & Commercial Bank of China (2019, total assets)	\$4T
Global Real Estate Sales (2021, per year)	\$3.7T
Apple Computers (2024, market value)	\$3.1T
GDP of Japan (2023, per year)	\$4.5T
GDP of Germany (2023, per year)	\$4.3T
GDP of India (2023, per year)	\$3.7T
U.S. Gen-Z and Millennials Consumer Spending (2022, per year)	\$2.5T
NVIDIA 英偉達 (2024, market value)	\$2.5T
<i>Retail Investors (2023, liquid assets)</i>	\$1.8T
Blackstone (2023, total assets)	\$1T
Bitcoin (2024, market cap)	\$1T
GDP of Taiwan (2023, per year)	\$0.8T
GDP of Finland (2023)	\$0.3T
Ethereum (2024, market cap)	\$0.3T
<i>Individual Climate Investors (2020, per year)</i>	\$0.1T
GDP of Estonia (2023, per year)	\$0.04T

While these assets and GDP values reflect different aspects of the global economy, the comparison illustrates that redirecting a relatively small fraction of global wealth and economic activity towards sustainable investments can close the investment gap. This perspective should inspire confidence that the goal is achievable with coordinated effort and policy support. Indeed, it would be easier for large institutional investors to move their money to sustainable assets than for retail investors to move their relatively small investments.

11.3.6 Retail Investing Enables Financial Inclusion and Growing Money Sustainably

Retail investing can be seen as a form of financial inclusion. Ant Group's CEO Eric Jing remarked in (Turrin, 2021): “*The financial system of the past 200 years was designed for the industrial era and served only 20% of the population and organizations. As we enter the digital age, we must better serve the remaining 80%*”.

Many ecologically-focused funds with different approaches have been launched in recent years, with variations in asset mix and style of management; thematic asset management is expected to

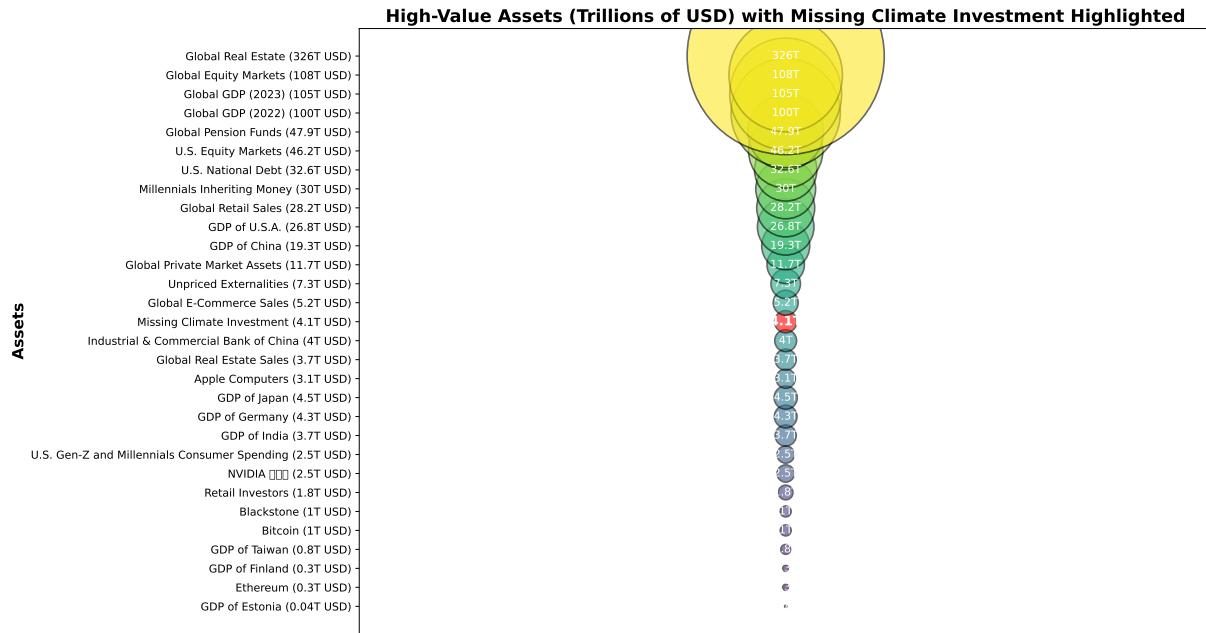


Figure 83: Climate Funding Gap vs High Value Assets

grow, with investors packaging opportunities based on consumer trends (Doorn, 2020). Among retail investors, there's some appetite for sustainability however investors are not sure how to separate sustainable assets from less sustainable ones (Ho, 2019). While literature has been debating if it's possible to "*do well while doing good*", latest research suggests it's possible to make investments that both make an attractive financial return and adhere to sustainability goals (Y.-M. Tan et al., 2023). "*sustainable investing is now part of mainstream financial strategy*" (Morgan Stanley, 2019).

(T. Smith, 2019) suggests 74% of Chinese youth are looking for "positive impact" and (Lingeswaran, 2019) philanthropy is on the rise in Asia in general. (M. Li et al., 2022) believes retail investors are important for innovation: "*investor attention can significantly improve enterprises' green innovation level*".

Sweden is a country with highly developed financial markets and active social campaigns demanding sustainability as well as well as the home for several green fintech companies, including Doconomy and Trine ("Meet the Fintechs Leading Sweden's Green Revolution," 2021). (Lagerkvist et al., 2020) undertook a choice experiment "Preferences for sustainable and responsible equity funds" with 559 Swedish private investors In Sweden, and found that sustainability strategies and an environmental focus carry more weight than fees, past performance or fund size.

(BlackRock, 2022) notes some ESG-oriented hedge funds can be "highly engaged with management teams" in order to influence management towards ESG practices in said companies. Barclays' 2021 investor survey found hedge-fund LPs (limited partners) adding screening for ESG data and willingness to start new "green alpha" funds if performance can be proven by robust

data (*ESG Hedge Funds | Barclays Corporate & Investment Bank*, 2021). High quality data is the key to unlocking this potential. ESG Analytics founder Qayyum Rajan introduces a sentiment - driven, alternative - data platform that maps real - time ESG events to SASB topics for deeper, faster screening (Qayyum Rajan, 2021). In addition to finance being increasingly data-driven, it's also increasingly personalized, for example Vise showcases its AI - powered portfolio - builder that lets RIAs customise, manage and explain client portfolios at scale, pitching itself as the “Copilot for wealth managers”, allowing creation of highly personalised portfolios (*Vise*, 2023). RavenPack provides an analysis tool tracking media and sentiment to gauge capital flows driven by ESG (RavenPack, 2021).

Companies themselves need to better understand their emissions, giving birth to the industry of climate accounting. The myclimate NGO is among the many providers or detailed calculate climate cost calculators, consulting and verified carbon - offset projects aimed at helping firms net - zero targets (*Myclimate – Your Partner for Climate Protection*, 2023).

Institutional finance is highly linked and constantly learning from each-other. For example, The Network for Greening the Financial System (NGFS) is a coalition of over 140 central banks that publishes scenarios, best - practice guides and policy papers on climate - related financial risk (NGFS, 2023). In Thailand, the Thai Fintech Association site lists its ecosystem map, events and membership tiers aimed at fostering fintech innovation and regulatory dialogue in Thailand (“Thai Fintech Association (TFA),” n.d.). Online news platforms such as (“Green Central Banking,” n.d.) aggregate research and daily news on how central banks integrate climate risk— scorecards, policy trackers and expert commentary.

11.3.7 Investable Asset Classes for Retail Investors: Increasing Exposure to Stocks, Bonds, Commodities, Real-Estate, Digital Tokens and Alternatives, Lending, Futures, Hedge Funds, Private Equity, and even Venture Capital

There are many asset classes with varying degree of access to a retail investors. The main categories of investment products are, based on the U.S. Securities and Exchange Commission categorization (U.S. Securities and Exchange Commission, 2025).

Table 80: Investment Types

Investment Product
Stocks
Bonds
Mutual Funds
ETFs
Insurance Products such as Variable Annuities

There are also newer asset classes.

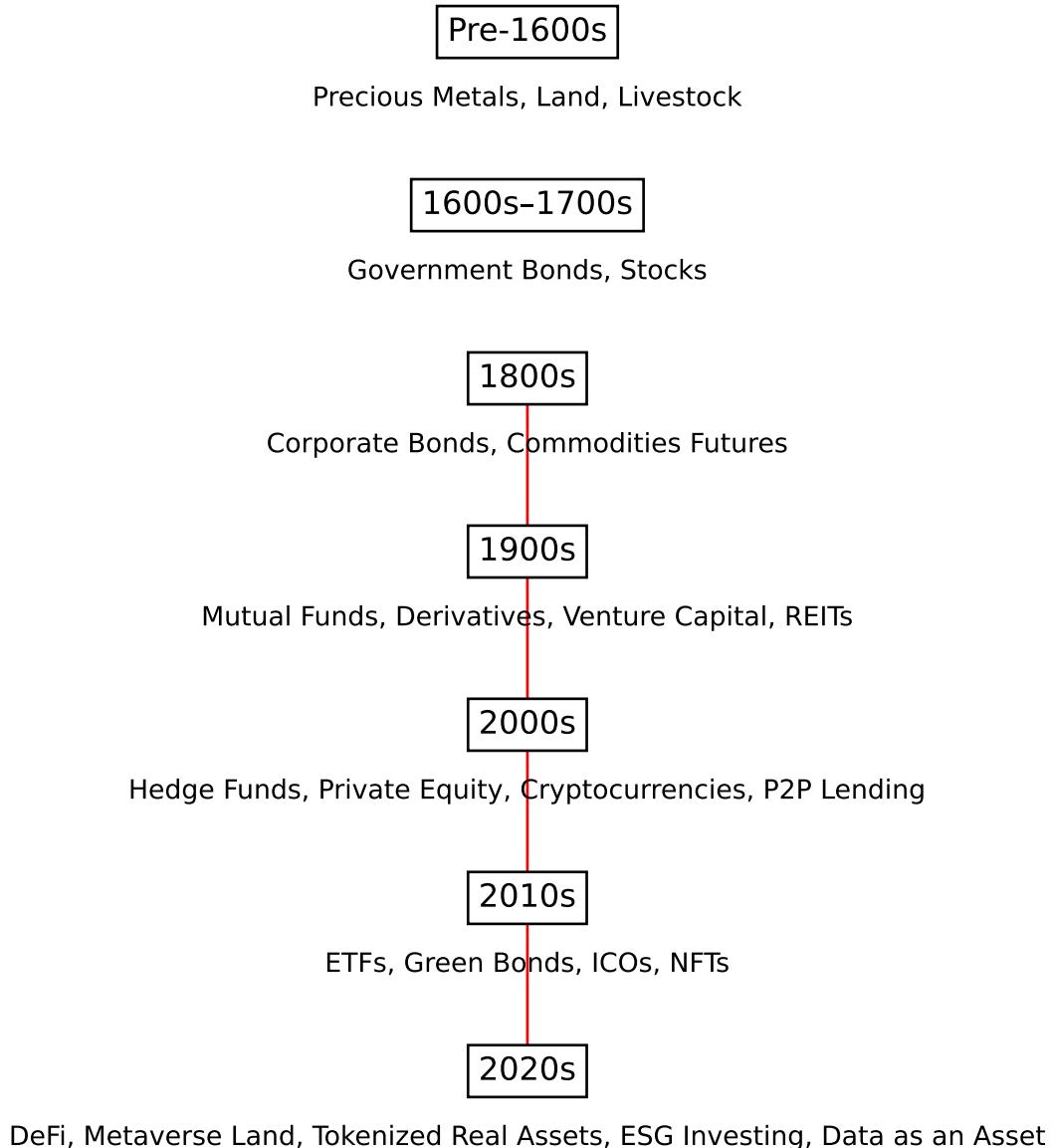


Figure 84: Asset Classes

Stocks are the most popular assets class with a long history and highly accessible to retail investor, albeit usually at the cost of a trading fee. *Meme stocks* are another aspect of the *entertainmenization* of investing. There are many groups of Twitter, Reddit, and elsewhere, where investing trends start, causing more volatility. Retail investing apps blend entertainment into the UX/UI of investing. For example stock-trading app Robinhood uses game-like features such as displaying a confetti animation to create a sense of excitement around trading investing. Retail investing UI/UX is simplified and gamified, which encourage impulsive short-term buying and selling with a focus on speculation over fundamentals and cause FOMO (fear of missing out).

Bonds are a form of debt investment also known as an fixed-income asset where the principal is repaid at the maturity date of the bond (usually in years) with an added premium. Individuals can't emit bonds but they can invest in them. It can be a way to invest locally in one's own city - or globally. For individuals, there's access to some green bond exposure through ETFs (exchange-traded funds) available on retail investing apps. Access is not universal and availability depends on the geography of the user and local legislation; for example Revolut, the most downloaded finance app in the EU, only enabled bond investing for European customers in summer 2024 (Revolut, 2024c, 2024a). Investing in bonds is a form of *Passive Investing* and allows investors focus on low-risk passive income instead of daily stock investing most popular on Robinhood and Revolut - albeit with much less potential for returns.

Lending is an attractive assets class with a significant social impacts providing opportunities to small farmers and other participants in the money markets while offering the lender a return, all possible through online apps and platforms. Retail investors can lend small amounts of money (also known as MicroLending) on peer-to-peer (P2P) lending platforms such as Twino. These loans are pooled and the risk is borne in aggregate as a form of risk-management.

Hedge funds generally are not accessible to retail investors, requiring a substantial minimum investment. However some Hedge Fund based ETFs (exchange-traded funds) and Mutual Funds with Hedge Fund Strategies may try to mimic hedge funds, investing in the same underlying assets. While hedge funds used to be available for professional investors, online platforms such as (Hedge, 2023) aim to provide retail investors a social investing experience to "make a hedge fund with your friends", where people can come together and pool their funds in "mini - fund", with social tools such as chat and voting on trades built-in, aiming to democratize the hedge - fund model for small retail groups. It's how many people in the world of venture capital invest, investing together, or after a lead investor, who they trust. An early entrant into the market, (Renato Capelj, February 16, 2021 6:47 PM) positions Titan as a "*mobile hedge - fund*" app, which is actively managed, with transparent fees, and a competitor to automated robo - advisors.

Commodities are increasingly investable, with retail investors can now buy gold and silver as well as rare metals on financial platforms such as Revolut. Democratization of commodity trading lowers the barriers and allows individuals to diversify their portfolios beyond equities and bonds.

Real-estate is increasingly available on co-investing platforms allowing retail investors access into this asset class with a relatively low starting price. Thus investing in sustainable architecture

can be an attractive proposal both from an environmental as from a financial standpoint, potentially providing a passive income stream in the form of rent. According to (Debnath et al., 2022) 39% of global CO₂ emissions comes from the building sector. Construction is large emitter because of the use of concrete; super tall buildings are very CO₂ intensive (Zhao & Qin, 2015). Building emissions can be reduced by using sustainable design and materials, *digital twins* of architecture enable pre-visualization of different designs (Panaro et al., 2024) as well modeling the usage of the building, for example the interior shop floors in commercial real-estate (Jia et al., 2023). In housing development, there's evidence of 'green' buildings achieving a 'higher financial return than conventional buildings, both in terms of rent and sale price' (Oyedokun, 2017).

Venture capital largely remains inaccessible for retail investors, and not only for its high capital requirements; groups like the Investment Company Institute (ICI) pushing to increase retail access to private markets are criticized for exposing retail investors to increased risk (Langton, 2025). While value investors love rules-based screens such as the Piotroski F-score, used to identify stocks that have strong fundamentals, these measures break down for high-growth startups whose financials are distorted by deliberate burn (Gurung et al., 2025).

Thematic Capital refers to choosing a clear investing thesis around a topic and building a resilient strategy. For example, for ESG-themed investments might pick Green Bonds, Sustainable Equities, and ESG - focused Mutual Funds and ETFs as the core, each screened through ESG metrics integration to ensure material impact rather than superficial marketing however although there is a wide range of investment products marketed as sustainable, many are fake, so rigorous due diligence is essential to weed out greenwashing and align holdings with authentic sustainability outcomes. Just like there are "green shops" for buy everyday products, there are also green investing platforms for purchasing various types of investment products that have been rated on some type of sustainability metric, for example green ETFs, green bonds, and the like. All of these are essentially forms of green branding, designed to make it easier for investors to find an investing product they trust.

There are many investment platforms self-describe as green, but the question remains, who to trust.

Table 81: Green Investment Platforms

Name	Description	Link	Sources
Trine		trine.com	
The Many		the-many.com	
Sugi		sugi.earth	
ClimateInvest		clim8invest.com	
Circa5000		circa5000.com	

Name	Description	Link	Sources
FairOwn	Aims to use product subscriptions to simplify circular economy, instead of buy-throw-away culture.	fairown.com	(Hankewitz, 2021)

Beyond the core, a diversified sustainable portfolio might incorporate *Impact Investing*. I've listed a sample of existing platforms that channels capital into mission - driven ventures, Renewable Energy Infrastructure (via ETFs or mutual funds) supporting wind, solar, and hydro assets, and Sustainable Real Estate accessed through REITs or ETFs that prioritize energy efficiency and low - carbon construction. *Social Bonds* expand the opportunity set by financing healthcare, education, and affordable housing, while Carbon Credits (via ETFs or specialized funds) and Sustainable Commodities (via ETFs or funds) offer exposure to emissions - reduction markets and responsibly sourced raw materials, respectively. For deeper community impact, one might allocate some funds to crowdfunding and crowd-loan platforms and to Sustainable Infrastructure Funds (available as ETFs, bonds, and mutual funds) that upgrade transport, water, and grid systems for a low - carbon future. In short, disciplined selection across various investment vehicles increasingly available to retail investors, guided by a robust investing thesis and aide by monitoring tools, in theory, would enable one to align financial performance with genuine social and environmental progress while avoiding the pitfalls of superficially labeled products.

11.3.8 Green and Sustainability-Linked Bonds

Green bonds are released by companies, international organizations, and cities to raise money for green transformation, usually for building something to improve sustainability, tied to specific projects. There's a growing global trend in green bond emission, with 257 Billion USD worth of green bonds issued in 2019, expected to reach 1 Trillion USD annually by 2030 (MacAskill et al., 2021). That prediction was too low with 870 Billion USD green bond emissions reached already in 2023; currently Europe is the largest emitter of green bonds (Climate Bonds, 2023). China has the 2nd largest green bond market in the world and it's growing fast; buyers are looking for green bond certification to reduce yield spread, meaning the price of the green bond is becoming more similar to the price of a 'regular' bond (Q. Li et al., 2022; W. Peng & Xiong, 2022). The Climate Bonds Initiative, which is working on greening the entire short-term debt (bond) market, puts the size of the entire market at \$55 trillion, underlining the relative percentage of green bonds is tiny ("Climate Bonds Initiative Calls for Greening of \$55trn Short-Term Debt Market," 2022).

In 2017 the Malmö city in Sweden released green bonds to finance a sustainable transition of the city (City of Malmö, 2017). An independent analysis found bonds may not be emitted for financial reasons but to improve the reputation and city image, lower interest rate (aptly named

(*greenium*) with a similar in returns to traditional bonds - and have their share of challenges, namely being difficult to certify, monitor, report and measure impact of (Sjöström et al., 2020).

Making sure a green bond is truly supporting sustainability is a challenge. For example, Aramco, the Saudi Arabian public petroleum and natural gas company faced scrutiny for what critics deemed as ‘Fake green bonds’ (Anthropocene Fixed Income Institute (AFII), 2022). Green bonds can also be emitted on blockchains with the stated goal of improving transparency. Hong Kong multi-currency green bond on the blockchain. The issuer (Hong Kong government) hopes to reduce greenwashing (Hall, 2024; Kitano, 2024). In the EU as well, there are emerging tools for monitoring green bonds on blockchain (Christodoulou et al., 2023). (Qin et al., 2023) finds evidence that the combination of green bonds and blockchains are an enabler carbon neutrality in China. The World Bank successfully raised 110 Million USD in Australia in 2018-19 and has since doubled the amount in a new 220 Million USD emission in Switzerland using bonds on a blockchain ledger for SDG-related projects (World Bank, 2018, 2019, 2024).

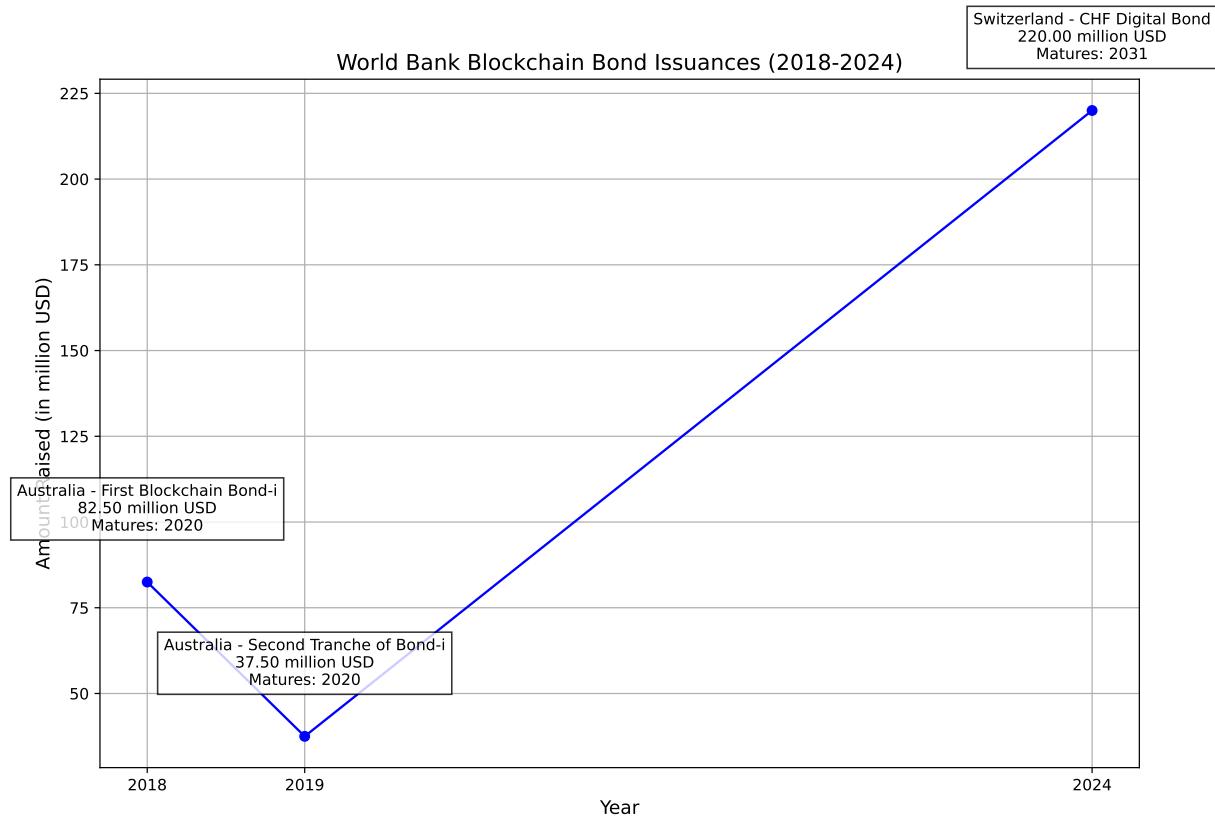


Figure 85: World Bank Bonds

Sustainability-Linked Bonds are less stringent than green bonds; they are not tied to specific projects but more broad sustainability targets (Priscila Azevedo Rocha et al., 2022): “Sustainability-linked bonds let companies borrow cheaply if they meet environmental, social, and governance targets. A Bloomberg News analysis found those goals are weak”. (Priscila Azevedo Rocha et al., 2022) suggests “So far, most ESG investing is in the stock market. But

the the \$22 trillion corporate bond market, where mature global companies such as Chanel go to borrow money from investors, has a particularly powerful role to play. Companies rely on debt much more than they do on stocks.”

11.3.9 Fusion of Traditional Finance and Decentralized Finance (DeFi)

Crypto-assets and digital tokens (known as decentralized finance or DeFi) are a highly accessible yet risky asset class, offering investment opportunities to anyone with a mobile phone and internet access. The low entry barrier makes crypto among the most potentially inclusive forms of investment, though bearing significant risks, as well as regulatory challenges. Cryptocurrencies are popular among young people yet in many ways crypto needs even more financial literacy than traditional financial assets. Crypto investing removes most entry barriers while having high risk.

(Statista, 2024) estimates over 860 million cryptocurrency users worldwide by 2025, just shying away from 1 Billion users. A Brazilian study ($n = 573$) found that crypto investors in Brazil are young, male, and have a high risk tolerance, when compared to non-crypto investors (Colombo & Yarovaya, 2024). “Brazil’s planned adoption of CBDC (Central Bank Digital Currency).” “It finds that risk tolerance, economic pessimism, and a belief in better investment acumen are significant predictors of crypto investment.”

The large number of crypto users begs the question: what would investing look like at the scale of 1 Billion people? The most popular use cases for crypto have been NFTs, online smart contracts attached to some type of asset, typically a picture. Social media is even bigger, with over 2 Billion users, so it’s not difficult to image the combination of Social + Crypto (NFTs?) to become the largest retail investing revolution, albeit a risky one, with many users losing their assets. This is the vision behind Sandbox, a Metaverse cryptocurrency sold by banks such as LHV in Estonia (Raido Tõnisson, 2022a).

Taiwan has an active market for crypto-assets while with some limitations. In 2022, the Taiwan government banned buying cryptocurrencies with credit card quoting the volatility makes it similar to gambling (David Attlee, 2022; 廣編企劃, 2022). In January 2022, BlockTempo and OpenSea teamed up to mint the “Top Taiwan Influencers” collection—21 unique, limited-edition Taiwanese digital influencers as NFTs, depicting Taiwan’s leading blockchain figures, designed to honor their industry contributions in digital art (OpenSea, 2022).

In general, crypto ownership can be divided into self-custody (you own the keys to your wallet) and custodial ownership, where you trust someone else (i.e. a centralized exchange or a bank) to hold the cryptocurrency for you. Both have their risks (self-custody, losing your keys; custodial: the exchange steals your tokens or goes bankrupt). Centralized crypto exchanges are in essence loaning assets from the user. *“The piece of the settlement aimed at getting important information to customers is more understandable from a retail protection standpoint. Customers who lend crypto assets to a company in exchange for a promised return should get the information they need to assess the risks against the rewards”* (Hester M. Peirce, 2022).

There's also a large trend of fusion of decentralized finance (DeFi) and traditional finance (TradFi), with the largest established investors, such as BlackRock, launching tokenized funds (Matos, 2024; Sandor, 2024; Securitize, 2024). Tokenization is similar financial securitization which has been happening for a long time, with blockchains creating new tools for securitization: for example art can be securitized and tokenized (Masterworks, 2023). Blockchains makes this kind of financial engineering easier as any developer can do it; one does not need to be a bank.

In Switzerland, institutional funds entered crypto early. Licensed already in 2019 by the Swiss Financial Market Supervisory Authority (FINMA), AMINA, formerly known as SEBA Bank, was among the first regulated cryptocurrency banks (AMINA Bank AG, 2023). The first crypto fund was launched in September 2021, when FINMA approved Switzerland's first regulated crypto-asset fund—the “Crypto Market Index Fund” from the same AMINA bank, giving investors access to a FINMA-supervised vehicle that tracks a diversified basket of blockchain-based assets with the AMINA Bank's custody (FINMA, 2021). AMINA of course was not the only bank interested in crypto, with “[m]ore than half” of Swiss banks planning to offer digital assets services in the near future (swissinfo.ch/urs, 2022). Banks launching Crypto ETFs (Exchange Traded Funds) enable their clients to have exposure to crypto without ever buying cryptocurrencies directly themselves. However, while owning cryptocurrency directly allows one to use crypto tools to look at any wallet balance, ETFs hide that transparency.

To put it very simply (knowingly oversimplifying), in traditional finance legislation is an enabler of corruption as in the case of Swiss privacy laws, where illegal funds can be hidden, while in cryptocurrencies, the lack of clear and comprehensive regulation is an enabler of corruption.

Pricing crypto is not based on any single fundamental metric, but comes from tokenomics: a catch-all word for token design and internal economics, such as supply schedules, emissions cuts, burns and staking yields to frame the basic scarcity curve as well as demand side narratives, and real world utility and user sentiment. Crypto enables significant potential for financial engineering and innovation by anyone with enough programming skills.

Bitcoin is by far the most popular cryptocurrency with its high price volatility creating opportunities for high gains and high losses. While bitcoin has been called a “digital gold” for store of value, its volatility characteristics are very different from gold, as seen on this chart.

The volatility of the markets has notably shifted crypto research towards pricing theories (S. Peng et al., 2024). However volatility is relative. Volatile national currencies lead people to find other assets to hold. If one's national currency is collapsing, one might find crypto has a relative safe haven to keep one's funds. People in Turkey losing 75% of the value of their assets when currency collapses, is one of the reasons why people might buy crypto (Saba & Saba, 2022; T. R. Wilkes et al., 2021).

For example, an index of major sustainability news can be compared with crypto prices, which may have negative, positive, or no correlation with the listed cryptocurrencies.

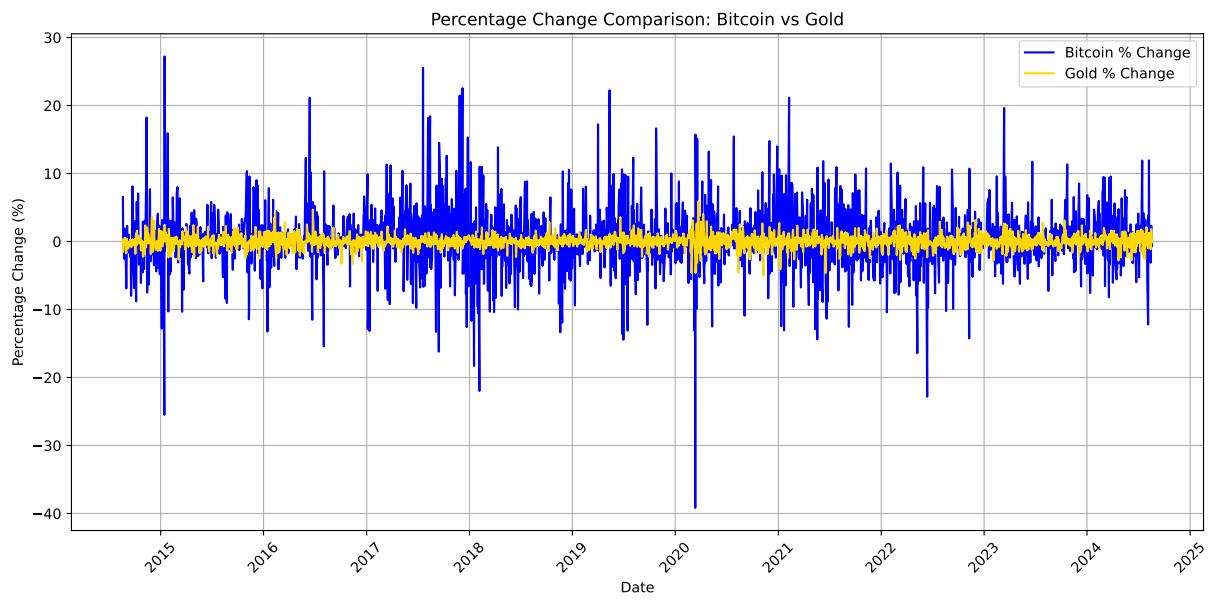


Figure 86: Bitcoin vs Gold Futures

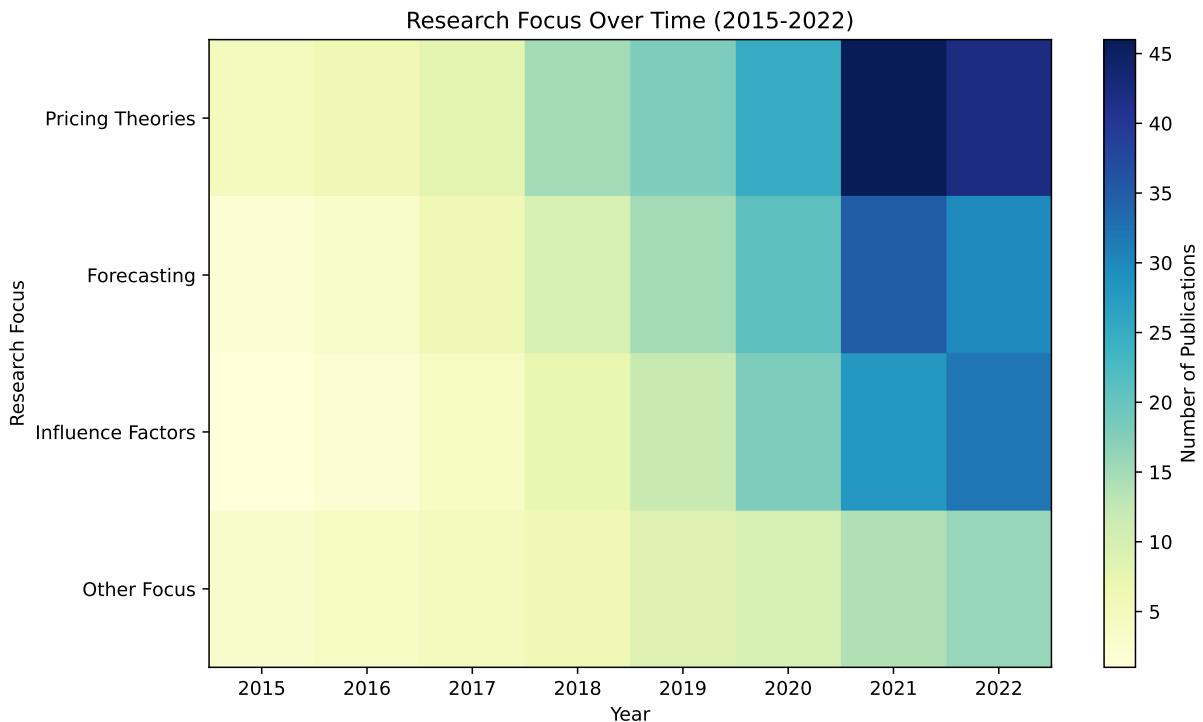


Figure 87: Crypto Pricing Theories

11.3.10 Regenerative Finance (ReFi) and DAOs

“Would you rather buy a DogeCoin or a regenerative food forest token?” Curve Labs founder Pat Rawson quotes Shiller (2019) in ReFi podcast about Kolektivo (ReFi DAO, 2022).

(Caio Jobim, 2022) believes Bitcoin has failed as a mainstream money but blockchain technology in general will underpin the next-generation digital-currency systems, ultimately replacing both cryptocurrencies and cash. While Bitcoin uses proof-of-work, and protocol which is highly energy intensive (and thus, unsustainable), later innovations such as proof-of-stake enabled the creation of blockchains, which are energy-efficient; an overview from 2023 details 23 low-carbon blockchains (Alzoubi & Mishra, 2023). (Sepandar Kamvar, 2022) Sepandar Kamvar, co-founder of Celo, famously calls “[a] blockchain is a database without a database admin”. (dGen & PositiveBlockchain, 2021) built a positive blockchain database of blockchain for good projects. Some traditional green investors have started to take note. (Marquis, 2021) reports on RSF Social Finance’s shifting from impact investing to regenerative finance, detailing its \$230 million under management and community-pricing innovations. Blockchains are proliferating, with newer blockchains being more energy efficient (and thus having better sustainability properties); as of early 2025, there are nearly 2000 unique public blockchains in existence (Routescan Research Team, 2025; L. Schwartz, n.d.).

Inspired by the decentralized finance (DeFi) Summer of 2020, when projects like Compound, Yearn, and Uniswap demonstrated blockchain-based financial tools could go viral, followed by COVID-19, which exposed systemic fragility and served as a wake-up call about global interconnectedness and ecological risk, crypto pioneers attempted to use their native tools for public good, instead of only financial goals, giving birth to the regenerative Finance (ReFi) movement, applying technology to carbon accounting, market development, and governance (B. Smith, 2021). Innovating on the intersection of blockchains, tokenization, nature-backed assets, and cryptocurrencies, ReFi leveraged DeFi to create financial systems that aimed to restore ecosystems and empower communities by prioritizing positive environmental and social impact (“What Is ReFi | Regenerative Finance Explained,” 2023).

Founded already in 2018, Regen Network built a blockchain for ecological data and carbon credits, using the Cosmos blockchain SDK (Regen Network, 22 C.E., 2023). Another early example is the Celo proof-of-stake blockchain, founded in 2020, which offsets carbon emissions at the protocol level, automatically investing a small percentage of each transaction into a reserve, which buys green assets, such as tokenized carbon credits (e.g. Moss MCO₂), laying the groundwork for a regenerative financial system (“Celo and Regenerative Finance - Climate and ReFi,” 2021). (“Planet of the Klimates - Luis Adaime - Founder & CEO of MOSS.Earth,” n.d.) details the issuance and tokenization of tropical-forest carbon credits (Moss.Earth MCO₂) and biodiversity tokens within the Celo ecosystem. Similarly, the (“KlimaDAO,” 2023b) KlimaDAO protocol, founded in 2021, tokenizes real-world carbon assets into liquid Klima tokens, establishing a DAO-governed, transparent market for carbon neutrality, which has \$4 billion in total transaction volume.

Social features has always been a weakness of Web3, and (Syndicate, 2022) contends that it's not enough to build decentralized financial rails to democratize wealth creation; crypto investing must also redesign the social networks around capital. The Web3-based attempt to achieve these goals is called DAO or Decentralised Autonomous Organizations, which allow wallet holders to collaborate and vote on issues. (BlockChannel, 2017) defines a DAO as a Decentralized Autonomous Organization on blockchain, using smart contracts and token-weighted voting to enable permissionless, community-driven governance. In the world of Web3 and cryptocurrencies, smart contracts make it possible for DAOs to also pool member resources for investing. Because of the on-chain nature where transactions are visible to anyone, they may be seen as more transparent. DAOs can be used in a similar way to Hedge funds; a DAO can have a treasury, with a shared multi-sign wallet (similar to a bank account) from which investments can be made together. Typically DAOs have a voting system to make decision while Hedge Funds may be more centrally controlled. A notable example, (Carra Wu & Chris Dixon, 2021) details how the Friends With Benefits (FWB) DAO transformed consumers into investors by requiring an application review and token buy-in, granting members governance rights and meaningful ownership in a token-gated community. With a specific sustainability focus, ("Trees for the Future," 2023) DAOs to enable concerted action towards climate goals using the pooled resources in a treasury, a blockchain (on-chain), similar to how hedge funds work.

(Ian Bezek, 2021) argues that DAOs and governance tokens could replace stock exchanges and corporations by using programmable blockchains for digital ownership and control of assets registered in on-chain distributed databases. (Nathan Reiff, 2023) explains how DAOs use smart contracts and cryptographic voting to manage organizations without a central authority; some advantages include transparency and community ownership, while existing challenges of being in a legal gray zones (one still needs to register a legal entity) and risks of security hacks, are real. (Rehash: A Web3 Podcast, 2022) insists that people and not just code must be the north star in Web3 design frameworks to achieve a truly human-centered Web3. Yet, the first wave of Web3 users were privacy-conscious and wouldn't answer questions, making it challenging to create good personas, making design difficult (Crabb, 2023). While somewhat out of date, (Ray, 2023) offers a comprehensive review mapping the Web3 technology landscape which serves as a good introduction. Finally, ("Empowering Digital Asset Banking," n.d.) notes it's not only retail investor entering the crypto world, large institutions are doing the same, with tokenisation, crypto custody and asset - management increasingly becoming a part of mainstream finance.

(Aikman, 2022) proposes using a DAO called OpenESG to cut opacity and greenwashing, with a Decentralized Expert Council and Community Voting to build transparent rating methodologies, while validator bounties would incentivize crowdsourcing and verification of data, making every scoring step is auditable; high scorers could gain direct access to sustainable financing, turning ESG excellence into tangible regenerative outcomes. While the ideas remain, the OpenESG organization itself has defunct for unknown reasons, leaving one to wonder if these ideas are workable.

A lot of financial tooling from traditional finance (called trad-fi in crypto circles) has been replicated using blockchains and related technologies. However, the legislation affecting Hedge Funds and DAOs would be different as hedge funds are an older and more established finan-

cial tool whereas DAOs still fall in somewhat of a gray area. For example, in the U.S. a federal judge ruled that crypto collectives (crypto investment clubs) like Lido DAO are general partnerships liable for unregistered securities offerings (*Investment Clubs and Collectives | Deprecation FAQ*, n.d.). In order to overcome these legal hurdles, VC-backed startups have launched platforms to support a new generation of DAOs, providing regulatory navigation and smart-contract tooling that broaden blockchain dependencies beyond DeFi protocols (Lucas Matney, 2022).

Oracles provide the intersection between finance and real world sustainability data. A data oracle is the concept of a source of real-world data which can be ingested through an application programming interface (API) to a blockchain system. There are many databases of sustainability information which could serve as an oracle for carbon labeling, packaging, transportation, consumption, and waste. For example, crypto crop insurance provided by IBISA Network uses blockchain triggers and satellite data to offer transparent, automated payouts for farmers facing weather-related risks (*IBISA Network – Enabling the Next Generation of Insurance for Agriculture*, n.d.). While (Caldarelli et al., 2020) notes it's a challenge to ensure the accuracy and trustworthiness of real-world data from Oracles, the largest Oracle provider ChainLink founder Sergey Nazarov believes the collaboration of oracles and blockchains can make carbon credits more trustworthy. (Brady Dale, 2021; Chainlink, 2022).

11.3.11 Divestment: Supporting Sustainability by Avoiding the Worst Polluting Companies

Divesting is the inverse of investing. If no sustainable alternative can be found, at least taking one's money out from polluting companies signals one's green preferences. "Sustainable development requires more investment in sustainable companies and less in unsustainable firms." (Van Zanten & Rein, 2023). In institutional finance, the Norwegian \$1.3T USD sovereign wealth fund (the world's largest) started a divestment trend in 2016 by divesting first from coal following by divesting from oil, gas and coal extracting companies (Ben Martin, 2017; Holger, 2019). Their plan to reach net zero CO₂eq nonetheless only targets 2050. Furthermore, who would be the counterpart for such large transactions. The fund also announced divesting from Russia after its invasion of Ukraine, however has yet to sell any shares citing lack of buyers on the Moscow stock market. Even with divesting from oil and gas, Norway Government Pension Fund Global (GPFG) still adheres to the Markowitz's Modern Portfolio Theory (MPT), with enough diversification between assets (Papaioannou & Rentsendorj, 2015).

University of California also followed suit with divestment of its \$126B USD portfolio from oil and gas. Other large university endowments, such as managed by Yale, Stanford and MIT are in decision gridlock.

While divesting makes news headlines, even divestment by large institutional investors, such as the Norwegian National Pension Fund (GPFG), has a negligible effect on the heavy polluters' business; by the same logic, it can be deducted, the financial effect of retail investors divesting, is meaningless. If retail investors act in aggregate, the reputational effect needs further research. *"To halt climate change, some investors have decided to divest from fossil fuel companies. Reviewing the literature suggests that divestment from fossil fuel has limited financial*

consequences; it slightly increases divested firms' risk and their cost of capital, while reducing divested firms' market value," is the pessimistic conclusion by (Plantinga & Scholtens, 2024).

By extension, it may sound feasible that divesting could have a meaningful impact on companies if a large numbers of retail investors collaborate on 'banning' the company to send a message to the board, yet in practice small individual divestments may be negligible to governance decisions.

11.4 The Economics of Decoupling: Attempts to Disconnect Economic Growth from Eco-Degradation

Is the "eco" in ecology and economy the same? *Oîkos*, the Greek word for "household", seeds two modern disciplines: ecology studies how the home works; economy sets the rules for managing it. The two have drifted apart: one guarding planetary health, the other chasing growth. This chapter reunites them by asking: how do we measure prosperity without wrecking our home?

11.4.1 Post-AI Economics

People around the world are discussing how traditional economics can adjust to the abundance provided by AI, known as *Post-AI, Post-Labor, or even Post-Scarcity economics*. Last year, the Seoul AI Summit pushed for voluntary safety standards to manage systemic risks while the French AI Summit tackled energy consumption and environmental costs, highlighting the need to embed AI sustainability into economic planning, regulatory frameworks, and corporate accountability (Hern, 2024; Milmo, 2024). More recently, the Anthropic Economic Index tried to capture how AI impacts human work and economics in general, noting that among millions of work tasks submitted to Claude - studied as anonymized conversations using a privacy-preserving clustering tool Clio, separately described in (Tamkin et al., 2024) -, that 43% of the work could be categorized as automation and 57% as augmentation of human economic activities (Handa et al., 2025). At the same time, economists' predictions of the future impact of AI are far from uniform, for instance MIT economist Daron Acemoglu estimating that in the U.S. only 5% of the tasks can be profitably automated and AI will only contribute a modest 1.1% to the GDP until 2035 (Acemoglu, 2024).

11.4.2 Econometrics: The Many Ways to Measure an Economy

Econometrics is the science of measuring the economy.

The creator of the Gross Domestic Product (GDP) metric in 1934 Simon Kuznets said: "The welfare of a nation can scarcely be inferred from a measurement of national income as defined by GDP...Goals for 'more' growth should specify of what and for what" (United States. Bureau of Foreign and Domestic Commerce et al., 1934).

GDP was the culmination of previous work by many authors, beginning with William Petty in the 17th century (Rockoff, 2020). This long journey underlines how a metric about a complex system such as the economy is continuous work in progress. There has been ongoing work to create improved metrics such as the Sustainable Development Goals (SDGs), Human Development Index (HDI), Genuine Progress Indicator (GPI), Green GDP, Inclusive Wealth Index, and others (Anielski, 2001; Bleys & Whitby, 2015; Kovacic & Giampietro, 2015).

Measuring wellbeing in addition to GDP and the metric should include resiliency dashboards, to visualize metrics beyond GDP and they are an integral part of country reports (GreensEFA, 2023). Similarly, the doughnut (donut) economics (more below) model calls for a “*dashboard of indicators*” (TED, 2018).

The National Academies links public health outcomes (air quality, water safety, and food systems) with sustainability actions, calling for an integrated cross - sector strategy to protect community well - being (*Public Health Linkages with Sustainability*, 2013). (Guidotti, 2015) argues environmental quality foundational to public health and urges embedding sustainability principles across healthcare systems and policies; in order to have healthy communities, we need clean air, pure water, and toxin - free surroundings.

11.4.3 The Evolution of Economic Metrics

Traditionally, the true cost of products is hidden. The work is hidden. The first two decades of the 21st century have seen increasing economic thinking, looking to challenge, improve and upgrade capitalism to match our current environmental, social, and technological situation, often called *New Economics*. Some of these include behavioral economics, sustainable capitalism, regenerative capitalism, doughnut economics, ecological economics, blue economy, degrowth, attention economy, gift economy, intent economy, among others. There's no lack of published books on changing capitalism, which goes to show there's readership for these ideas. Build a new economic theory is out of scope for my thesis design, however I'll focus on the parts of economic theory I believe are relevant for *interaction design*-ing for sustainability.

There are those looking for *new metrics*. One of the first innovators, already in 1972, was Butan, with the *Gross National Happiness Index (GNH)*, which in turn inspired the UN, decades later, in 2012, to create the International Wellbeing and Happiness Conference and the International Happiness Day(Kamei et al., 2021; Ribeiro & Lemos Marinho, 2017). The World Bank talks about the comprehensive GDD+ metrics in its Changing the Wealth of Nations report (World Bank, 2021).

The Wellbeing Economy Alliance (WEAll) countries (New Zealand, Iceland, Finland, Scotland, Wales) as well as the EU and Canada, started the coalition in 2018 looking to involve more broad-based metrics in developing their societies (CEPR, 2022; David Suzuki Foundation, 2021; Ellsmoor, 2019; Scottish Government, 2022; Wellbeing Economy Alliance, 2022). (Giacalone et al., 2022) looks at wellbeing of Italian communities and proposes a new composite index. There's also work ongoing on macroeconomic modeling, aiming to create a *digital twin* of the

Timeline of Notable Economic Theories and Authors

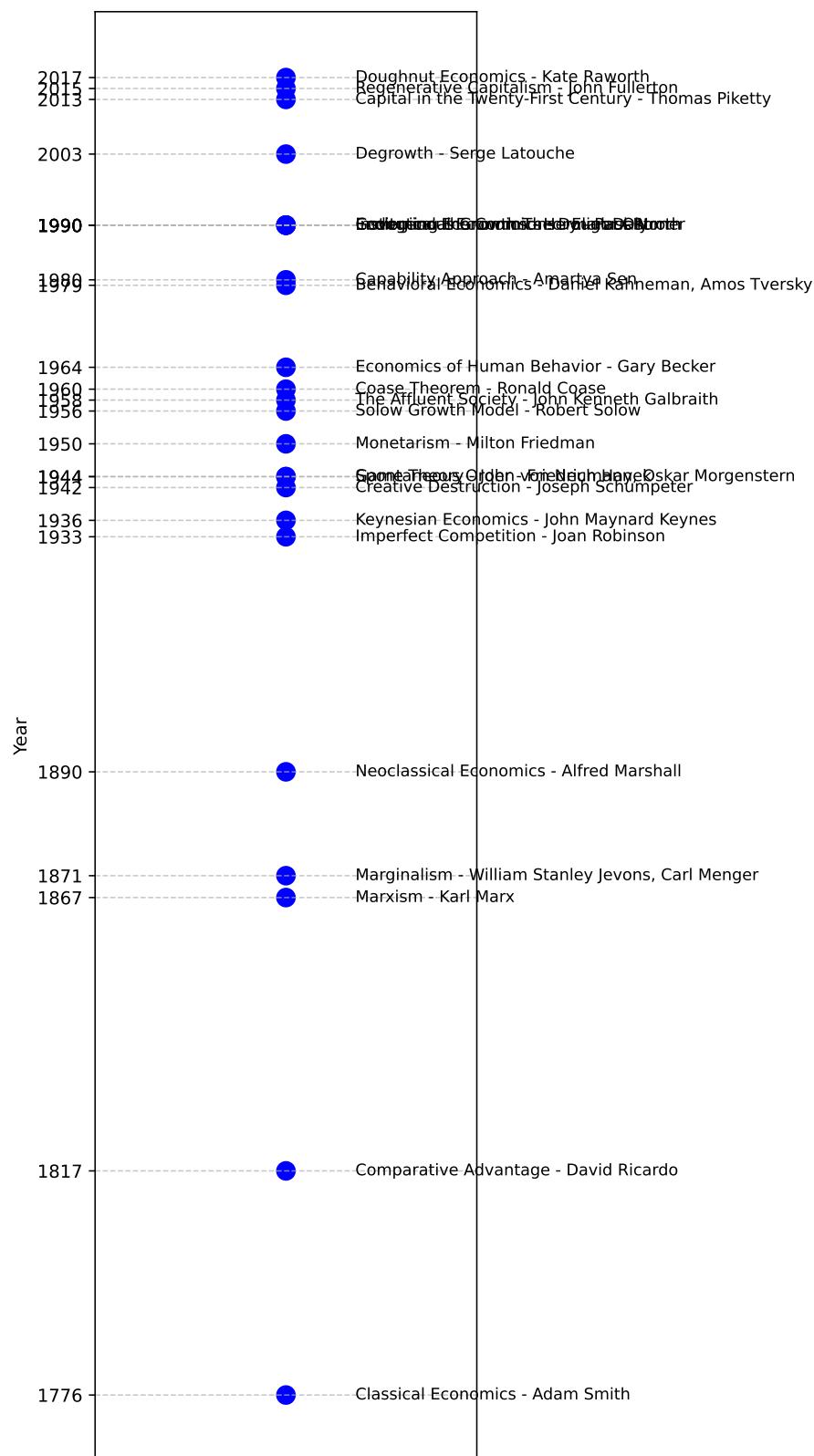


Figure 88: Economic History

economy. Some of the most complex computer models of the economy include the Global Integrated Monetary and Fiscal Model (GIMF) (Laxton et al., 2010) and DSGE (Dynamic stochastic general equilibrium).

11.4.4 Hidden Costs: Pricing Externalities

Markets misprice “home maintenance.”

Co-founder of Generation Capital with 50 Billion under management David Blood “the most significant thing we can do as capital allocators is to price in those difficult to price externalities” Liebreich (2025)

In the simplest sense, prices do not capture all costs. “Consumption, production, and investment decisions of individuals, households, and firms often affect people not directly involved in the transactions” (Helbling, 2012). Externalities as an economic concept was implied by Alfred Marshall, one of the founders of neoclassical economics, in his 1890 treatise “Principles of Economics,” and further developed by Arthur Cecil Pigou in his 1920 book “The Economics of Welfare” (Marshall, 1997; Pigou, 2002). As of 2023, the value of unpriced externalities which are not included in the GDP is 7.3 trillion USD per year (Trucost & TEEB for Business Coalition, 2023). The award-winning economist Mariana Mazzucato argues in (A. H. Gupta, 2020) we should include more into how we value unpaid labor, relating to the social (S in ESG) (Mazzucato, 2018) as part of our metrics.

11.4.5 Ecological Economics Builds Upon Classical Economics

While Adam Smith is most famous for his concept of the *invisible hand* first appearing in *The Theory of Moral Sentiments* (1759) and further developed in his seminal work *The Wealth of Nations*, published in 1776, his writings also highlight the interdependence of economic actors, who through specialization increase productivity, but also increasingly dependent on each other as well as the role of empathy in individual actions (Atal et al., 2024).

Ecological economics doesn’t necessarily argue with the foundation of classical economics, rather ecological economics finds the classical economics model and by extension neoclassical economics are *incomplete*, ignoring the physical limits of natural resources. Ecological economics draws attention to the interdependence of economy and the ecosystem; there are physical limits to economic growth on a planet with finite resources.

The biggest point of contention is the necessity of *economic growth*. The founder of ecological economics Herman Daly was talking about *prosperity without growth* more than two decades ago, focusing on the diminishing natural resources (Daly, 1997). Daly was teaching economics to undergraduates at Louisiana State University when he grew dissatisfied with the standard model of the market, which didn’t include any inputs (resources) or outputs (pollution), and later modeled his work by placing the economy *within* the larger system of the ecosphere (Ketcham, 2023). More recently.(Jackson, 2009, 2017) have expanded on these ideas with recipes for a *post-growth* world, making the ideas seem more tangible and precise, yet mostly untested in the real world.

Writing in 1973, E. F. Schumacher argued economics overlooks both natural resource depletion and environmental degradation and draws on religion (particularly Buddhism) to suggest a simpler way of life:

“Simplicity and non-violence are obviously closely related. The optimal pattern of consumption, producing a high degree of human satisfaction by means of a relatively low rate of consumption, allows people to live without great pressure and strain and to fulfil the primary injunction of Buddhist teaching: ‘Cease to do evil; try to do good.’” (Schumacher, 1985)

New economic thinkers are asking how can economic growth and sustainability be compatible. Some even ask if *economic growth* itself is the wrong goal? (Diduch, 2020). Lewis Hyde's book “The Gift” argues creativity thrives in “gift economies”; reciprocity is more important for creativity than market exchanges (Hyde, 2006).

(Yüksel et al., 2023) criticizes excessive financialization where the real economy and financial markets disconnected, blaming it for the the 2008 economic crisis, proposing a new index for *participation finance* aiming to ground the financial economy in the real economy; rooted in Islamic banking, participation finance avoids highly speculative activities, which are seen as exploitative, looking to promote stability, transparency, and fairness.

Degrowth is the most famous contender in that branch of economics. Is Decoupling Economic Growth and CO₂eq Emissions Possible? Is Green Growth an oxymoron? No-one knows as it hasn't been done before. Degrowth proponents are pessimistic it's possible to decouple greenhouse gas emissions from economic growth; historical data shows does not show any decoupling (Vadén et al., 2020).

The original Ramsey model introduced by Frank P. Ramsey in 1928, becoming foundational for traditional economic growth theory, does not assume infinite economic growth (Attanasio, 2015). (Marc Germain, 2016) has adopted the Ramsey Model and introduced constraints such as pollution, distinguishing renewable and non-renewable capital.

(Jackson, 2017) limits to growth update shows that absolute decoupling of GDP growth from environmental impact at the speed needed for climate targets is effectively impossible; prosperity should be redefined around wellbeing, sufficiency and resilience rather than perpetual economic expansion.

11.4.6 Doughnut Economics and Regenerative Capitalism

Doughnut Economics, introduced in the eponymous book uses a simple visualization of a doughnut (donut in American English) to help us grasp the big picture of the economy *embedded* inside the physical and social worlds (Raworth, 2017). Raworth calls to move beyond GDP growth, building economies that are regenerative and distributive by design, fitting human needs within planetary limits (De Balie, 2018). The Doughnut Economics model allows one to see the social shortfall and ecological overshoot of nations at the same time (A. L. Fanning et al., 2021). The doughnut concept is simple and deep at the same time, a useful as social object to enable starting

conversations with people from all walks of life, independent of their politics leanings. As Raworth calls it, it's a “*self-portrait of humanity in the beginning of the 21st century*”. Combining the *SDGs (Sustainable Development Goals)* inside the doughnut and the *Planetary Boundaries* (Earth’s ecological ceiling) outside the doughnut, leaves a space inside the donut represents a state of equilibrium and balance on spaceship Earth.

In some ways this Doughnut Economics can be described as a movement. Doughnut Action Labs enable local communities to build local donuts customized to local problems. While the ideas have not yet been implemented on a country-level, smaller scale doughnut economics’ success stories have inspired cities to take a comprehensive view of the doughnut of their own city with several EU cities adopting the vision (Jordan G. Teicher, 2021). While critics say doughnut economics would expand the role of the government (Horwitz, 2017), doughnut practitioners in Brussels believe everything can be adapted to the place and context (BrusselsDonut, 2022; Oikos Denktank, 2021).

The city of Amsterdam is developing shorter food chains (which save CO_{2e}) and linking residents with food production and reconnecting people to the food which foster collaboration in the community (Circle Economy, 2021). Amsterdam has also built comprehensive dashboards called the Circular Economy Monitor which makes it easy for anyone to see the progress being made towards the Dutch goal to be a circular economy by 2050 (Gemeente Amsterdam, 2022; Ministerie van Infrastructuur en Waterstaat, 2019).

Table 82: Circular Economics in Amsterdam’s Food Industry (Circle Economy, 2021).

Shortening Food Chains in Amsterdam
Spatial planning for food place-making in the city
Circular agriculture
Regionally produced food
Collaboration between chain members
Food education

In his 2015 paper Regenerative Capitalism, John Fullerton, an investor and a capital markets and derivatives expert, builds his economic theory on the ideas of Club of Rome and the Limits to Growth (Meadows & Club of Rome, 1972) as well as taking inspiration from R. Buckminster Fuller.

“Nature is a totally efficient, self-regenerating system. If we discover the laws that govern this system and live synergistically within them, sustainability will follow and humankind will be a success.” (Fuller, 1983)

“[H]uman civilization is embedded in the biosphere,” Fullerton’s ideas aim to balance efficiency with resiliency so the whole system doesn’t become brittle and break (Confino, 2015; John Fullerton, 2011, 2022). While regenerative capitalism recognizes the need for economic growth it also deems “[t]he quality of growth matters” (“Regenerative Capitalism,” 2023). For example, he cites the example of Triodos Bank which already in the 1980s focused on sustainable banking

championing responsibility, transparency, and business ethics. A member of the Global Alliance for Banking on Values, Triodos finances projects in nature preservation and restoration (GABV, 2023).

11.4.7 Decarbonization Scenarios

The possibility of decoupling economic growth from CO₂e emissions (also known as decarbonizing the economy or eco-economic decoupling) or is hotly debated (pun intended) among scientists. (Keyßer & Lenzen, 2021) provides several scenarios for low, medium, and high levels of decoupling titled Degrowth, IPCC, and Dec-Extreme.

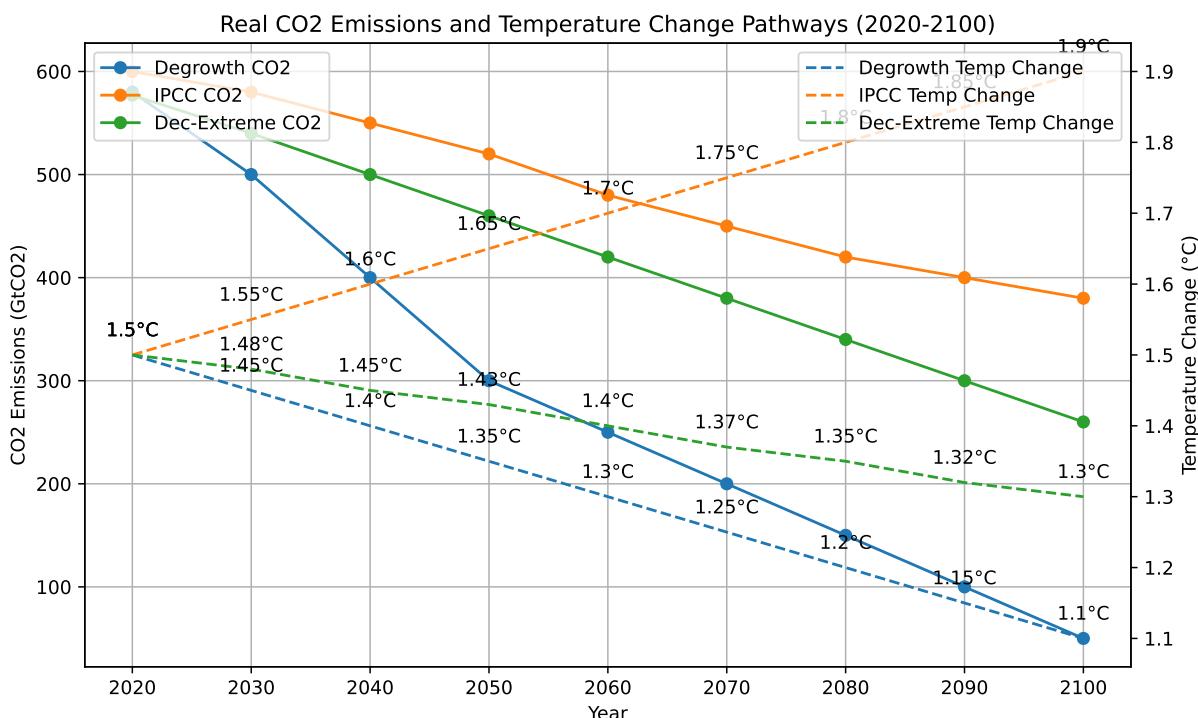


Figure 89: Climate Scenarios

Looking at the United Kingdom, (harrisson, 2019) concludes UK's CO₂e emissions have fallen 43% from 1990 to 2017 through the use of less carbon-intensive energy sources and argues for moderate policies in (Hausfather & Peters, 2020).

Meanwhile the cumulative CO₂e emissions trend in the UK in the same time-frame show the historic responsibility of UK (Global Carbon Budget, 2023).

CO₂e emissions and GDP growth per capita follow a similar path in the BRICS countries (Brazil, Russia, India, China, South Africa) as well as in Vietnam and Somalia (Raihan et al., 2024; Viana Espinosa De Oliveira & Moutinho, 2022; Warsame et al., 2024).

In practice, there's ample evidence from several countries suggesting moving to renewable energy brings environmental benefits. In Bangladesh, (Amin et al., 2022) suggests "removing fossil fuel

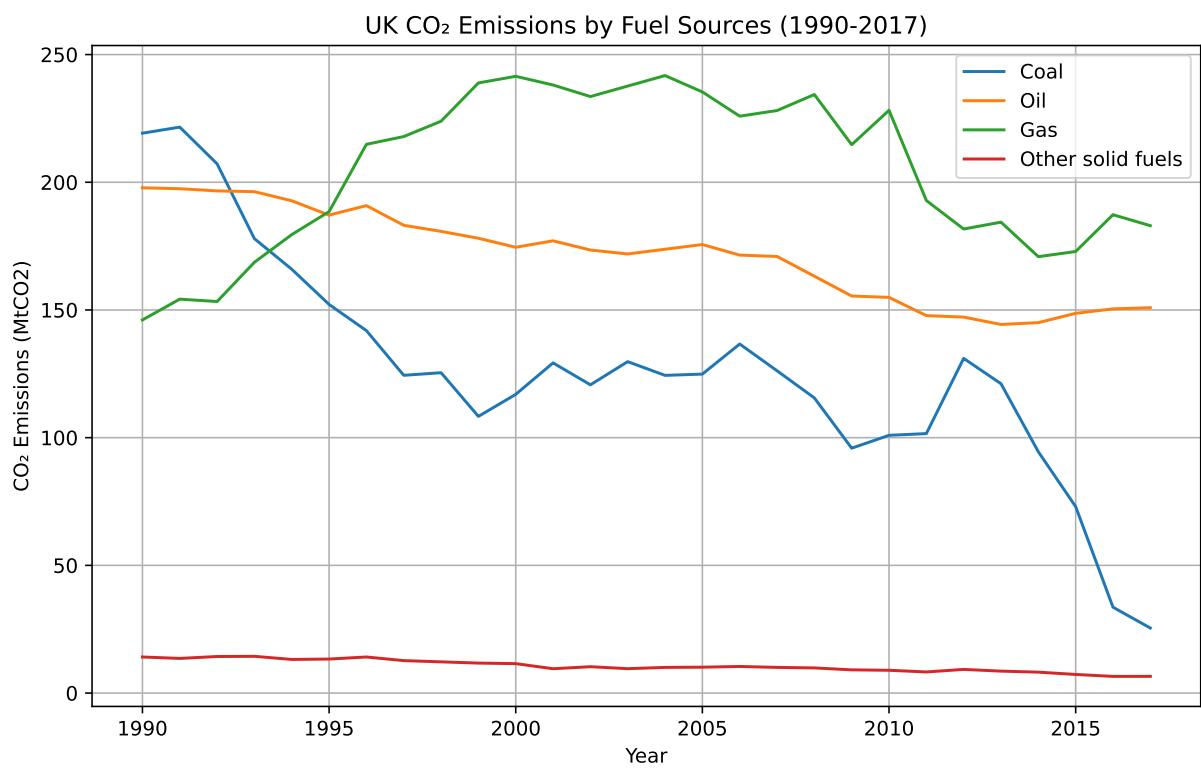


Figure 90: UK Energy Emissions' Trends

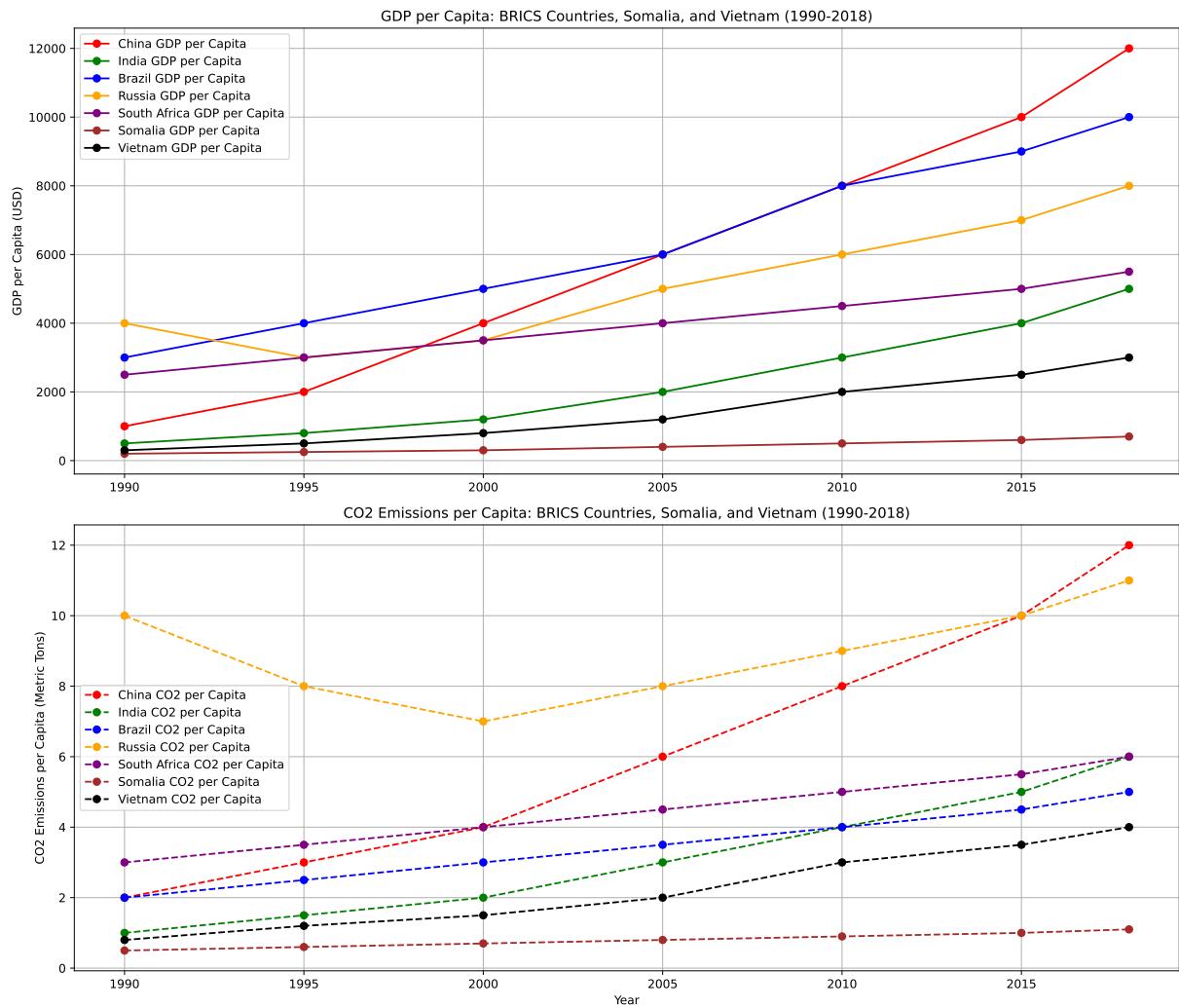


Figure 91: BRICS Emissions' vs GDP Growth Trends

subsidies and intra-sectoral electricity price distortions coupled with carbon taxes provides the highest benefits" for both the economy and the environment. In other words, green energy is a win-win solution, for both the environmental health and financial wealth.

There are still low-hanging fruits to be picked in terms of energy efficiency. (Devlin & Yang, 2022) analysed regional steel supply chains between Australia and Japan, finding that co-locating steel manufacturing with renewable energy sources would provide the highest energy efficiency, reducing energy consumption by up to 45%; moreover, a carbon tax of 43-123 USD per tonne of CO₂eq would mitigate the "green premium". (Stefan Klebert, 2022) CEO of GEA, a large producer of machinery and heat pumps, highlights that heating and cooling account for between 50-90% of energy use in processing plants; deploying state-of-the-art heat pump technology can half CO₂eq emissions; large-scale carbon-neutral manufacturing is already possible with existing technologies.

One example is Innocent's Rotterdam juice plant, which operates a carbon-neutral facility (in terms or energy use for processing) by integrating heat pumps to capture and reuse waste heat across the production process; the article does not cover emissions from the juice source materials (*Innocent Opens £200m Carbon-Neutral Factory in Rotterdam - Investment Monitor*, n.d.). Palsgaard, a large producer of emulsifiers and stabilisers for food industries, reports similar results of carbon-neutral production, through using advanced heat-management and green energy (hydro-power in Denmark) sources (*CO2-neutral Factories*, n.d.). The Green Transition Denmark think-thank has published a report calculating that the complete decarbonization of Denmark by 2040 would cost about 6.2 billion Danish krone (close to \$1 Billion USD) per year, achieving full net-zero emissions, full electrification of road transport, electrification of 75% of industry and 30% of heating, capping biomass use at 10.5 PJ (petajoules) to boost forest carbon storage by 1.6 Mt CO₂, expand forests by 290 000 ha, and reduce farmland by 34%, while producing 90 PJ of green fuels (Møller & Tang, 2024).

Already in 2019, Alois Müller built an example "Green Factory" in Ungerhausen, where a 1.1 MW rooftop photovoltaic system supplies 2/3 of the electricity (feeding excess power to the grid), combined with a heat and power boiler powered by biogas and pellets (note: pellets have become very controversial as their sustainability highly depends on the source material), a 100000 liter buffer tank for waste heat, and a 230 kWh lithium battery (VDI Zentrum Ressourceneffizienz, 2020).

Advances in sensors, AI, and robotics, increasingly enable *lights-out manufacturing*, which leverages full automation, producing 24/7, with minimal to no human interaction, while increasing productivity and efficiency (Eric fogg, 2020).

11.4.8 Reducing the Gap Between Climate Science and Climate Economics

William Nordhaus won a Nobel Prize in 2018 for attempting to combine climate change and economics in a single, integrated assessment model, named *Dynamic Integrated Climate-Economy (DICE)*, however his predictions are considered inaccurate by climate scientists, underestimating the risk of catastrophic warming, tipping points, and the probability of higher temperatures

leading to mass death (Jones & Steffen, 2019; Kemp et al., 2022; Ketcham, 2023; Stern et al., 2022; Stern, 2022a; Y. Xu & Ramanathan, 2017).

Energy and climate change economist Noah Kaufman says economists don't understand climate and climate scientists don't understand economics; and calls out economic calculations which try to estimate climate damages over hundreds of years or find a price for climate equilibrium, as nonsensical (dessler2, 2024). Instead, in a recent paper, co-written with another Nobel prize-winning economist, Joseph Stiglitz, they argue economics can solve climate change through a risk-management approach for policy support, focusing on lowering climate risk by achieving net-zero carbon emissions (Stiglitz et al., 2024).

While Nordhaus has been criticized for his numbers, the general idea of his early book titled “The Climate Casino” doesn’t disagree. Nordhaus himself likens the current trajectory of climate change to humanity entering a “climate casino,” where we’re gambling with the planet’s future (Nordhaus, 2013). Written a decade later, Nordhaus asks if we can still exit the casino, and is much more pessimistic than in his early work (Institute of International and European Affairs (IIEA), 2023).

Although over 100 different scientific journals now publish work on sustainability economics, the field remains highly fragmented, with little interaction between research clusters. A bibliometric study of 1987–2013 publications found 11 largely self-contained research clusters, with minimal cross - citation; for example the Nordhaus - style integrated - assessment - modeling literature had almost no overlap with another prominent researcher, Elinor Ostrom, whose work focuses on commons governance within sustainability economics (Drupp et al., 2020).

Kaufman decries the lack of real-world data in the economic-climate models, and believes the simple assumptions should be replaced with much more complex scientific analysis (dessler2, 2024).

(T.-P. Wang & Teng, 2022) conducted a systematic comparison of 3 leading integrated assessment models (IAMs) to quantify climate change damages globally and for China specifically, valued as percentage of GDP; the models are as follows FUND (Framework for Uncertainty, Negotiation and Distribution), RICE (Regional Integrated model of Climate and the Economy) and PAGE (Policy Analysis of the Greenhouse Effect)

Table 83: Quantifying climate damage scenarios using integrated assessment models (T.-P. Wang & Teng, 2022).

Climate Damage	Value	Context
Climate damage per 1 °C warming (China)	≈ 1.5 % of China's GDP	Average estimate across FUND, RICE and PAGE
Climate damage per 1 °C warming (global)	≈ 0.7 % of world GDP	Average estimate across FUND, RICE and PAGE
Average reduction in climate damage: 2 °C target (China)	93 % reduction	vs business-as-usual in average-case scenario

Climate Damage	Value	Context
Average reduction in climate damage: 2 °C target (global)	87 % reduction	vs business-as-usual in average-case scenario
Worst-case reduction in climate damage: 2 °C target (China)	80 % reduction	vs business-as-usual in the worst-case damage scenario
Worst-case reduction in climate damage: 2 °C target (global)	84 % reduction	vs business-as-usual in the worst-case damage scenario

11.5 Efforts to Curb Greenwashing: Data-Driven Benchmarks and the Fight for Transparency

Because corporate hypocrisy is a blocker of sustainable action, both the European Commission and the Chair of U.S. Securities and Exchange Commission (SEC) Gary Gensler have called for more legislation to curb business greenwashing practices. “*If it’s easy to tell if milk is fat-free by just looking at the nutrition label, it might be time to make it easier to tell if “green” or “sustainable” funds are really what they say they are*” says Gensler (US Securities and Exchange Commission, 2022).

Upcoming EU greenwashing legislation hopes to curb misleading communications by companies. The EU regulation for standardizing sustainability reporting, called the Corporate Sustainability Reporting Directive (CSRD) entered into force on 5 January 2023 and will be phased in across fiscal years 2024 to 2026 (with reports due in 2025 through 2027), requiring companies to comply with the new European Sustainability Reporting Standards for detailed environmental, social and governance disclosures (Normative, 2025). Environmental information legislation generally entitles all individuals to access environmental data through environmental information disclosure (EID), and the notion of “environmental information” spans a wide variety of topics (Oelkers, 2020).

EU’s Ecodesign Regulation for Sustainable Products (ESPR) requires mandatory documentation of environmental impacts for all product categories, bans self-declared green claims by, and sets out specific design criteria, including durability, reparability, recycled content, remanufacturing, lifecycle impacts, and waste prevention (Nastaran Vadoodi, 2022). Until new legislation is ramped up to shift from linear to circular product development, building consumer awareness is crucial as currently most emission-reduction programs are voluntary and thus affected only by consumer demand (André & Valenciano-Salazar, 2022). Greenwashing is widespread in company social media communications (Geoffrey Supran, 2022). A number of new AI-based tools aim to find instances of greenwashing. ClimateBert AI finds rampant greenwashing (Bingler et al., 2021; Sahota, 2021).

“Make benchmark methodologies more transparent when it comes to ESG & put forward standards for the methodology of low-carbon and ESG benchmarks in EU”
(European Commission, 2019b).

While the EU has proposed legislation to curb greenwashing, EU climate policy itself has been criticized for greenwashing. Sometimes greenwashing comes under legislative protection, due to oversight or private business interests and lobbyists (Frédéric Simon, 2020; Kira Taylor, 2021). (Booth, 2022) describes how wood pellets may be counted as an sustainable energy source, even though they cause deforestation:

“A recent investigation shows illegal logging of protected areas in eastern European countries that supplies residential wood pellets in Italy. Belgium, Denmark, and the Netherlands are importing pellets from Estonia, where protected areas are logged for pellets and the country has lost its forest carbon sink, despite large-scale wood pellet plants being certified ‘sustainable’ by the Sustainable Biomass Program” - (Booth, 2022).

While new EU legislation for deforestation-free products may eventually solve this issue (or at least mitigate the worst outcomes), the application of these laws is delayed as of writing (European Commission, 2024a; Parrish, 2025). In the US, a large wood pellet producer Enviva filed for bankruptcy protection after being sued for misleading the public about the sustainability of its products, yet managed to survive and is now again expanding its biomass business; likewise, Drax Group, another large pellet producer managed continues business after a public backlash (Catanoso, 2024; Diver, 2025; Millard, 2025).

In recycling systems,(Purkiss et al., 2022) highlights the confusion between compostable and biodegradable plastics and public misunderstanding what happens to these plastics when they reach the landfill: “[m]ost plastics marketed as “home compostable” don’t actually work, with as much as 60% failing to disintegrate after six months”. Shopping bags marketed as *biodegradable* don’t show deterioration after 3 years in salt-water sea environment (Napper & Thompson, 2019).

Green investing only makes sense if it’s possible to distinguish sustainable investments from not sustainable ones. If humans feel as if choosing green is useless, they easily give up. Sustainable investing is firstly about changes in legislation which set stricter sustainability standards on companies (as discussed above). Secondly, increased transparency, new metrics, and new tools make it feasible to differentiate more sustainable companies from less sustainable ones.

If I may conclude with a list:

- Sustainable investing is based on data.
- Greenwashing is a large detractor from environmental action as it’s difficult to know what is sustainable and what is not.
- Greenwashing disturbs sustainable capital allocation.
- Greenwashing erodes trust.
- Greenwashing has a negative impact on credibility.

The promise of ESG is to counter misinformation with transparency.

11.5.1 Anti-Greenwashing Efforts in Taiwan

The Taiwanese Financial Supervisory Commission, the Ministry of Environment, the Ministry of Economic Affairs, the Ministry of Transportation and Communications, and the Ministry of the Interior collaborated on the “*Reference Guidelines for the Identification of Sustainable Economic Activities*” to encourage the financial industry to assist enterprises in their transition to sustainable carbon reduction” (金管會 & Financial Supervisory Commission, 2022)

The Taiwanese Corporate Governance Sustainable Development Roadmap published by the Corporate Governance Reform Task Force established by the Executive Yuan (Taiwanese Government), identifies *lack of diversity and independence in boards* and *insufficient ESG and financial information transparency* as key issues (Taiwan Stock Exchange Corporation, 2023).

The Taiwanese Green Citizens Action Alliance published a comprehensive report in 2024 tracking Taiwanese Corporate Sustainability Reporting focused directly at fighting corporate greenwashing (綠色公民行動聯盟, 2024).

11.5.2 Product Databases as a Precursor for Traceability and Supply Chain Mapping

In order to consider the sustainability on a product level, there should be a directory of all the world’s products - a world product database. GS1 is the organization responsible for issuing EAN/UPC barcodes found on most consumer products worldwide (GS1, n.d.). However, while the UPC stands for Universal Product Code, there is no truly centralized, authoritative database of all UPCs, which has led to duplication and inconsistency across products sharing the same codes, especially with the rise of e-commerce marketplaces (Semantics3, 2017). As early as 2016, (Håkon Bogen, 2016) raised questions whether a global database of all EAN (European Article Number) barcoded products could be created. Barcodes help identify products within supply chains and retail systems, but they do not alone create a central product registry. On a basic level, standardized product codes ensures product inventory, traceability, automated checkout, and support global trade. All of the world’s products already are subject to one or another standard and although they are not uniform, some documentation does exist about every product.

A number of specialized product databases have been created to fill specific needs. The Open Product Database maintained by Datakick (Datakick, n.d.) aimed to crowdsource product information but faced limitations and is no longer widely active. WIPO GREEN, the global green technology database, catalogs environmentally sustainable innovations (WIPO GREEN, n.d.). The World Packaging Database provides detailed information about product packaging worldwide, important for understanding material impacts (“Packaging World,” n.d.).

In a similar vein, Konrad (n.d.) imagines the possibility of an internet-wide directory of purchasable products, akin to how platforms like Spotify have made nearly all of the world’s music easily searchable and accessible. However, despite the obvious need, attempts to build such directories have faced significant challenges. For example, the Open Knowledge Foundation’s

Open Product Data initiative (“Open Product Data” (n.d.)) was eventually shut down, highlighting how difficult it is to maintain open, comprehensive, and up-to-date product information at a global scale.

While some infrastructure exists, including bar and QR-codes, standards, and partial databases, the world still lacks a unified, reliable, open-access product database. Building such a system could improve sustainability assessments, supply chain transparency, and informed consumer choices at the global scale.

11.5.3 Indices, Certifications and Sustainability Standards Enable Product Comparisons

Research shows certification does matter. In Europe, consumers are willing to pay more for bio-based products “*72% of Europeans are willing to pay more for environmentally friendly products. The study identifies a “green premium” and a “certified green premium,” indicating increased WTP for bio-based and certified bio-based products*” (Morone et al., 2021). Particularly in Italy, a study of consumer awareness of sustainable supply chains shows Italian consumers have a strong preference for antibiotic-free meat (Mazzocchi et al., 2022).

Open ESG data platform Wikirate currently lists 4316 different metrics, essentially questions which companies should answer (Wikirate, 2025).

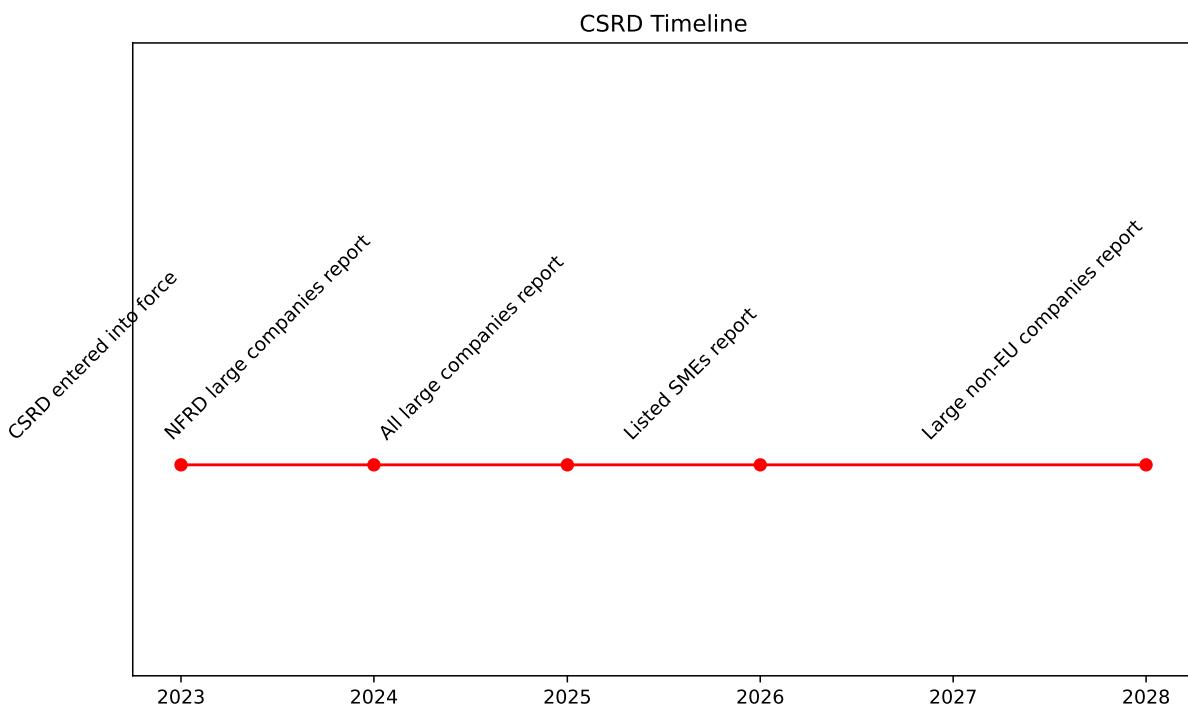


Figure 92: Corporate Sustainability Reporting Directive (CSRD) Timeline

Companies assess customer’s credit score to decide credit-worthiness, however inversely, how can customers rate companies? Indices make comparing companies possible. There are many-

many indexes, scoring systems, ratings, certifications, etc. Most sustainable companies. Make a database?

Sustainability indices need transparency and standardization (Bolognesi et al., 2024).

Based on Corporate Knights data (Corporate Knights, 2024)

Energy productivity and carbon productivity are measures of how energy intensive a product is per unit of productivity. There are people working on improving efficiency; for example (J. Luo et al., 2022) suggests using reinforcement learning to reduce energy use in cooling systems.

Energy productivity

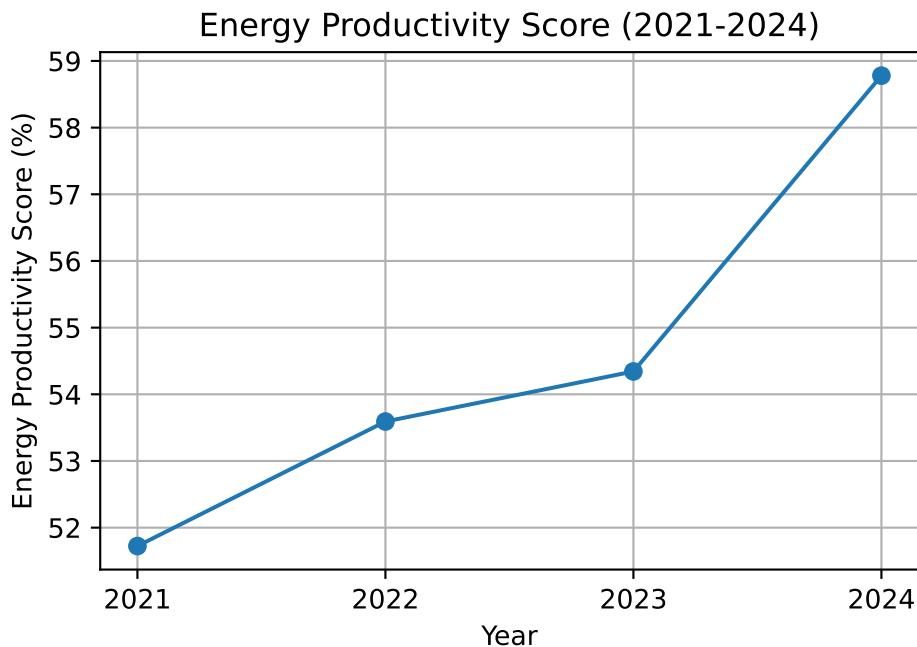


Figure 93: Energy Productivity

Carbon productivity

There are many standards. (International Trade Centre, 2022) currently lists 334 different sustainability standards: “Towards a meaningful economy” “The world’s largest database for sustainability standards”, “We provide free, accessible, comprehensive, verified and transparent information on over 300 standards for environmental protection, worker and labor rights, economic development, quality and food safety, as well as business ethics.”

Table 84: Sustainability Certification Systems

Type	Rating System	What It Does?
Certificate	B Corporation ESG	B Impact Assessment

Type	Rating System	What It Does?
Certificate	Fair Trade	
Ranking	Responsible Business Index	Responsible Business Index (<i>Estonian Responsible Business Index</i> , n.d.)
Index	Greenly	Greenly Decarbonization Index (Greenly, 2023)
	Science-Based Targets	Science-Based Targets initiative (SBTi) provides step-by-step guidance per economic sector to help companies get started with meeting climate criteria and emission reduction requirements.
Certificate	Green Web Foundation	The Green Web Foundation certifies how sustainable is the web hosting used by websites (“The Green Web Foundation,” 2023). Also tests website CO ₂ emissions (Wholegrain Digita, 2023).
	Leafscore for product	Sustainability rating for products (LeafScore, 2023)
Rating	Ethical Consumer Ratings	Ethical shopping and sustainability criteria (<i>About Ethical Consumer Ethical Consumer</i> , 2018)
Standard	1% For the Planet Climate Neutral Certified Standard	
Standard	The Conservation Alliance	(Climate Neutral Certified, 2023)
Index	Impakter Sustainability Index	

There are many different certifications for sustainable brands. Existing rankings include fashion brand ratings and ethical shopping. The Top 100 Consumer Brands report showing brands ranked by consumer sustainability preferences from the largest consumer goods companies (“Top 100 Consumer Goods Companies of 2021,” n.d.).

The Ethical Consumer Research Association active since 1989 publishes a magazine and keeps an active list of boycotts, which currently (as of May 15, 2025) includes 47 boycott campaigns (*About Ethical Consumer | Ethical Consumer*, 2018; *Boycotts List | Ethical Consumer*, 2018).

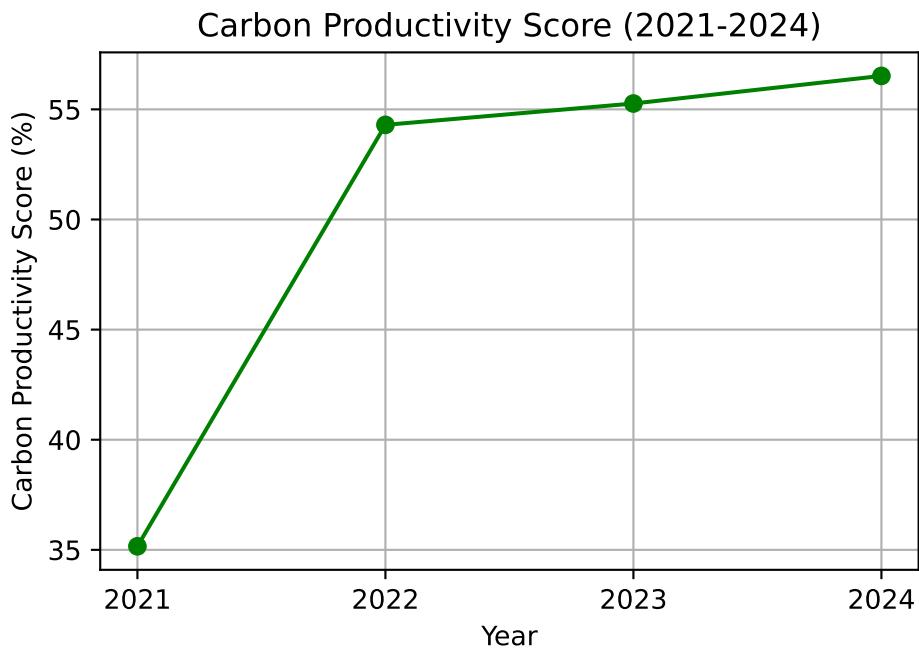


Figure 94: Carbon Productivity

Table 85: Boycotts - Active Boycotts Against Companies

Target	Category	Organizer	Launch
Airbnb	Human Rights	BDS National Committee	2016
Amazon	Human Rights	BDS National Committee	2024
Amazon (tax-avoidance)	Tax Avoidance	Ethical Consumer	2012
AXA	Human Rights	BDS National Committee	2019
Barclays Bank	Human Rights	Palestine Solidarity Campaign	2024
Booking.com	Human Rights	BDS National Committee	2024
Burger King	Human Rights	BDS National Committee	2024
Chevron	Human Rights	BDS National Committee	2022
Coca-Cola Coconut milk (from Thailand)	Human Rights Animal Rights	Friends of Al-Aqsa PETA	2014 2022

Target	Category	Organizer	Launch
Crufts dog show	Animal Rights	PETA	2014
Disney / Marvel	Human Rights	BDS National Committee & allies	2023
Ecover	Animal Testing	Naturewatch Foundation	2018
eToro	Human Rights	Tech for Palestine	2024
Expedia	Human Rights	BDS National Committee	2024
Get Your Guide	Animal Rights	World Animal Protection	2023
Google	Human Rights	BDS National Committee	2024
Groupon	Animal Rights	World Animal Protection	2023
Hewlett Packard Enterprise (HP)	Human Rights	BDS National Committee	2012
Israeli dates	Human Rights	American Muslims for Palestine	2012
Israeli produce in supermarkets	Human Rights	BDS National Committee	2005
JCB	Human Rights	BDS National Committee	2024
Kellogg's	Environment	GMO-Free USA	2012
L'Oréal	Animal Testing	Naturewatch Foundation	2000
"Made in China" goods	Human Rights	Friends of Tibet & others	2020
McDonald's	Human Rights	BDS National Committee	2024
Method	Animal Testing	Naturewatch Foundation	2018
Mitie	Human Rights	Women for Refugee Women	2023
Nestlé (baby-milk)	Human Rights	Baby Milk Action	1977
Nestlé (water extraction)	Environment	Lakota People's Law Project	2018
Papa John's	Human Rights	BDS National Committee	2023
Pizza Hut	Human Rights	BDS National Committee	2023
Russia (national boycott)	Oppressive Regimes	Government of Ukraine	2022

Target	Category	Organizer	Launch
Sabra Hummus	Human Rights	BDS National Committee	2010
Siemens	Human Rights	BDS National Committee	2022
SodaStream	Human Rights	BDS National Committee	2012
Starbucks	Habitats & Resources	Lakota People's Law Project	2023
Tesco Bank	Human Rights	Palestine Solidarity Campaign	2024
Texaco	Human Rights	BDS National Committee	2022
Trip.com	Animal Rights	World Animal Protection	2023
Tui	Animal Rights	World Animal Protection	2023
X / Twitter	Human Rights	Stop Toxic Twitter coalition	2022
Unilever (Russia operations)	Human Rights	B4Ukraine	2024
Volvo (AB Volvo trucks)	Human Rights	BDS National Committee	2024
Wendy's	Workers' Rights	Coalition of Immokalee Workers	2005
Wix	Human Rights	Tech for Palestine	2023
World Wildlife Fund (WWF)	Human Rights	WTF WWF coalition	2020

OpenCorporates attempts to map all the companies around the world - “*the largest open database of companies in the world*,” - as per their tagline, launched a collaboration with the UNSD (United Nations Statistics Division) and the OECD (Organisation for Economic Co-operation and Development) to close the information gap on the 500 largest multinational enterprises (termed *MNEs*) to tackle the problem (as per their tweet on X, formerly known as Twitter): “*Hidden data is a big problem, and it's limiting our understanding of the world's largest #Multinational enterprises*” (Communications, 2023; opencorporates [@opencorporates], 2024)

WikiRate, started in 2010, is a tool for checking green credentials and “[t]he largest open registry of corporate sustainability data in the world” (Mills et al., 2016; WikiRate, 2023). Transparency is about culture but also mechanisms and tools, which is why WikiRate defines Data Sharing Archetypes (WikiRate, 2021).

Table 86: Data Sharing Archetypes defined by WikiRate.

Type	Example
Transparency Accountability	
Advocate	
Compliance Data Aggregator	
Data Intelligence Hub	
Worker Voice Tool	(Caravan Studios, 2022): “ Worker Connect ”
Traceability tool	trustrace.com
Open data platform	
Knowledge sharing platform	business-humanrights.org

At the 2023 Scottish AI Summit, practitioners demoed how AI pipelines can analyze modern slavery statements to flag missing disclosures, suggesting how humans and machines can “scale corporate accountability” like never before (Laureen van Breen et al., 2023). Meanwhile, WikiRate’s Facility Checker uncovers living-wage gaps in real time for advocacy organizations (Wikirate, 2022a)

Certified B Corporations undergo a rigorous B Impact Assessment (only those scoring 80 or above can earn the B Corp seal) and adhere to strict sustainability practices, which gives as placement in the B Lab global directory. Stakeholders can explore B Corps by country and industry, complete with verified impact scores and performance details. This digital platform is used by over 150 thousand businesses to manage their ESG performance (B Corp, 2025).

Maintaining that trust matters. In 2017, Etsy lost the certification after failing to convert a public company into a public benefit company for fear of shareholder reaction (Alba, 2017; Silverman, 2017). Instead, Etsy launched a campaign to focus on transparency, called “Made Mistakes”, publicly sharing user-experience errors to build trust (“Etsy Made Mistakes, but Its Commitment to Social Responsibility Wasn’t One of Them,” 2017).

Citywealth’s “*ESG branding with B-Corps*” guide shows how companies can leverage their B Corp status—using consistent logo placement, stakeholder storytelling, and transparent impact data to avoid greenwashing and attract impact-focused investors (Citywealth, 2021). (“Social Enterprises, B Corps, Benefit Companies, ESG,” 2025) explains how the true social and financial value of mission-driven enterprises comes from aligning the documentation with the reality.

11.6 Navigating Complexity with Data: Probabilistic Risk-Based Assessment of Sustainability

In order to make a difference in sustainability, with large capital flowing into the environment at scale to deliver climate action, the markets for ecosystem assets would need to scale urgently, starting with carbon credits. BeZero is a startup innovating in the Voluntary Carbon Credit Market (VCM) by providing *risk-scoring*, a language financial professionals are accustomed

to working with other types of asset classes (BeZero, 2022b; *Navigating Net Zero with Co-founder of BeZero Carbon*, 2023). The VCM is limited by immature market structures, which means market participants still struggle to price and manage risk properly; BeZero ratings frames carbon credits in a probabilistic, risk-based language familiar to large investors who oversee roughly 200 Trillion USD of global assets (BeZero, 2022a).

“The challenge is to make these instruments as recognizable as tradable assets, as measurable as financial securities, and as investable as other asset classes. Efficient financial markets allocate and manage risk based on effective price mechanisms, and this relies on access to credible information.” (BeZero, 2022b)

Table 87: Bottlenecks in Carbon Markets

Bottleneck in VCM	BeZero	Carbonmark
Hard to gauge quality and downside risk Fragmented, slow, OTC trading	Provides probabilistic ratings investors already understand —	— Consolidates registries, offers 24/7 liquidity and smart-contract settlement
Need to move big capital fast	Gives financiers a common risk language	Cuts friction so large orders can clear quickly

Sustainability is a complex web of interconnections. To treat nature as commodity is a category mistake: it's impossible to bring back already destroyed biodiversity which took millennia to develop. Humans create hugely complex systems using technology, instead of simply conserving nature. In a sense, climate action as an asset-liability problem, however the assets are non-fungible. They are rare and incredibly valuable.

12 RESULTS

“Research shows that showing people research doesn’t work,” John Sterman (P. Tan, 2018)

It is famously difficult to convince humans of anything using facts, logic, and sound argumentation. However, at the same time, humans are fallible to manipulation. This section will focus on the facts, while the next section (Discussion) will attempt to operationalize some of the findings.

12.0.1 Survey and Data Analysis Overview

- A survey of Taiwanese college students, covering attitudes towards shopping, saving, investing, economy, nature, sustainability, and AI.
- The survey was open from October 13th 2023 to May 31 2025
- 3000 cards with a QR code printed out
- Distribution conducted at 21 universities handing out the cards
- 1644 people started the survey, and 658 quit
- 986 people completed the whole survey
- Data after filtering 675 people aged 18-29 GenZ; Taiwanese; current students; respondents studying in BA (large majority), MA (small minority) or PhD level (very few).
- 36 likert fields, 5-point scale, used for clustering the students into 3 personas with K-means clustering-
- 14 product features multiple-choice used for Kmodes clustering
- 4 choice experiments
- 2 option ranking questions
- 10 qualitative text fields used to enrich the personas
- K-Means clustering was used on quantitative survey data to build similarity-based personas. K-Means is akin to vector distances for similarity, used in large language models (LLMs), word embeddings, and deep learning.

12.0.2 Quotes from the Survey

Even though most of the survey questions were numeric, the respondents did have the opportunity to write more in open-ended questions. Here are some selected quotes:

“I worry whether info from AI is trustworthy, whether politics or business bend it, and whether my own data steers the algorithm and reshapes what I see.”, anonymous student at National Taiwan University

“Right now I care most about how carbon emissions could raise future costs for companies, so when I invest I look at whether their carbon liabilities outweigh their carbon assets.”, anonymous student at Taichung Feng Chia University

“People will only focus on sustainability if they can afford to. When a family’s budget is tight, putting food on the table beats caring about the planet.” anonymous student at Tainan National Cheng Kung University.

“When we were kids, Dad made us bring a shopping bag and reuse it. Even if it got dirty, we could turn it into a trash bag.”, anonymous student at Taoyuan Ming Chuan University.

“Take our school as an example. We boast about being the top green university in the country and we run plenty of green research projects, yet students’ eco-awareness has not really improved. Even with constant green messaging, the cafeterias are still flooded with ‘eco’ chopsticks and plastic spoons.”, anonymous student at National Pingtung University of Science and Technology (NPUST)

“Every purchase is a vote for our own future. College students can keep choosing green brands and changing their habits. Paying attention to these issues puts pressure on companies and pushes them toward cleaner production.”, anonymous student at Fu Jen Catholic University (FJU)

“AI can handle the time-consuming math and analysis, but I can only use it effectively if I have baseline knowledge of what I am asking.”, anonymous student at National Taiwan University (NTU)

“If eco-friendly products use fewer materials, they ought to be cheaper. No one should strong-arm me into buying something expensive.”, anonymous student at National Chung Hsing University (NCHU)

“Probably eco-education. Taiwan’s education system is lousy in many ways, yet the part that builds environmental awareness in students is actually useful.”, anonymous student at Fu Jen Catholic University (FJU)

“Let’s talk about why people want sustainability, what benefits it brings to the environment, how we can see the results, and how much worse things get if we ignore it.”, anonymous student at Chang Gung University (CGU)

“Your survey is interesting, but in my opinion most Taiwanese citizens will find it hard to fill out. There are specialised terms without explanations. Otherwise it is great. A few typos could be fixed, but you are a foreigner, you are already doing awesome.”, anonymous student at National Dong Hwa University (NDHU)

“You could ask Taiwanese friends to review the survey’s wording. Keep going. Thank you for your bright smile, a smile can advance sustainability. I believe in the power of the spirit.”, anonymous student at National Tsing Hua University (NTHU)

There are many, the above is a sample of the responses.

12.1 Respondent Demographics

12.1.1 Study Level

	Study Level	Number of Students
0	學士	780
1	碩士	88
2	博士	8

Figure 95: Study Level

12.1.2 Age Distribution

	Age	Number of Students
0	18.0	214
1	21.0	167
2	19.0	163
3	20.0	146
4	22.0	82
5	23.0	45
6	24.0	25
7	25.0	17
8	29.0	6
9	26.0	6
10	27.0	4
11	28.0	1

Figure 96: Age Distribution

12.1.3 University

12.1.4 Field of Study

Fields of study have not been normalized: there may be several expressions of the same academic department, written slightly differently.

12.1.5 Personality Type

	University	Number of Respondents
0	國立成功大學 National Cheng Kung University (NCKU)	188
1	輔仁大學 Fu Jen Catholic University (FJU)	159
2	銘傳大學 Ming Chuan University (MCU)	134
3	國立臺灣大學 National Taiwan University (NTU)	101
4	逢甲大學 Feng Chia University (FCU)	52
5	國立東華大學 National Dong Hwa University (NDHU)	45
6	國立臺東大學 National Taitung University (NTTU)	24
7	長榮大學 Chang Jung Christian University (CJCU)	22
8	國立臺南大學 National University of Tainan (NUTN)	19
9	南臺科技大學 Southern Taiwan University of Science a...	18
10	國立中興大學 National Chung Hsing University (NCHU)	15
11	開南大學 Kainan University (KNU)	14
12	國立高雄師範大學 National Kaohsiung Normal University ...	9
13	嘉南藥理大學 Chia Nan University of Pharmacy and Sci...	8
14	臺南應用科技大學 Tainan University of Technology (TUT)	7
15	僑光科技大學 Overseas Chinese University (OCU)	5
16	國立屏東科技大學 National Pingtung University of Scien...	4
17	國立臺灣科技大學 National Taiwan University of Science...	4
18	國立清華大學 National Tsing Hua University (NTHU)	3
19	國立政治大學 National Chengchi University (NCCU)	3
20	國立中央大學 National Central University (NCU)	3
21	國立臺灣師範大學 National Taiwan Normal University (NTNU)	3
22	臺北醫學大學 Taipei Medical University (TMU)	2
23	東海大學 Tunghai University (THU)	2
24	高雄醫學大學 Kaohsiung Medical University (KMU)	2
25	國立臺灣海洋大學 National Taiwan Ocean University (NTOU)	2
26	中華醫事科技大學 Chung Hwa University of Medical Techn...	1
27	國立臺北大學 National Taipei University (NTPU)	1
28	南台科技大學	1
29	國立中正大學 National Chung Cheng University (CCU)	1
30	國立嘉義大學 National Chiayi University (NCYU)	1
31	國立高雄科技大學 National Kaohsiung University of Scie...	1
32	元智大學 Yuan Ze University (YZU)	1
33	我是台南一中的高三生	1
34	國立臺東專科學校 National Taitung Junior College (NTC)	1
35	東吳大學 Soochow University (SCU)	1
36	國立臺南藝術大學 Tainan National University of the Art...	1
37	明道大學 MingDao University (MDU)	1
38	國立臺北科技大學 National Taipei University of Technol...	1
39	玉山神學院	1
40	國立金門大學 National Quemoy University (NQU)	1
41	台南應用科技大學	1
42	南港高中	1
43	經國管理暨健康學院 Ching Kuo Institute of Management an...	1
44	國立暨南國際大學 National Chi Nan University (NCNU) ²⁸⁵	1
45	佛光大學 Fo Guang University (FGU)	1
46	亞洲大學 Asia University (ASIA)	1
47	國立中山大學 National Sun Yat-sen University (NSYSU)	1

	Field of Study	Number of Students
0	犯罪防治學系	26
1	影像傳播學系	20
2	影像傳播	17
3	華語文學系	13
4	外文系	12
...
407	英文	1
408	行銷流通系	1
409	科技管理研究所	1
410	行流系	1
411	保健營養系	1

Figure 98: Field of Study

12.2 Shopping

12.2.1 Boycott Count (Overall)

12.2.2 Why Boycott

12.2.3 Trusted Brands

The following responses were counted as “no brand”: “無”, “沒有”, “沒有特別”, “無”, “目前沒有”, “No”, “沒”, “沒有特別關注”, “沒有特別信任的”, “不知道”, “無特別選擇”, “目前沒有完全信任的”, “沒有特定的”, “沒有特定”, “沒有特別研究”, “目前沒有特別關注的品牌”, “N”, “none”, “無特別”, “目前無”, “沒有特別想到”, “沒有固定的”, “x”, “沒在買”, “nope”, “一時想不到...”, “沒有特別注意”, “無特別的品牌”, “無絕對信任的品牌”, “不確定你說的範圍”, “還沒有”

12.3 Choice Experiments

	MBTI Type	Number of Students
0	INFP	121
1	INFJ	91
2	ENFP	63
3	不知道	55
4	ISFJ	48
5	ENFJ	39
6	INTP	37
7	ISFP	31
8	ENTP	29
9	ESFJ	23
10	ESFP	22
11	INTJ	20
12	ESTJ	16
13	ISTJ	15
14	ESTP	11
15	ISTP	11
16	ENTJ	9
17	INTJ, INFJ	2
18	INFP, INTP	2
19	INFP, ISFP	2
20	INFP, ENFP	1
21	INTP, INFP	1
22	ISTJ, 不知道	1
23	ESFP, ENFP	1
24	ESTJ, ENFP, ENTP, ESFJ, ESTP, ESFP, INTP, INFP	1
25	ENTP, ENFP	1
26	ISFJ, INFP	1
27	ISFJ, ESFJ	1
28	INFJ, ISFP, INFP	1
29	ESFJ, ENFJ	1
30	ENTJ, ISTJ	1

Figure 99: Personality Type (MBTI)

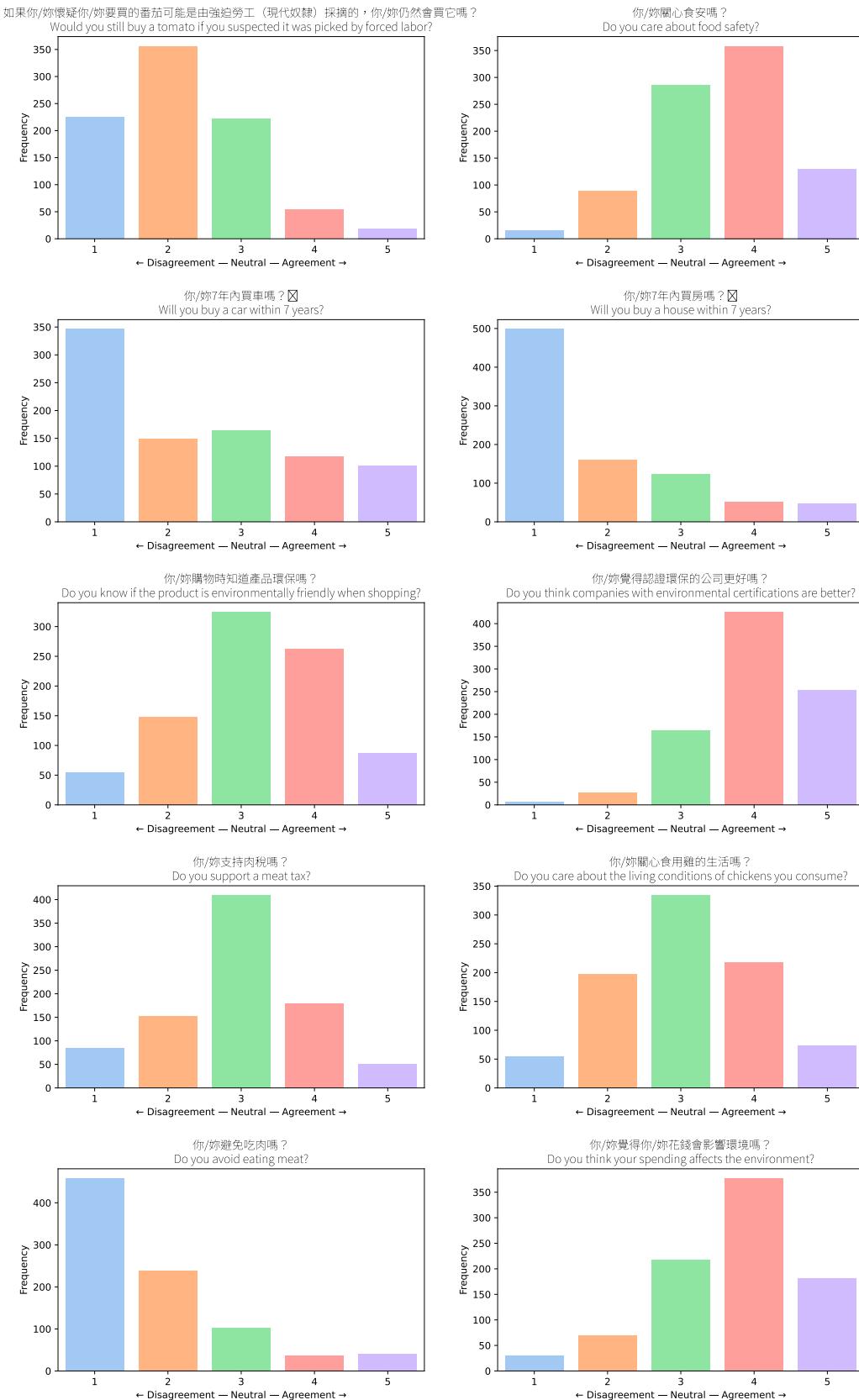


Figure 100: College Student Attitudes Towards Shopping

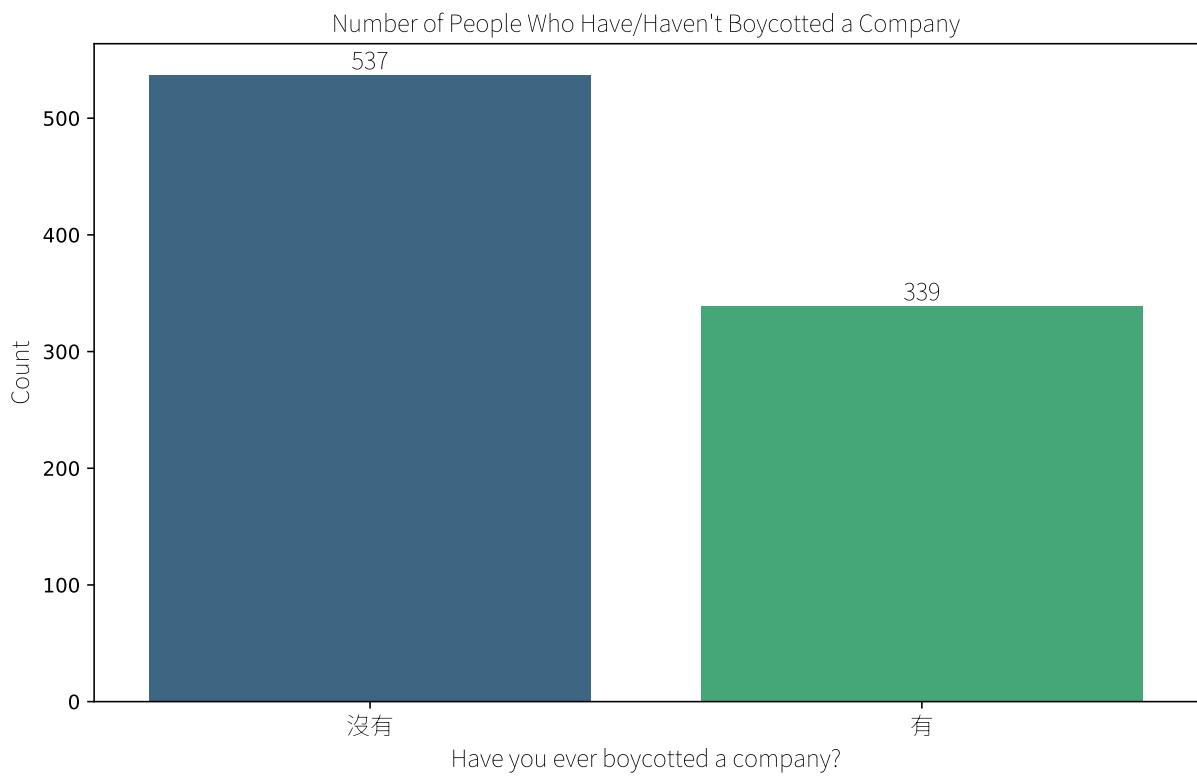


Figure 101: College Students Boycott Experience

	Reason	Count
0	食安問題	40
1	地溝油	12
2	黑心油	10
3	食安	8
4	政治因素	4
...
219	喜好問題	1
220	因為我覺得它們不好	1
221	沒有社會企業良心	1
222	因為黑心	1
223	有食安問題，避免自己吃了出事	1

Figure 102: College Students Boycott Reasons

	Brand	Count
246	No trusted brand	421
247	Have but not specified	68
0	義美	48
1	Apple	14
2	光泉	9
...
109	garena	1
110	Lego	1
111	Canon	1
112	統一企業	1
124	muji	1

Figure 103: College Student Trusted Brands

12.4 Taiwanese College Student Attitudes (Overall)

These are student attitudes across all 36 likert fields without clustering. Clustered results are available under the Personas section.

12.4.1 Economy

12.4.2 AI Use

12.4.3 Nature

12.4.4 Environmental Protection

12.4.5 Learning Environment

12.4.6 Correlations Between Fields

12.4.7 Environmental Knowledge Ranking Experiment

Test knowledge about the environment.

Design implications: - A majority of the respondents don't plan to buy a house or car within 7 years: don't focus on these categories - Majority don't fly much: don't focus on flights.

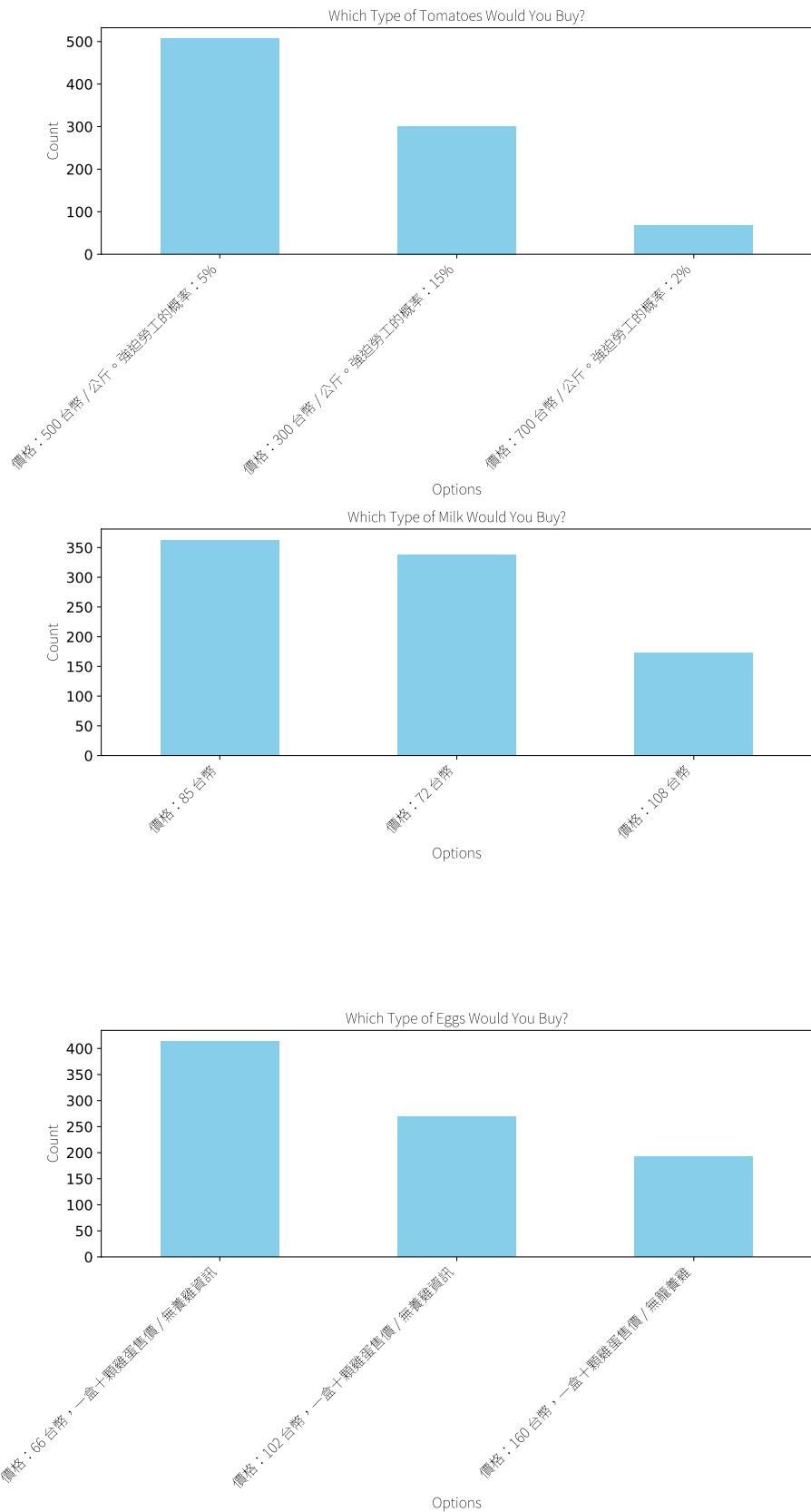


Figure 104: College Student Shopping Choice Experiment

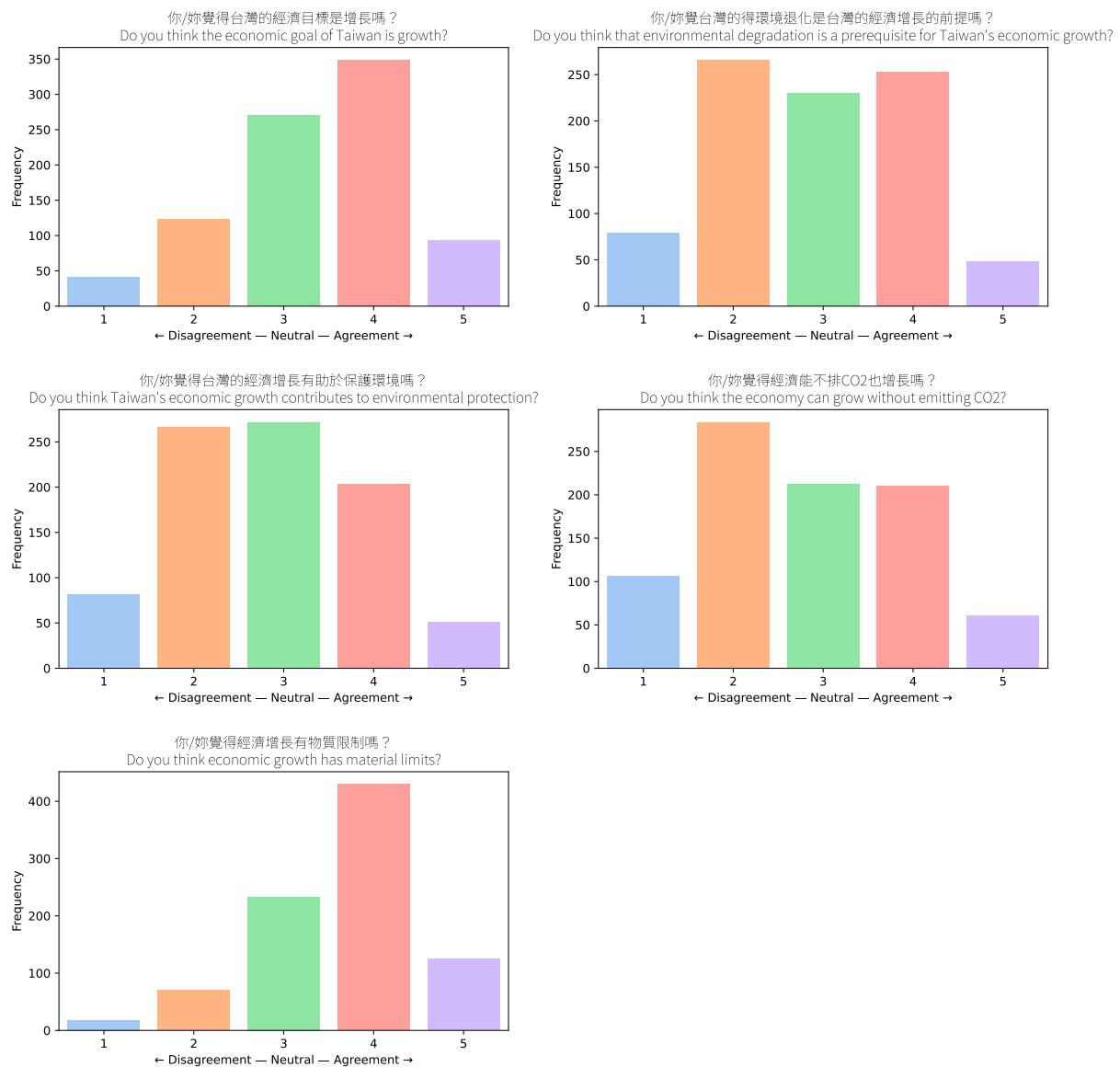


Figure 105: Student Attitudes Towards Economics Issues

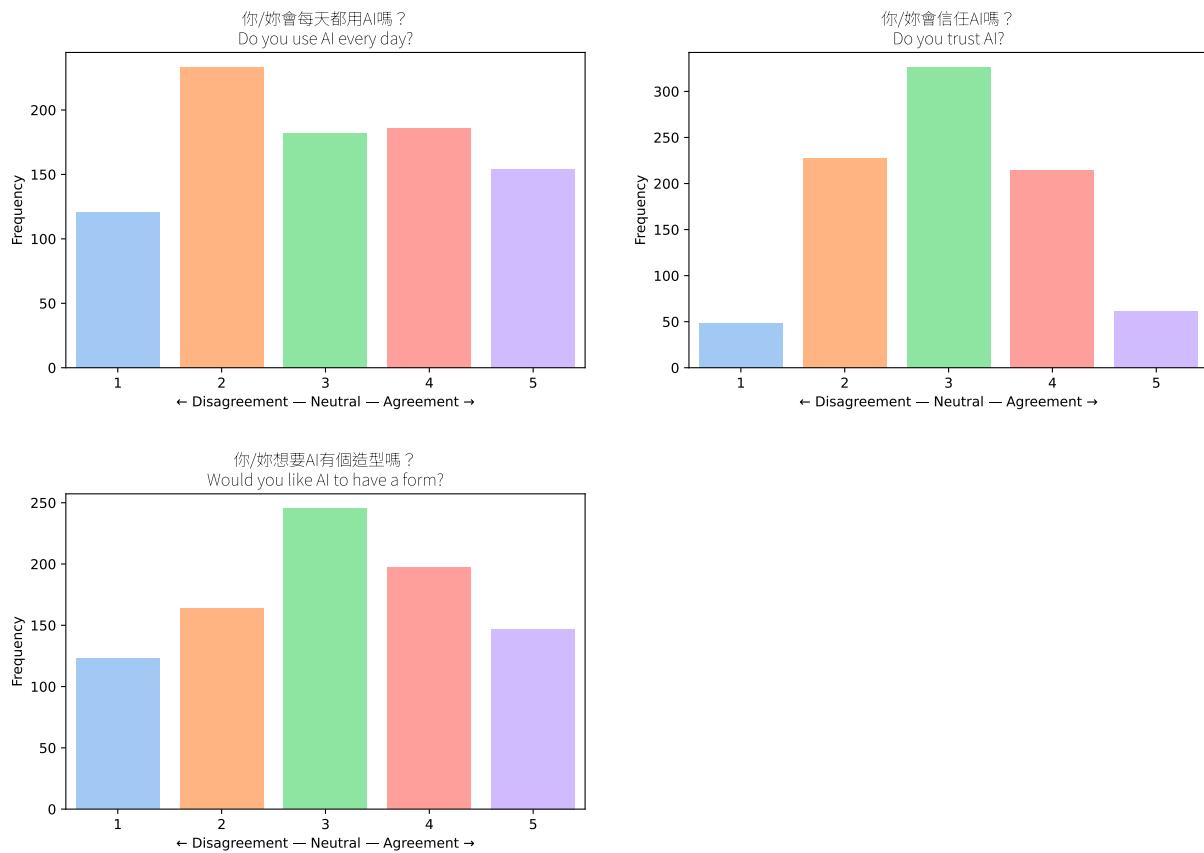


Figure 106: Student Attitudes Towards AI Use

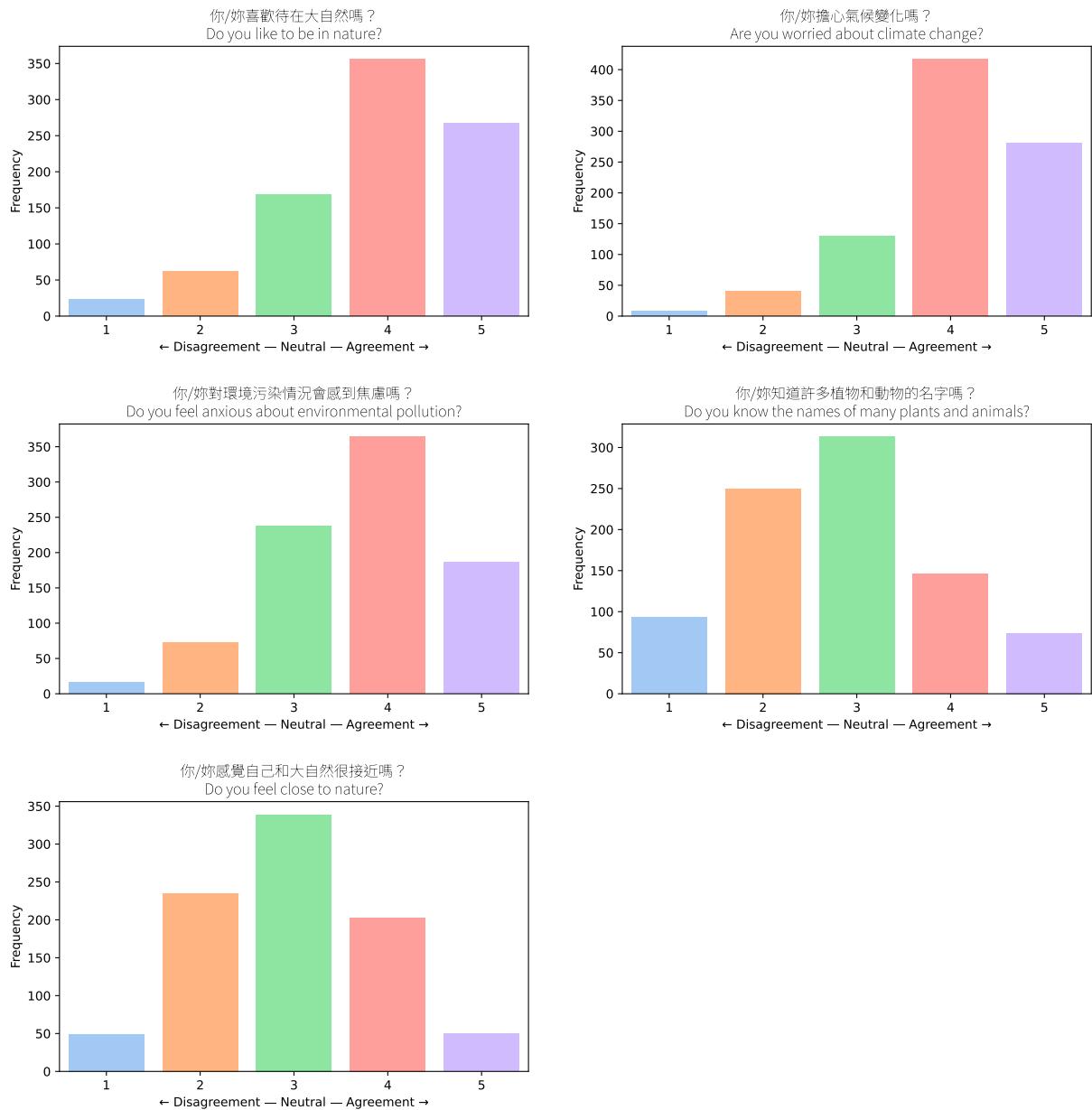


Figure 107: Student Attitudes Towards Nature

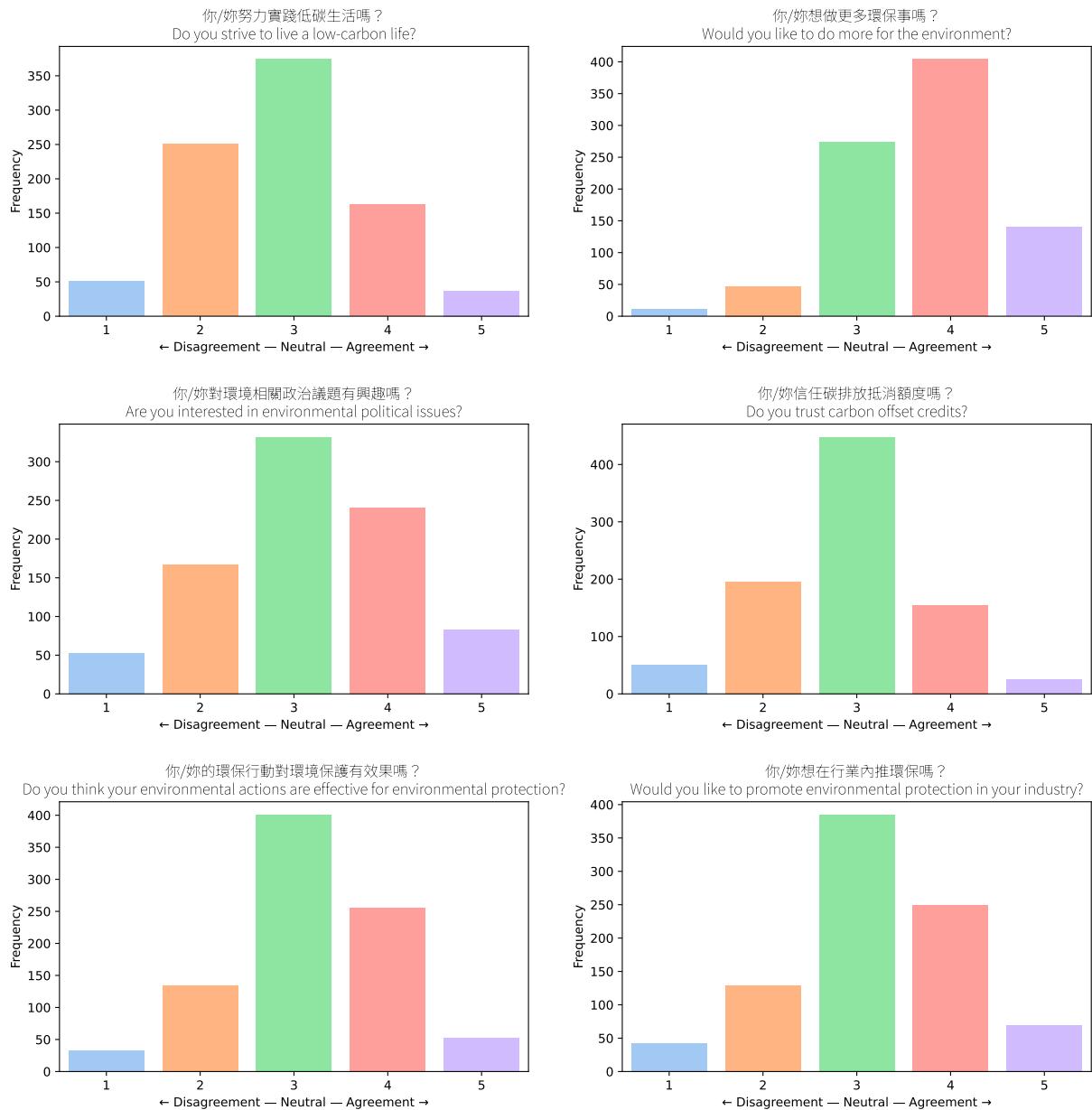


Figure 108: Student Attitudes Towards Environmental Protection

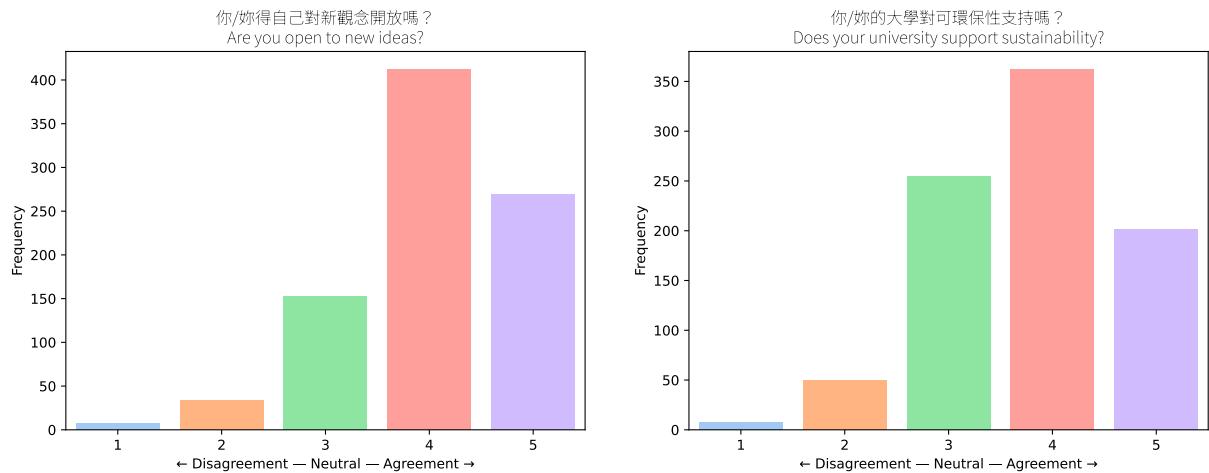


Figure 109: Students' Learning Environment

12.5 Saving

Correlation between saving levels and investing: the students with higher level of saving invest more.

Correlation Network

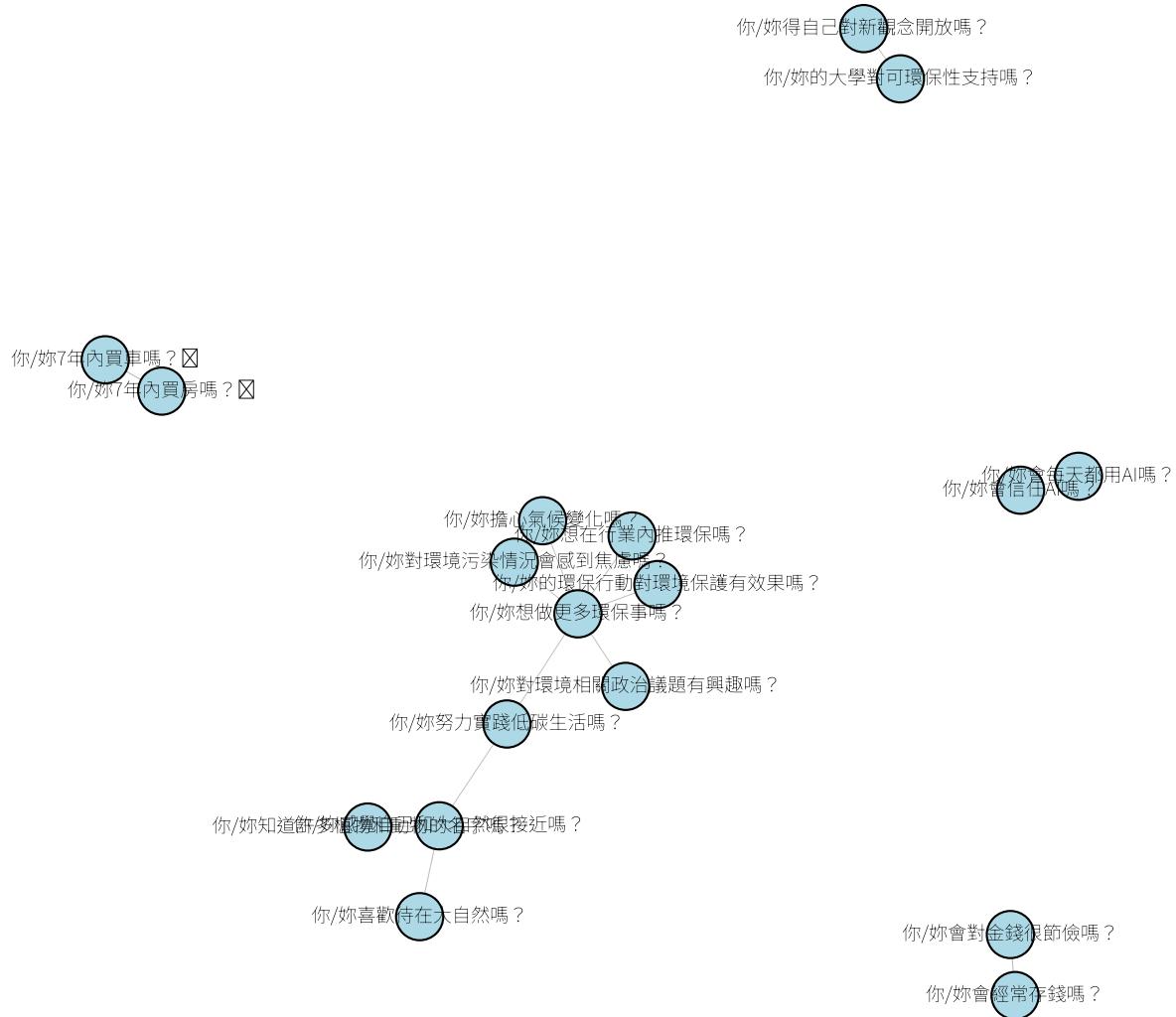


Figure 110: Correlations Between Student Attitudes

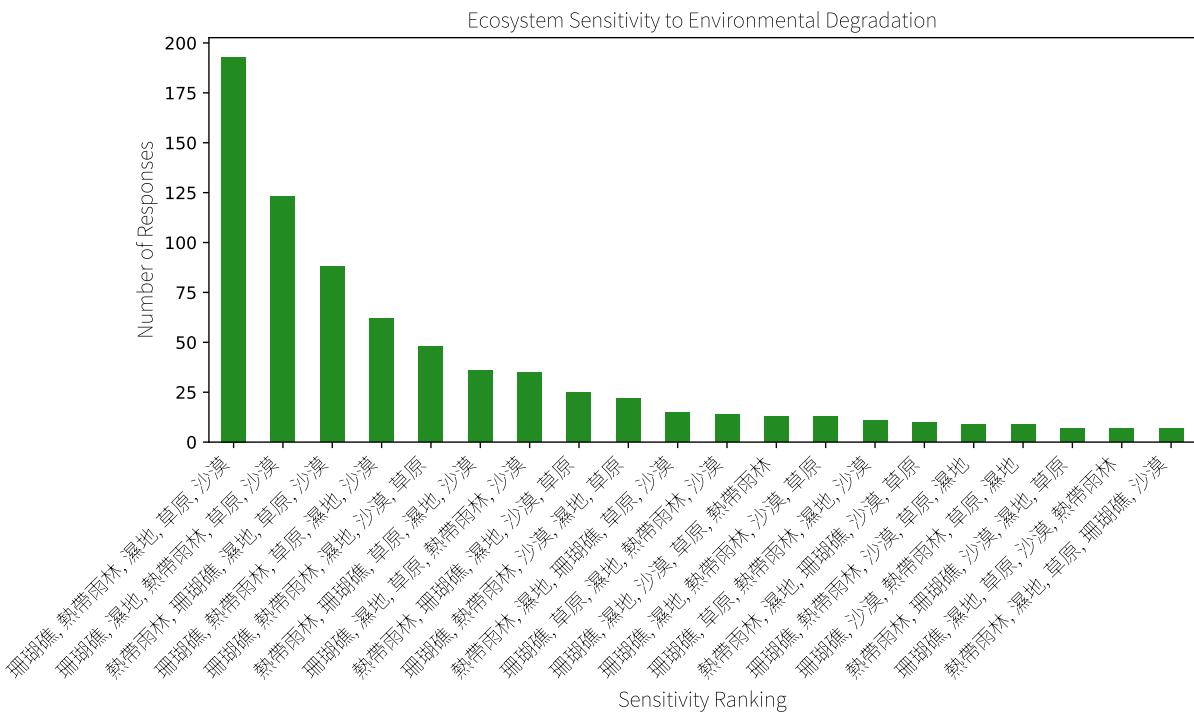


Figure 111: Students' Environmental Knowledge

12.6 Investing

Student attitudes towards investing.

12.6.1 Saving and Investing

12.6.2 Investing Experience (Overall)

12.7 Choice Experiment

Question: 你/妳選哪個投資？ Which investment do you choose?

Savings Frequency → Investment Status

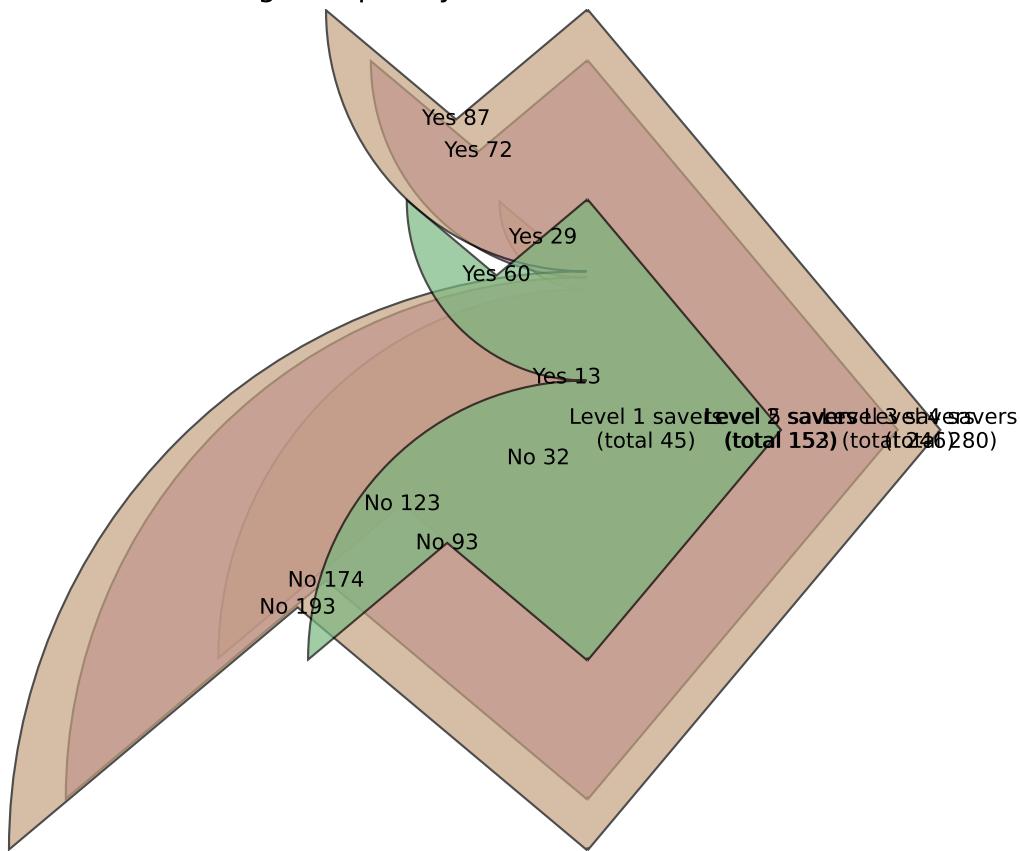


Figure 112: Correlation Between Saving Levels and Investing

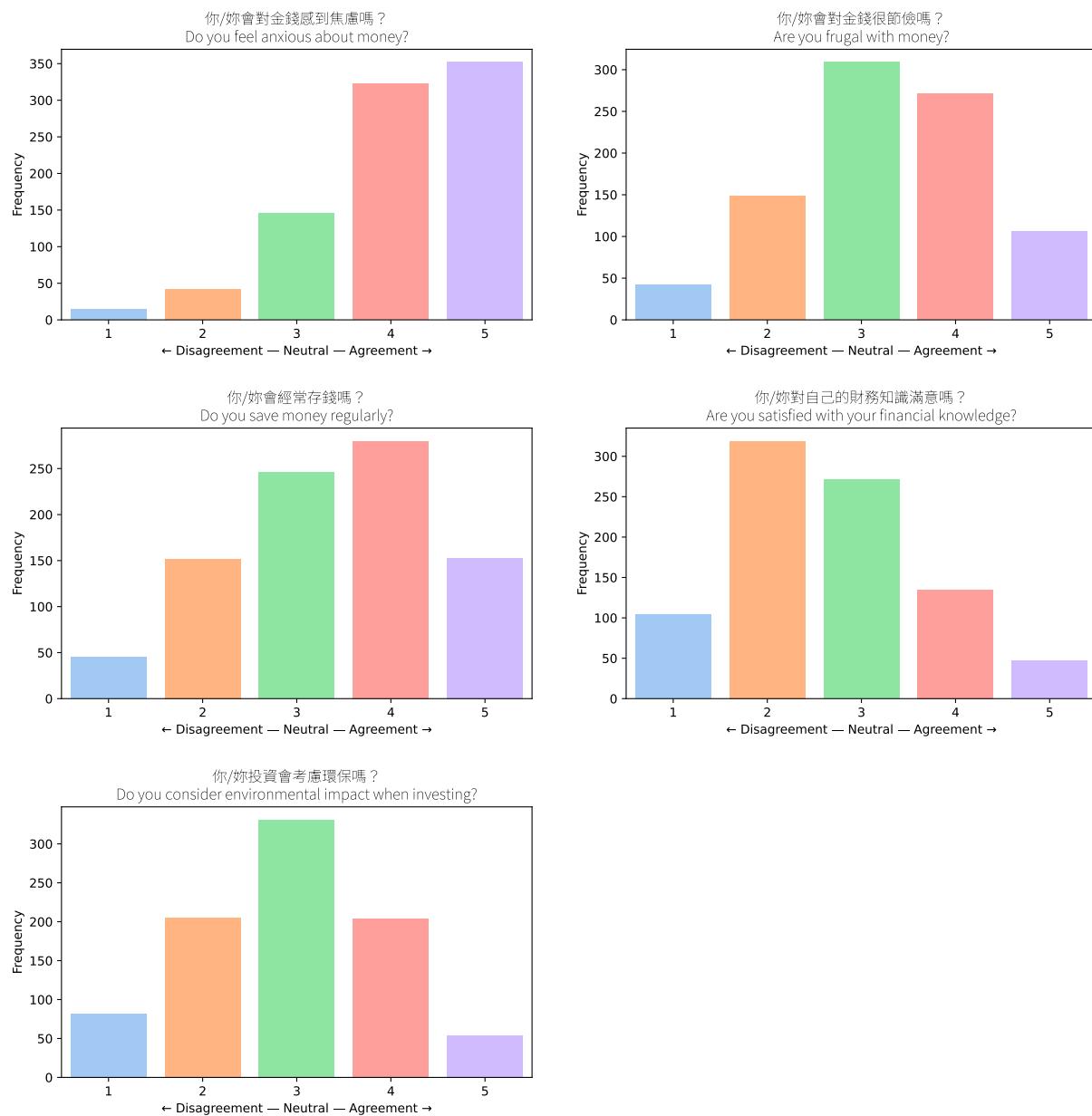


Figure 113: Student Attitudes Towards Saving and Investing

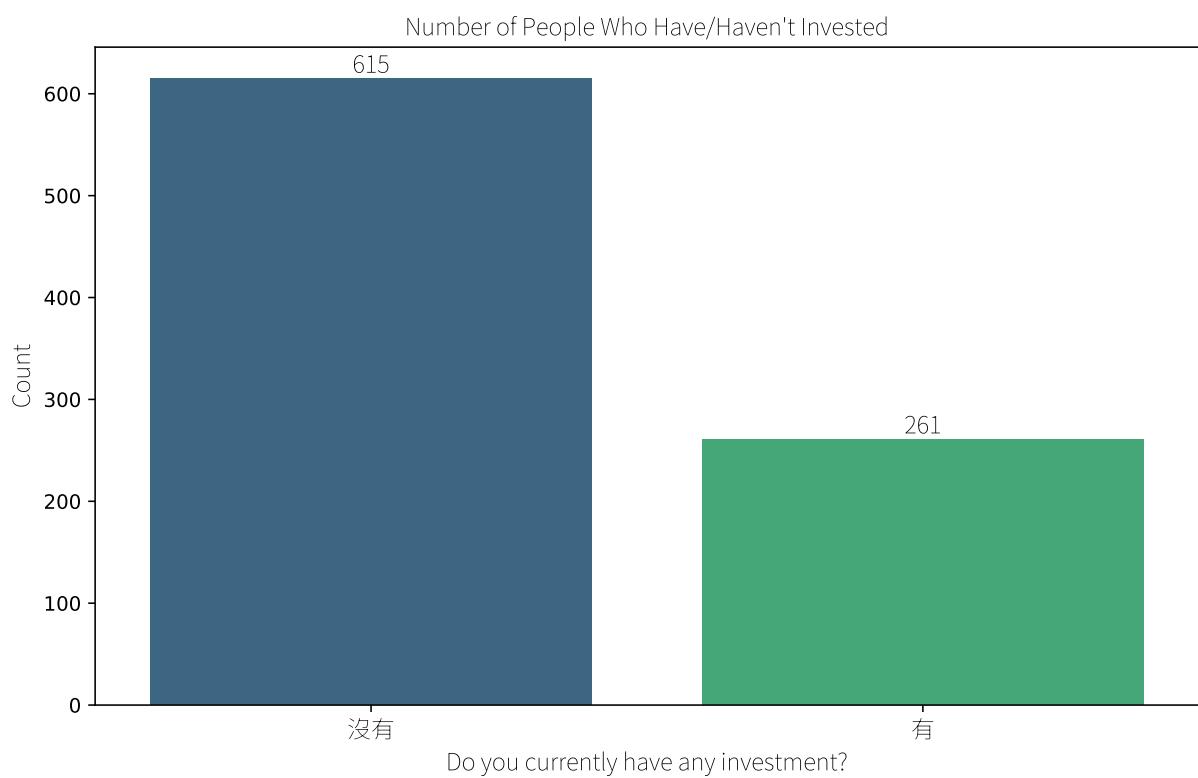


Figure 114: Students' Investing Experience

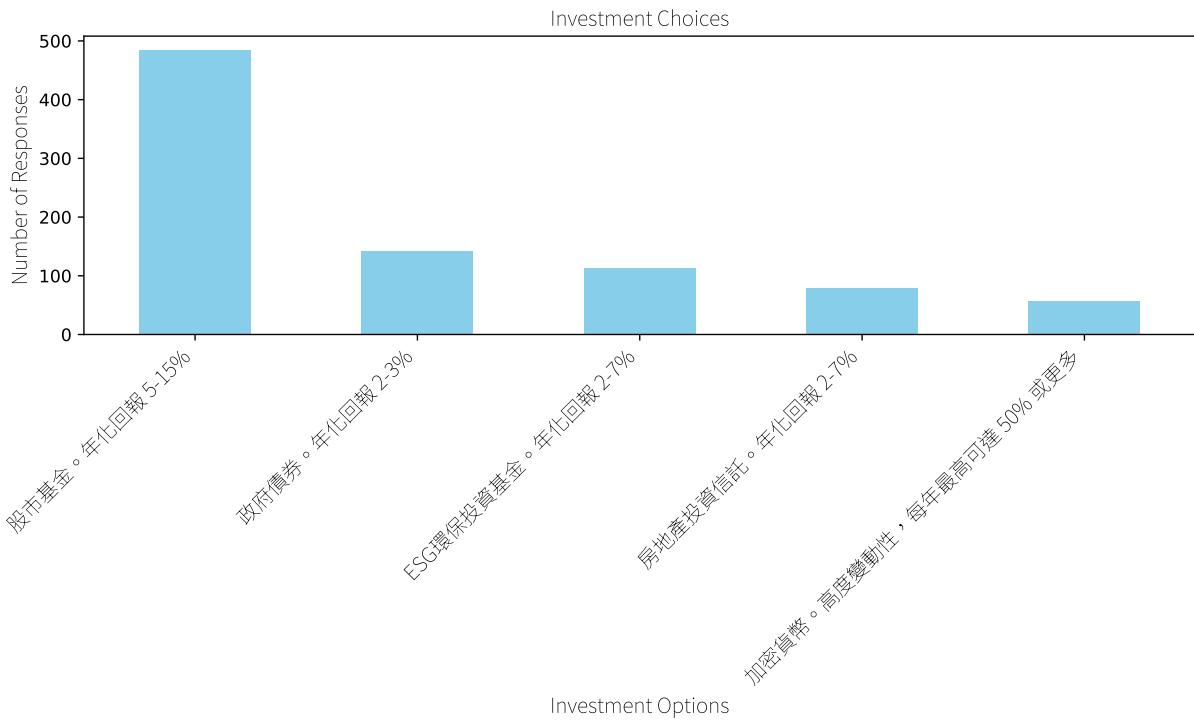


Figure 115: Investing Choice Experiment

12.8 Personas

12.8.1 Clustering Students to Build Personas

Customer segmentation

Personas are created using K-means clustering, an unsupervised machine learning algorithm, which clusters college students based on their responses across 36 Likert-scale fields in the online survey. Clusters are visualized using Principal Component Analysis (PCA), where the principal component loadings on the X and Y axes represent the weights of the original Likert-scale fields, transformed into the principal components that capture the most variance.

K-prototypes combines K-mean and K-modes unsupervised machine learning algorithms.

- There is some similarity between clusters. All 3 personas report a high level of financial anxiety and below-average satisfaction with their financial literacy.
- Principal Component Analysis (PCA) is used to convert data to lower dimension space. This is a predecessor of embeddings.

12.8.2 Persona 1: “Eco-Friendly”

Questions Most Affecting Persona Creation include...

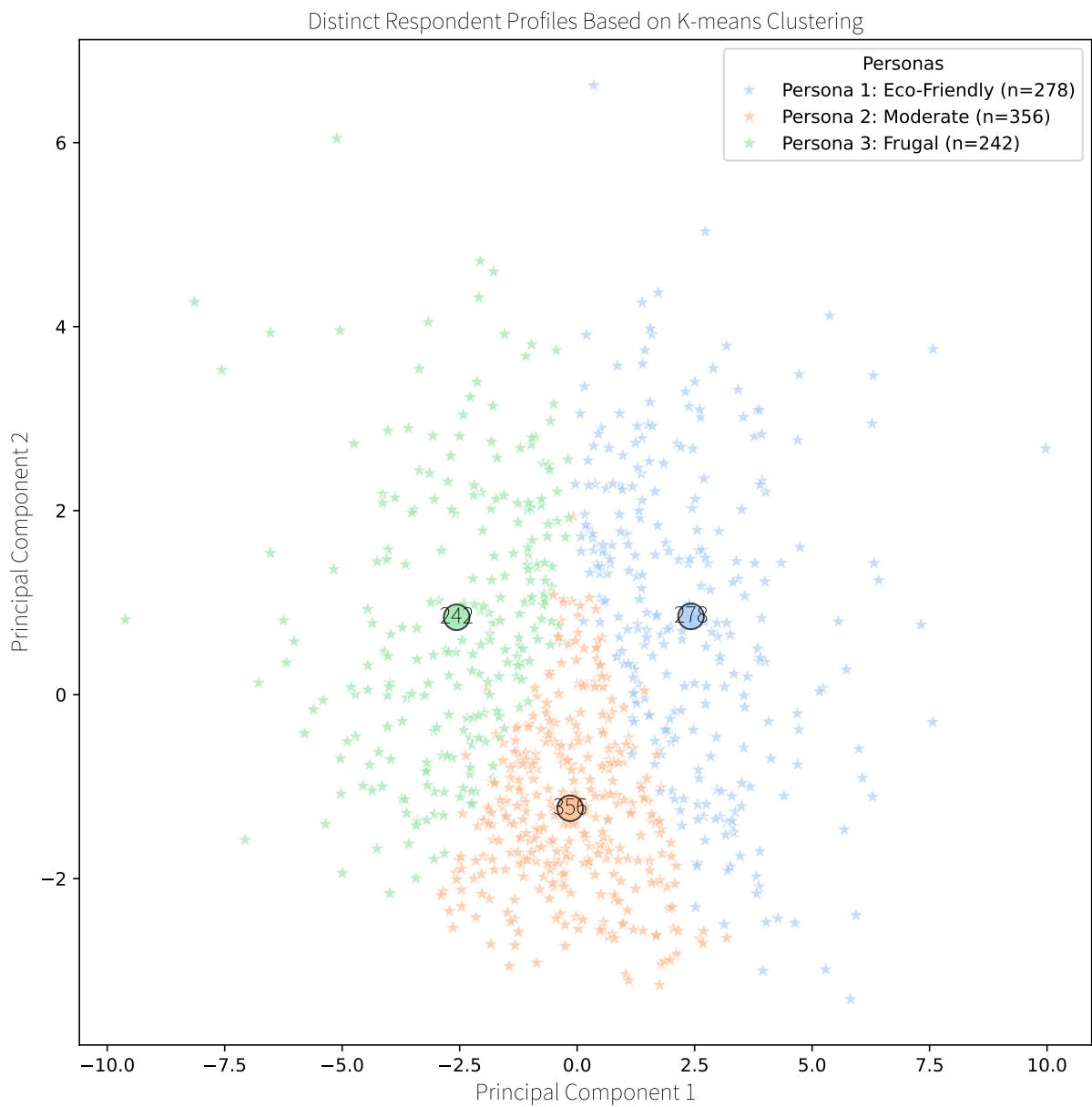
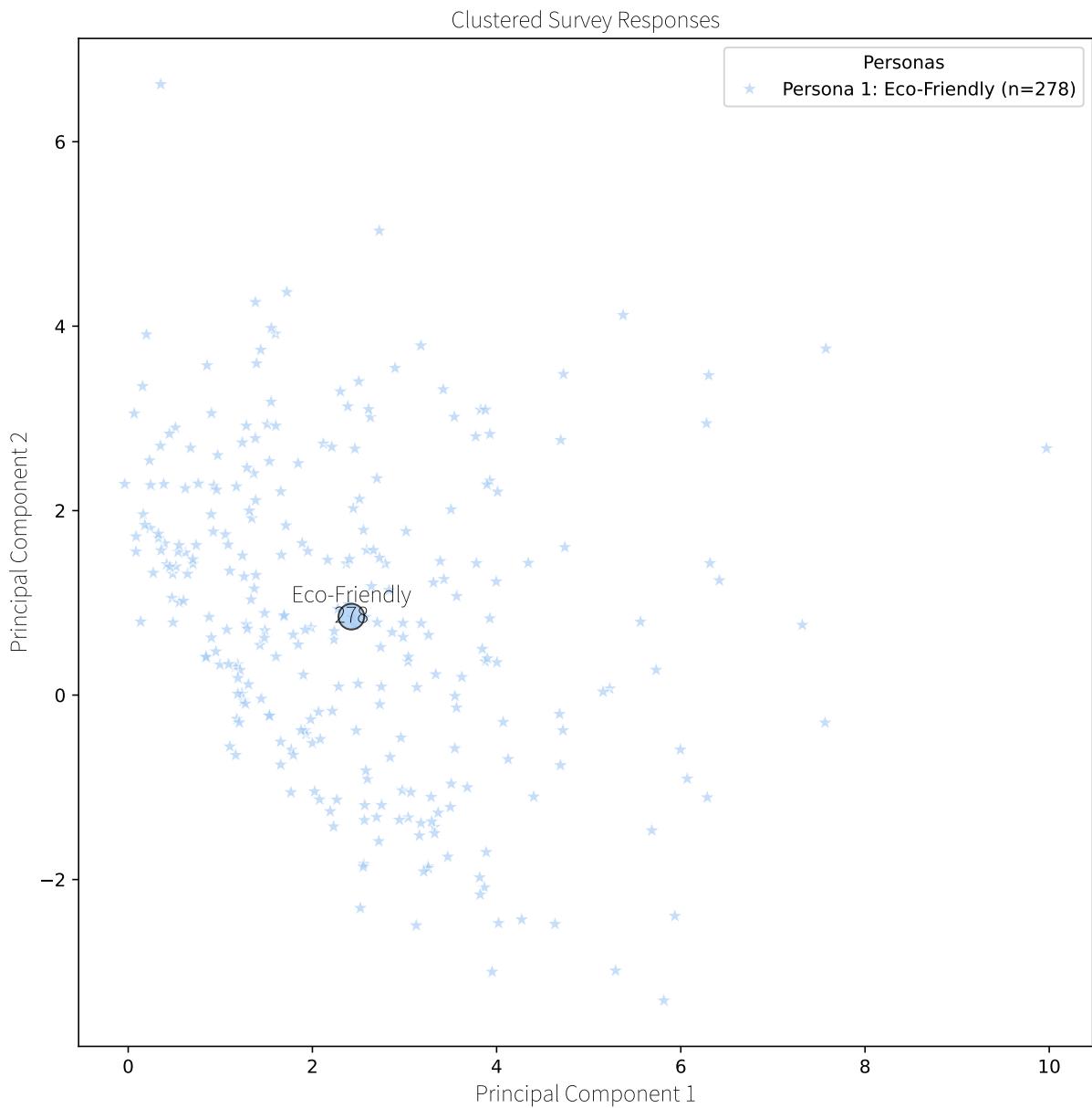
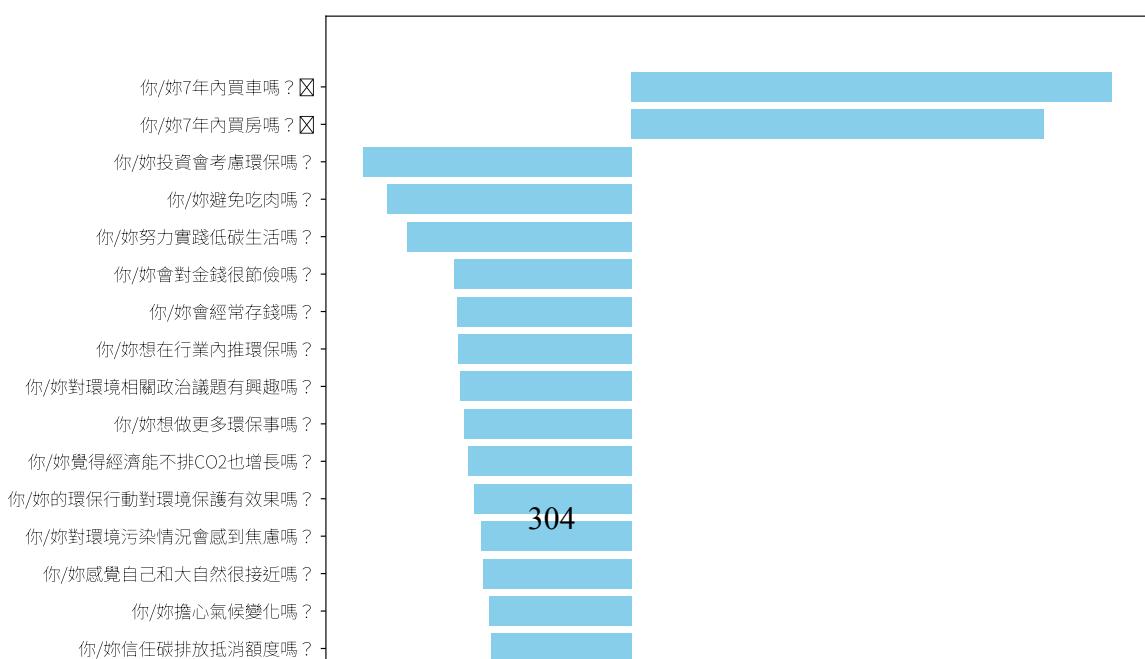


Figure 116: College Student Personas



(a) Persona 1 - Eco-Friendly



12.8.3 Persona 2: “Moderate”

Questions Most Affecting Persona Creation include...

12.8.4 Persona 3: “Frugal”

Questions Most Affecting Persona Creation include...

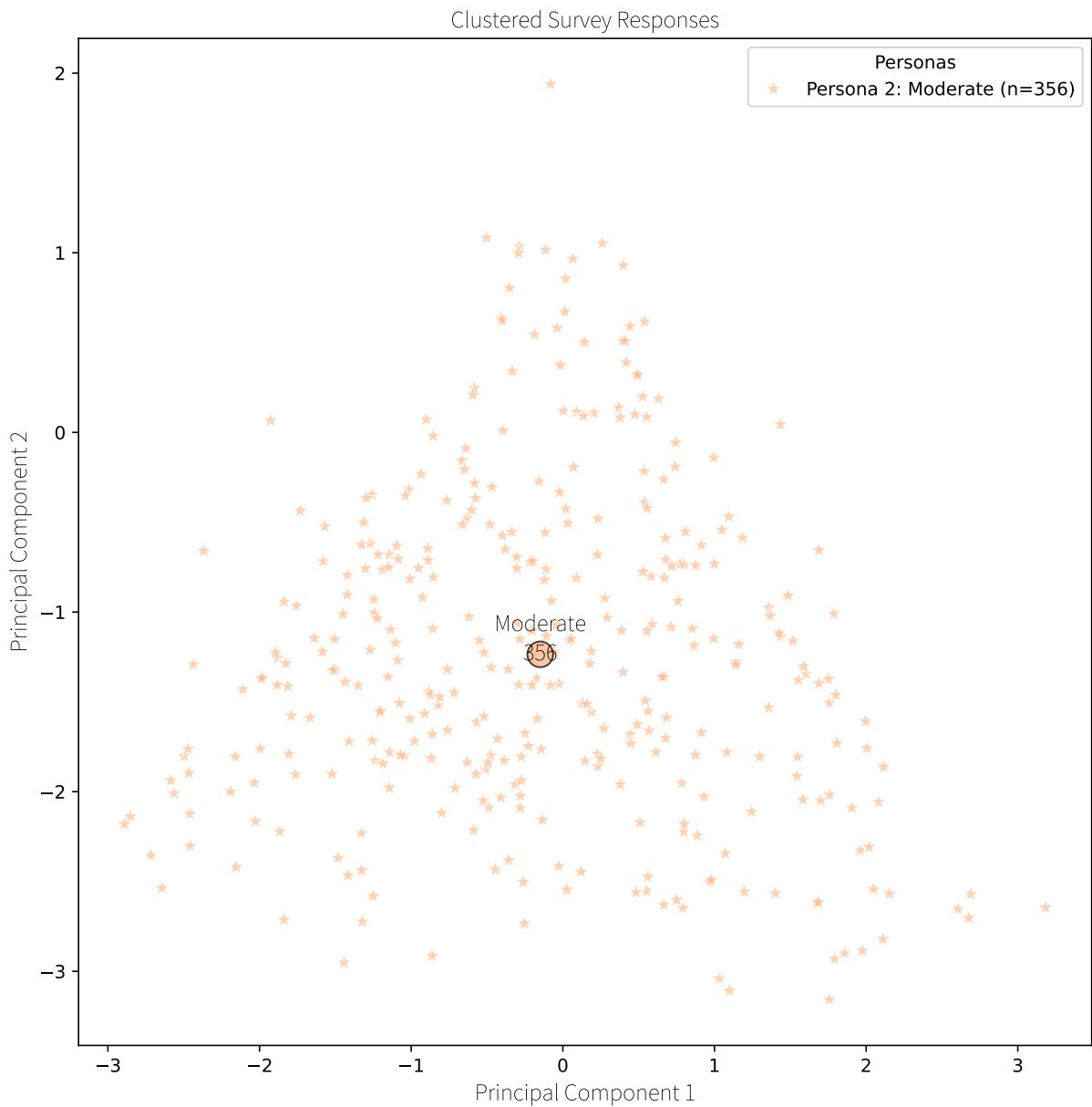
12.9 Clustering Heatmap

12.10 Mean Answer Scores

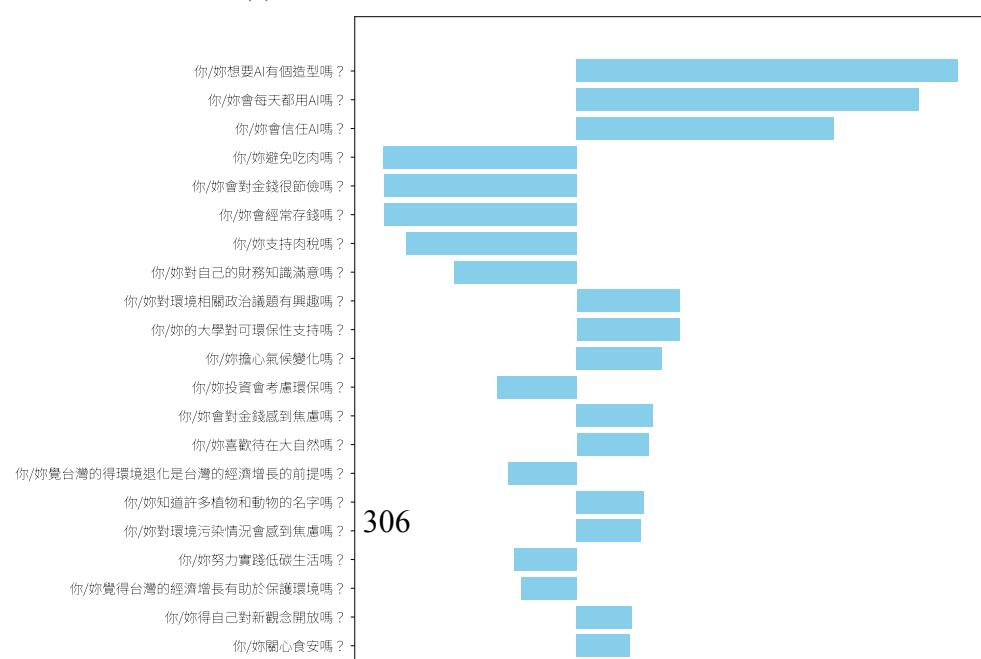
Mean response values for each Likert question in each cluster:

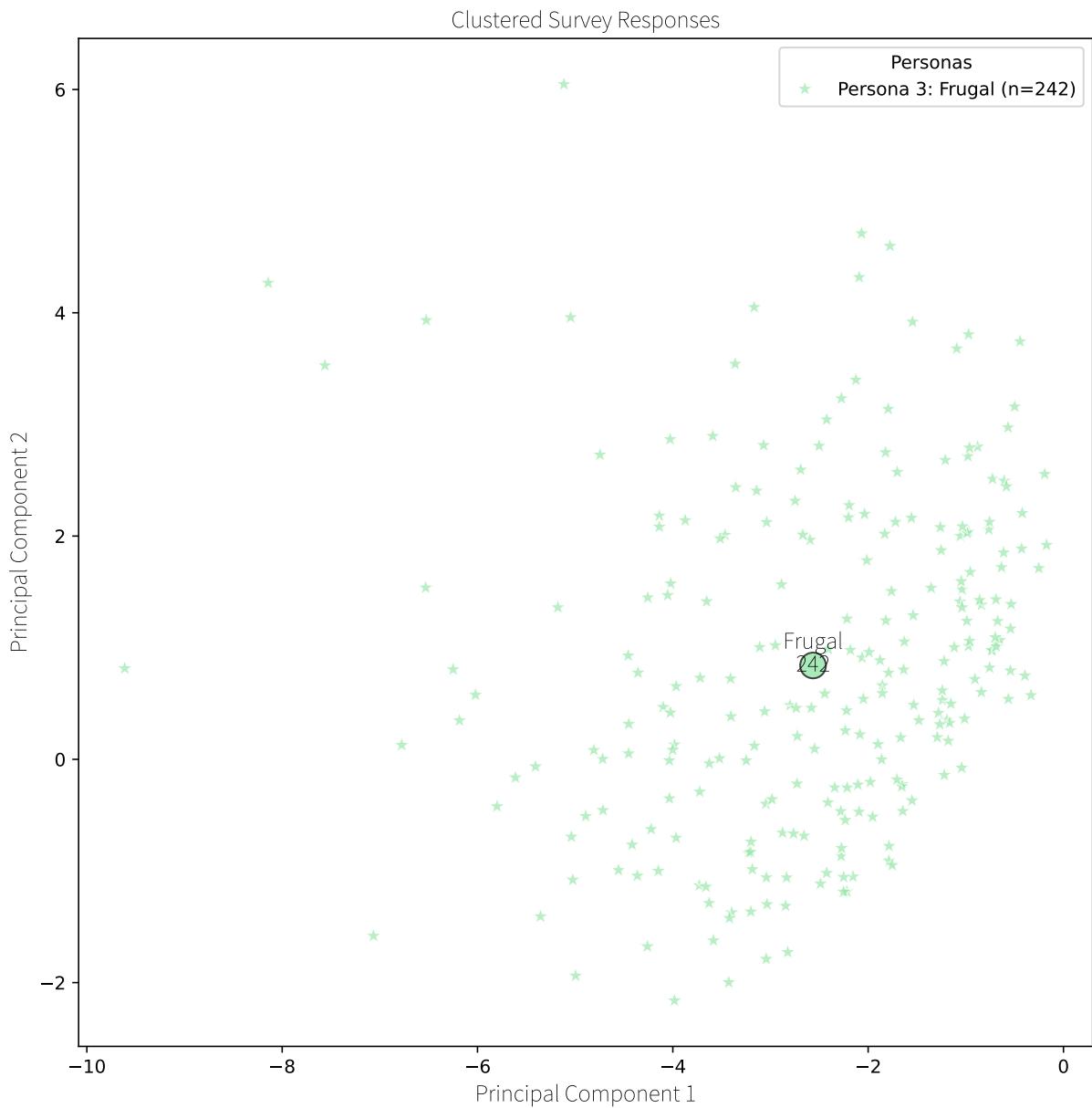
12.11 Agreement Between Personas

Highest agreement between personas is about health, safety, pollution and climate concerns.

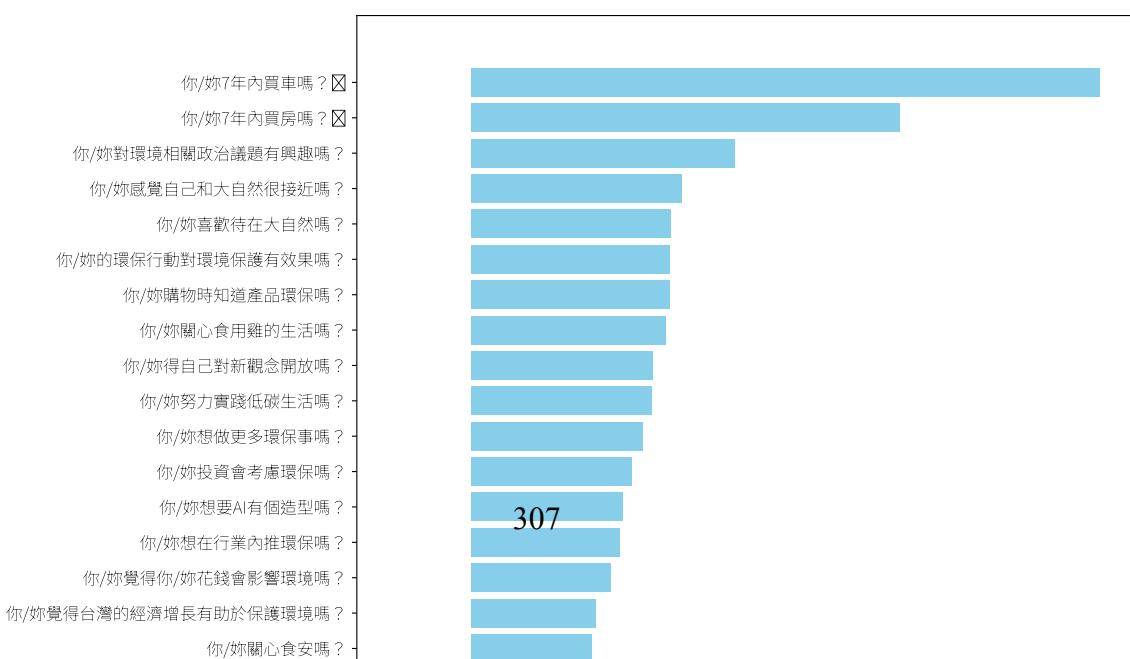


(a) Persona 2 - Moderate





(a) Persona 3 - Frugal



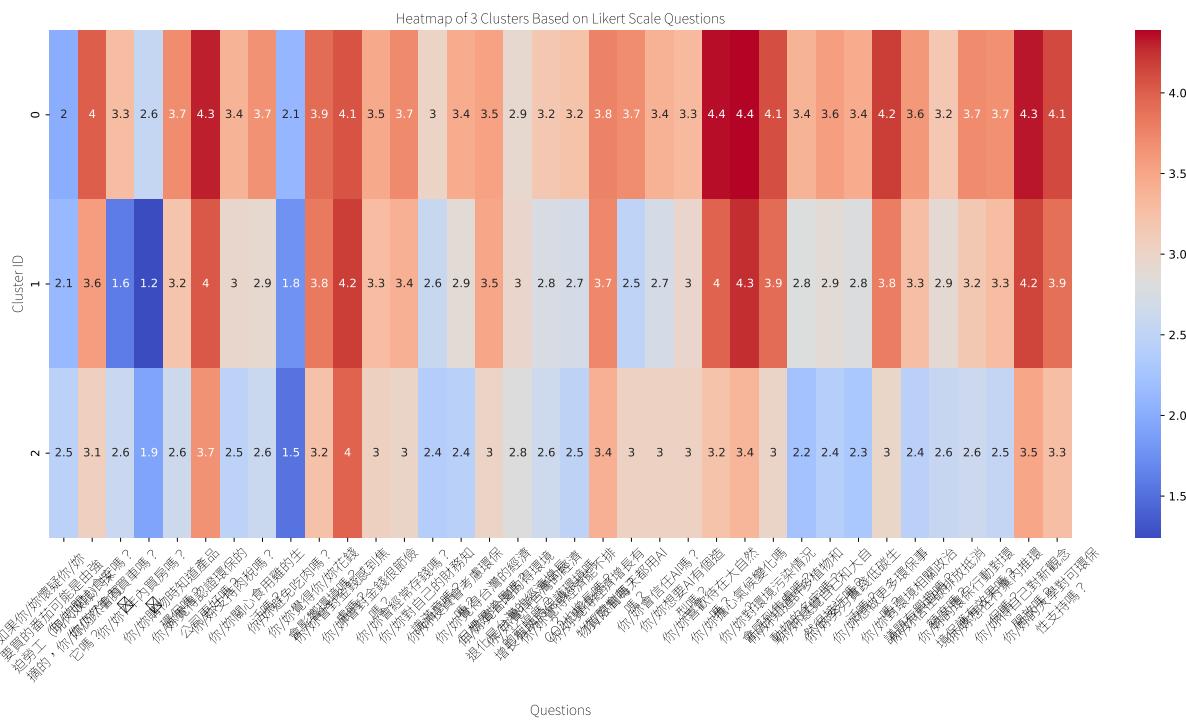


Figure 120: College Students' Clustering Heatmap

Cluster	如果你/妳懷疑你/妳要買的番茄可能是由強迫勞工（現代奴隸）採摘的，你/妳仍然會買它嗎？
0 0	2.014388
1 1	2.137640
2 2	2.450413

Figure 121: Mean Values of Survey Responses

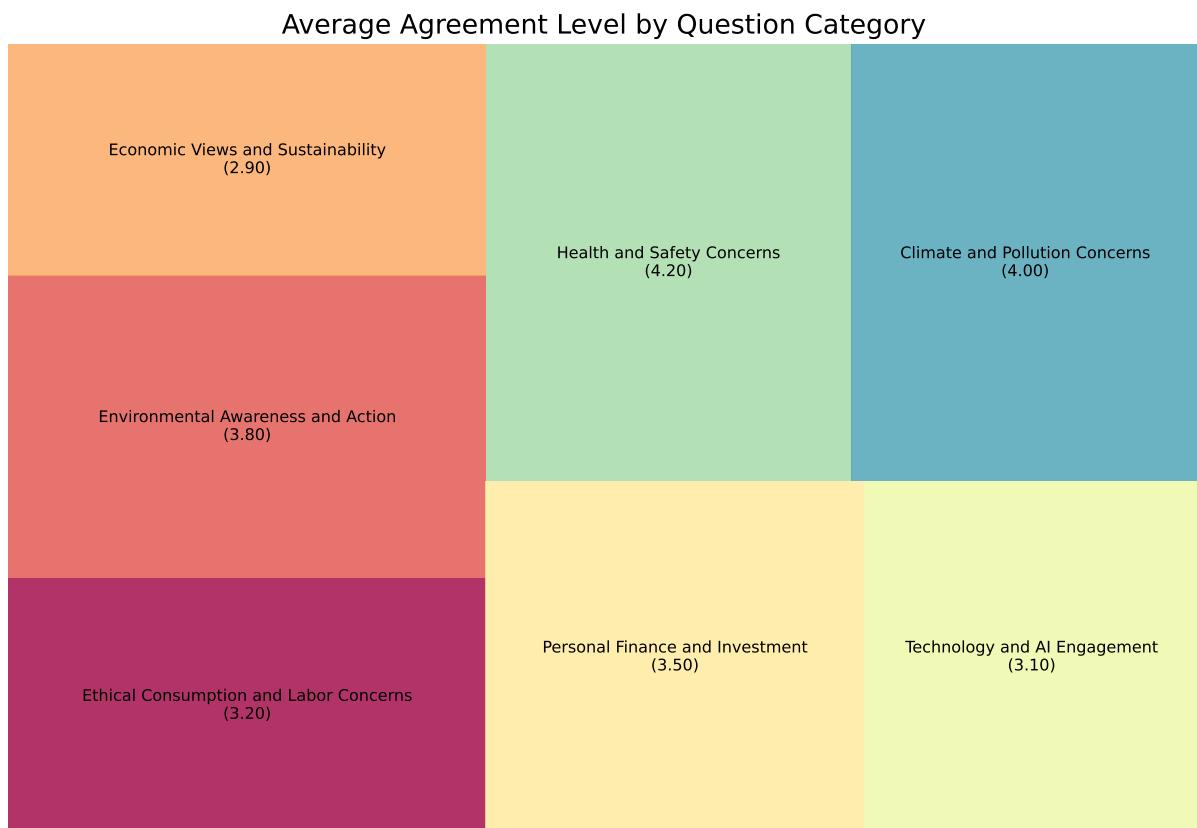


Figure 122: Topics With Highest Agreement Between Personas

12.12 AI Companion

12.12.1 Likert-Based Clustering

AI-assistant feature choices per Likert-based Personas

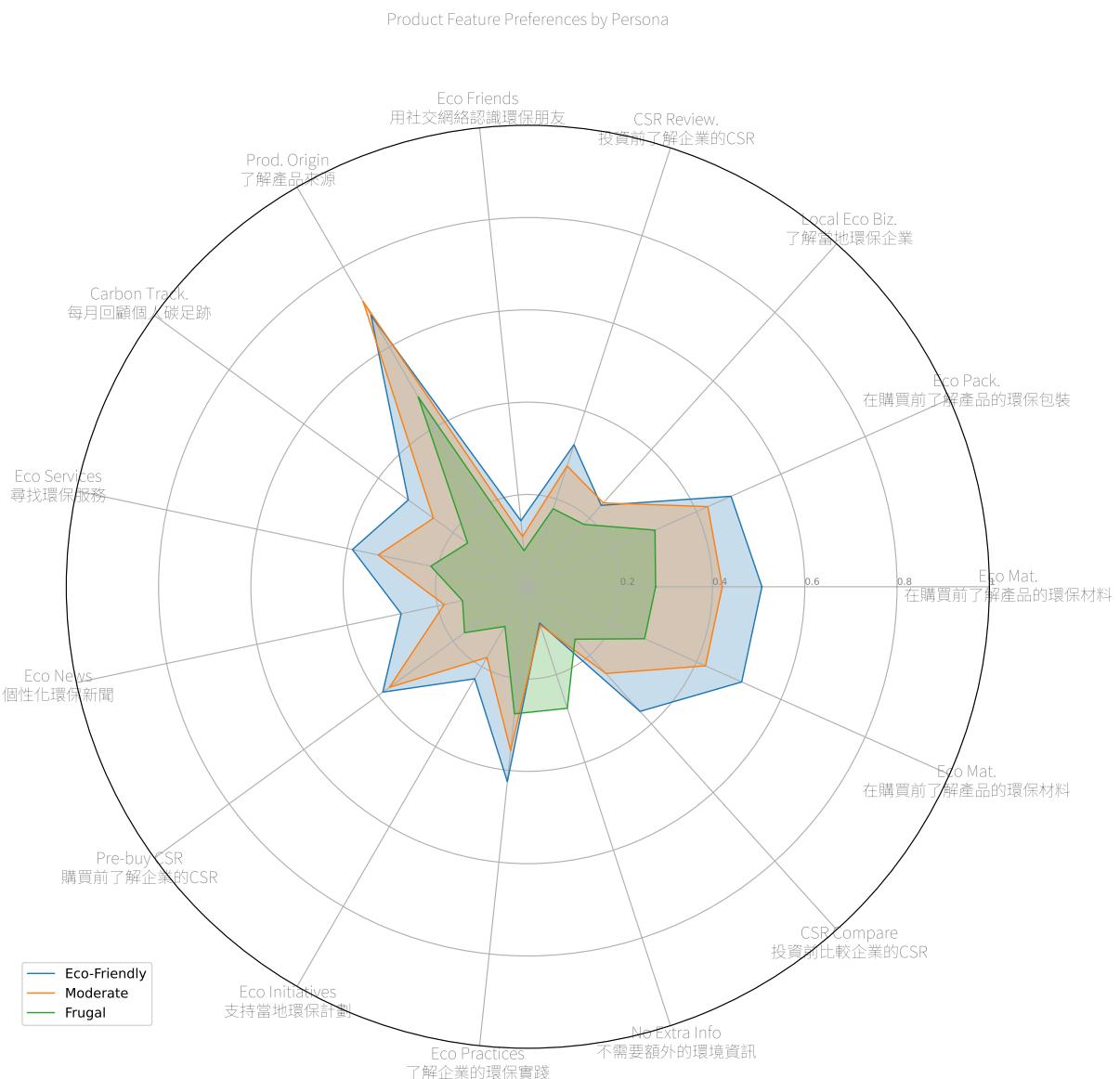


Figure 123: AI-Assistant Feature Choices per Likert-based Personas

This chart visualizes three distinct personas based on 36 Likert answers: Eco-Friendly (n=340), Moderate (n=215), and Frugal (n=126) based on their overall sentiment profiles.

Want: - Product origin - Product materials - Product packaging

Don't Want: - News - Carbon tracking - Eco-friends - ...

12.13 Feature-Based Clustering

Clustering students based on AI-assistant feature choices.

Want: - Product origin - Product materials - Product packaging - Eco services

12.13.1 Feature Preferences (Overall)

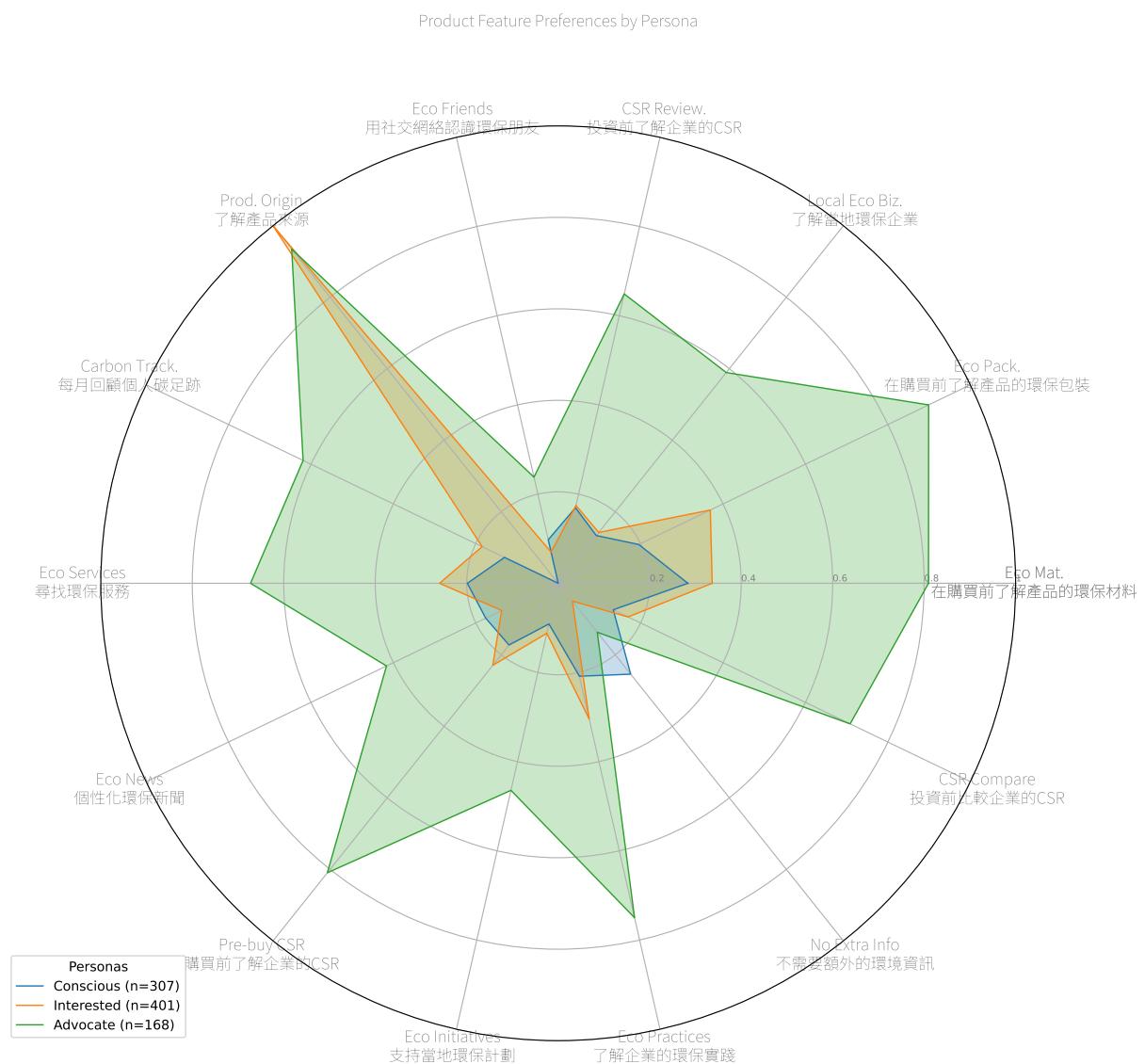


Figure 124: AI-Assistant Feature Preferences (Overall)

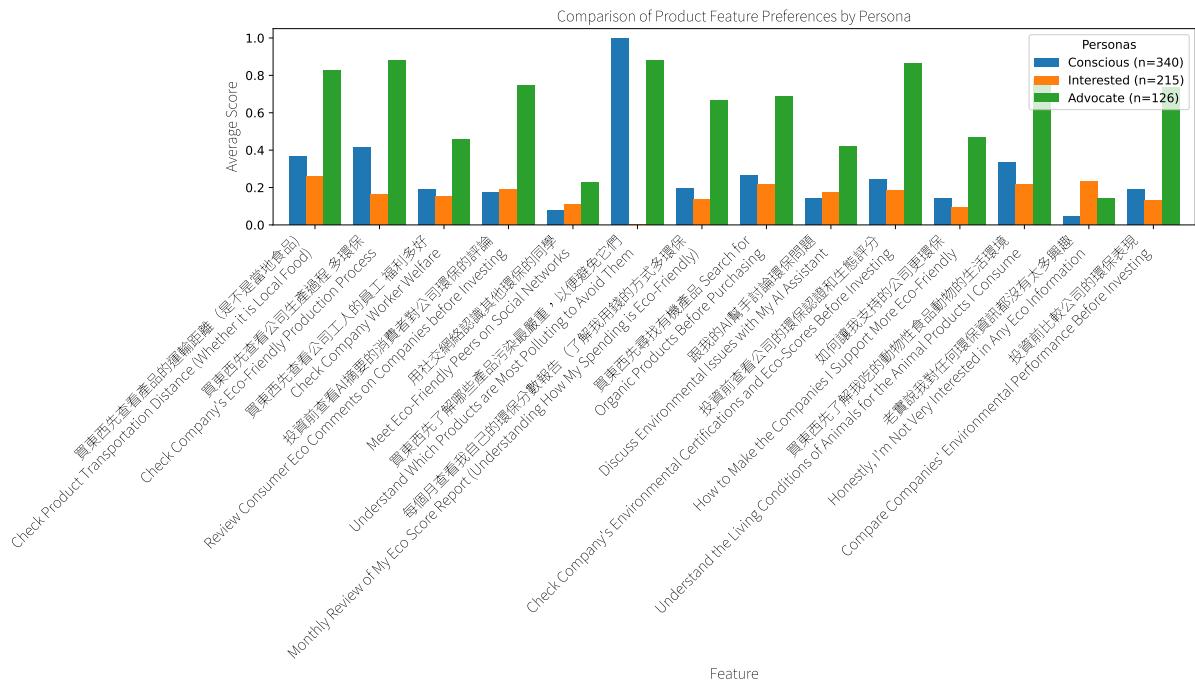


Figure 125: AI-Assistant Feature Preferences (By Cluster)

12.14 Feature Preferences (By Cluster)

12.15 Preferred AI Roles (Overall)

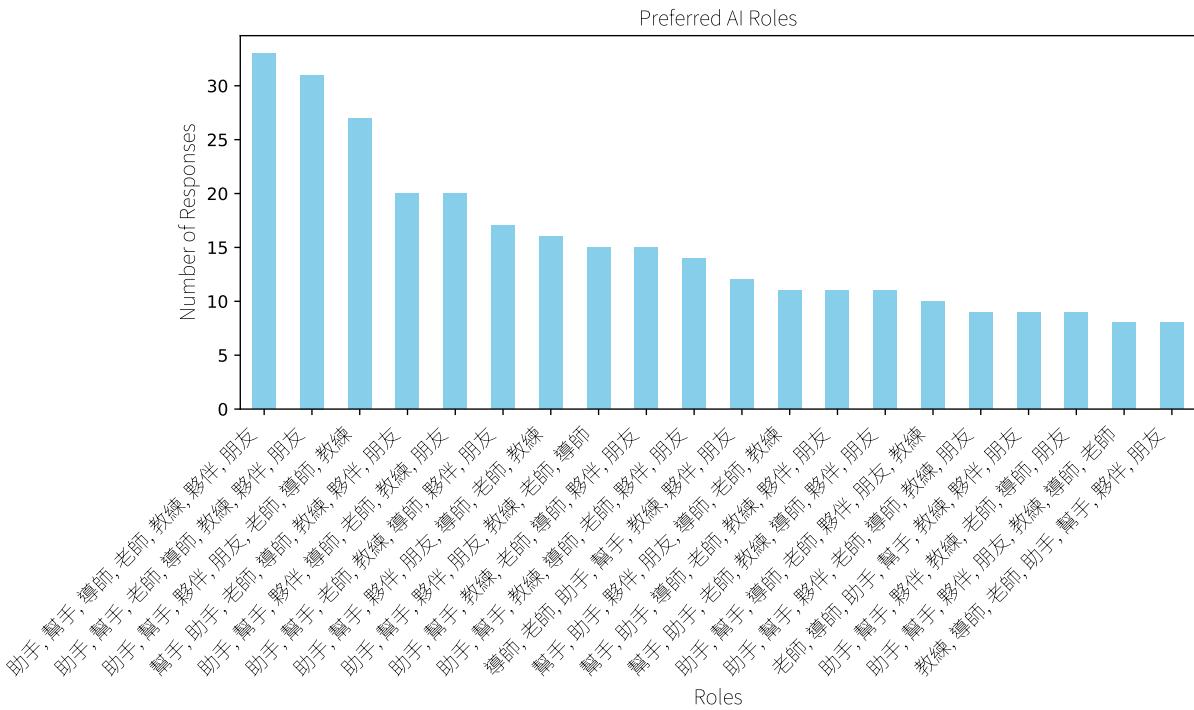


Figure 126: AI-Assistant Role Preferences

12.16 First Wave of Experts (2023-2024)

Analysis of recorded conversation from 7 experts. Thematic content analysis using ATLAS.ti for labeling/coding the data for grounded theory. Conversations were recorded and transcribed using Google Meet, Fireflies AI, and WhatsApp. Labeling and thematic analysis was performed using Atlas.ti. Visualisations were produced using Atlas.ti and Python.

For thematic analysis, I conducted 2 types of coding: -

- Unsupervised AI-coding which discovered topics and patterns in the interviews.
- Intentional AI-coding, directed by my own judgment towards keywords most relevant to developing my AI assistant.

Table 96: Overview of the experts interviewed.

Interviewee	Expertise	Thematics Codes
Chen-Ying	Economics, Behavioral Research, Survey Design	3
Huang-Cathy	Interaction Design, Business & Org Dev	25
Wang		

Interviewee	Expertise	Thematics Codes
Audrey Tang	Digital Democracy, Civic Tech, Policy	36
Yuping Chen	Economics, UX Research, Information Systems	3
Peijing Li	Accounting, Data Analysis, Governance,	28
Jessica Cheng	Venture & Service Design, Strategy	22
Carlos Serra	Sustainability, Environmental Law, Zero Waste, Circular Economy	23

12.16.1 Interview 1: Designer - Cathy Wang

Date: 2023-11-10 Expert: Cathy Wang is a designer and business leader with 20 years of experience in bringing hyper-growth and hundreds of millions of EUR in revenue in digital transformation of industry. Country: Taiwan / Canada Topics: Design, Business.

“Design is more of a mindset for me... how do you actually unpack a problem? How do you think about the problem... and find the different intricate parts in a very system thinking way to be able to find a solution?” - Cathy Wang

Thematic Analysis.

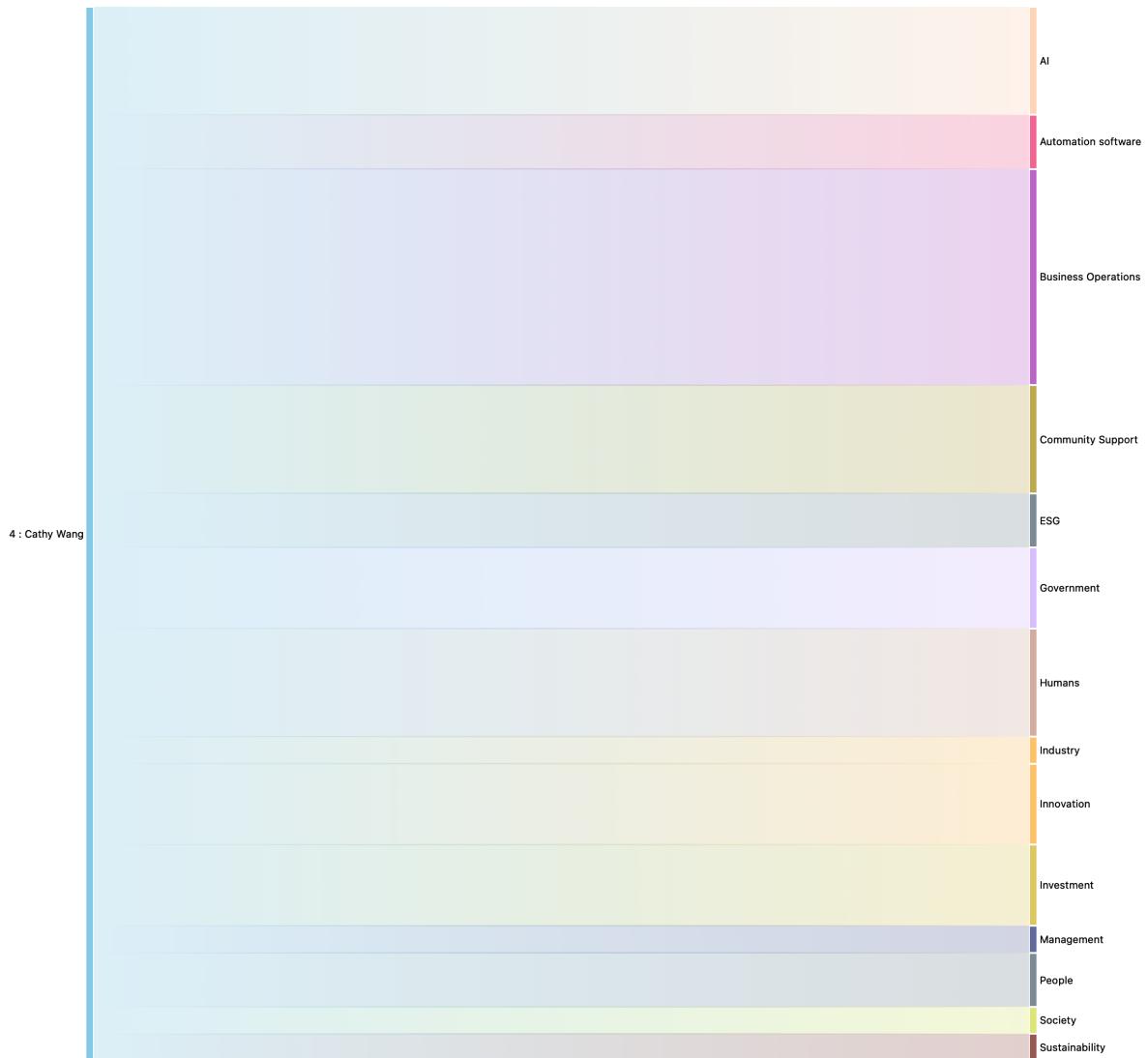


Figure 127: Cathy Wang

12.16.2 Interview 2: Accountant - Peijing Li

Date: 2023-11-18 Expert: Peijing Li is an accomplished financial controller and accountant with experience in varied industries from dairy to education. Country: New Zealand Topics: Economics

Thematic Analysis.

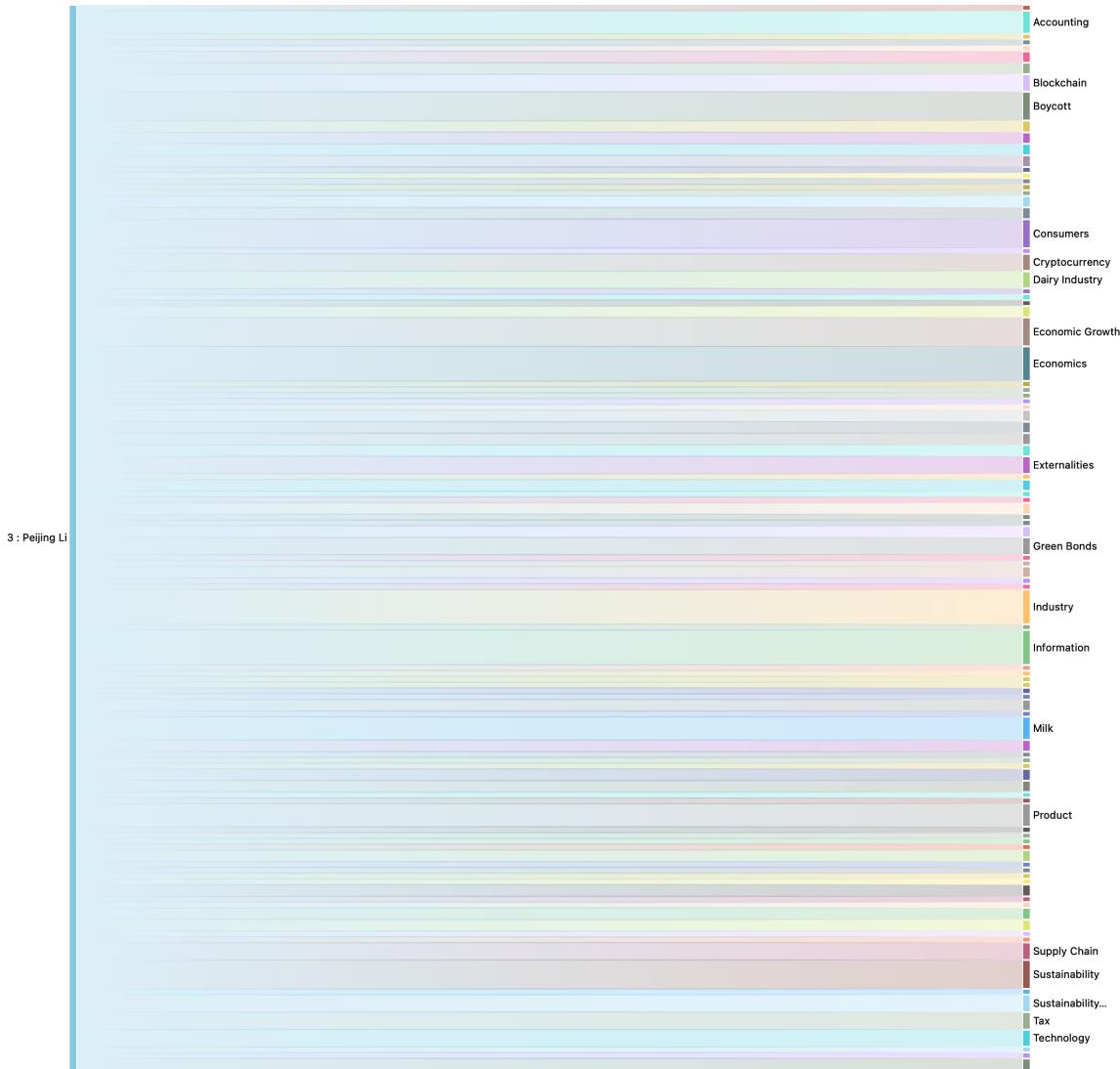


Figure 128: Peijing Li

12.16.3 Interview 3: Designer - Jessica Cheng

Date: 2023-12-04 Expert: Jessica Cheng is a designer with cross-industry experience from the UK and Taiwan. Country: Taiwan Topics: Design, Business

“Design whichever kind of design methodology is more like a mindset rather than just a tool to use... how you observe things and how you empathize — that is really important.” - Jessica Cheng

Thematic Analysis.

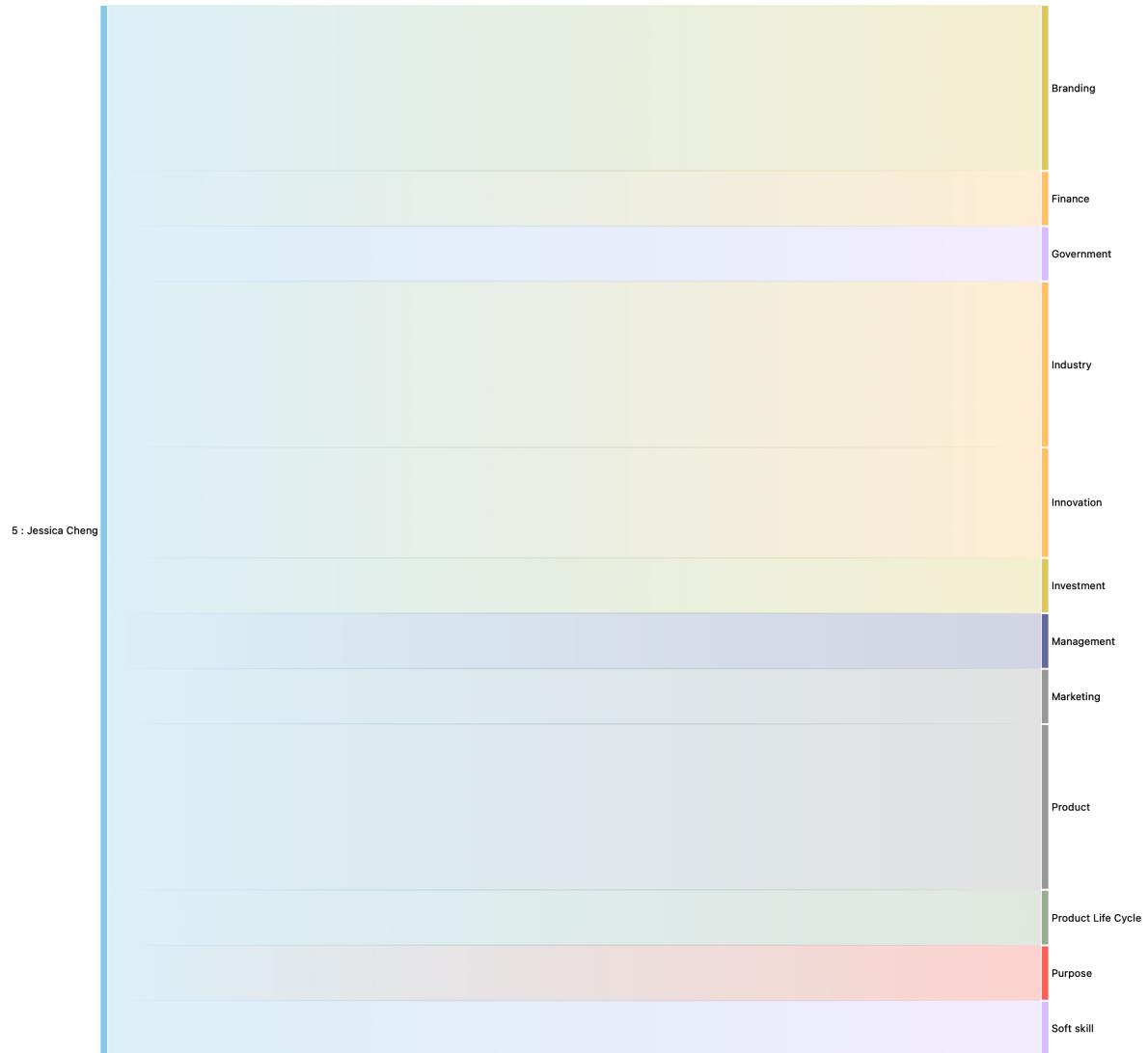


Figure 129: Jessica Cheng

12.16.4 Interview 4: Economist - Chen-Ying Huang

Date: 2024-05-19 Expert: Chen-Ying Huang is an economist and professor at National Taiwan University. Country: Taiwan Topics: Economics

“I’m really lazy when shopping... if it’s easier to get the information that I don’t have to click on the button... it’s more likely that I will even pay attention to that.”
- Chen-Ying Huang

Thematic Analysis.

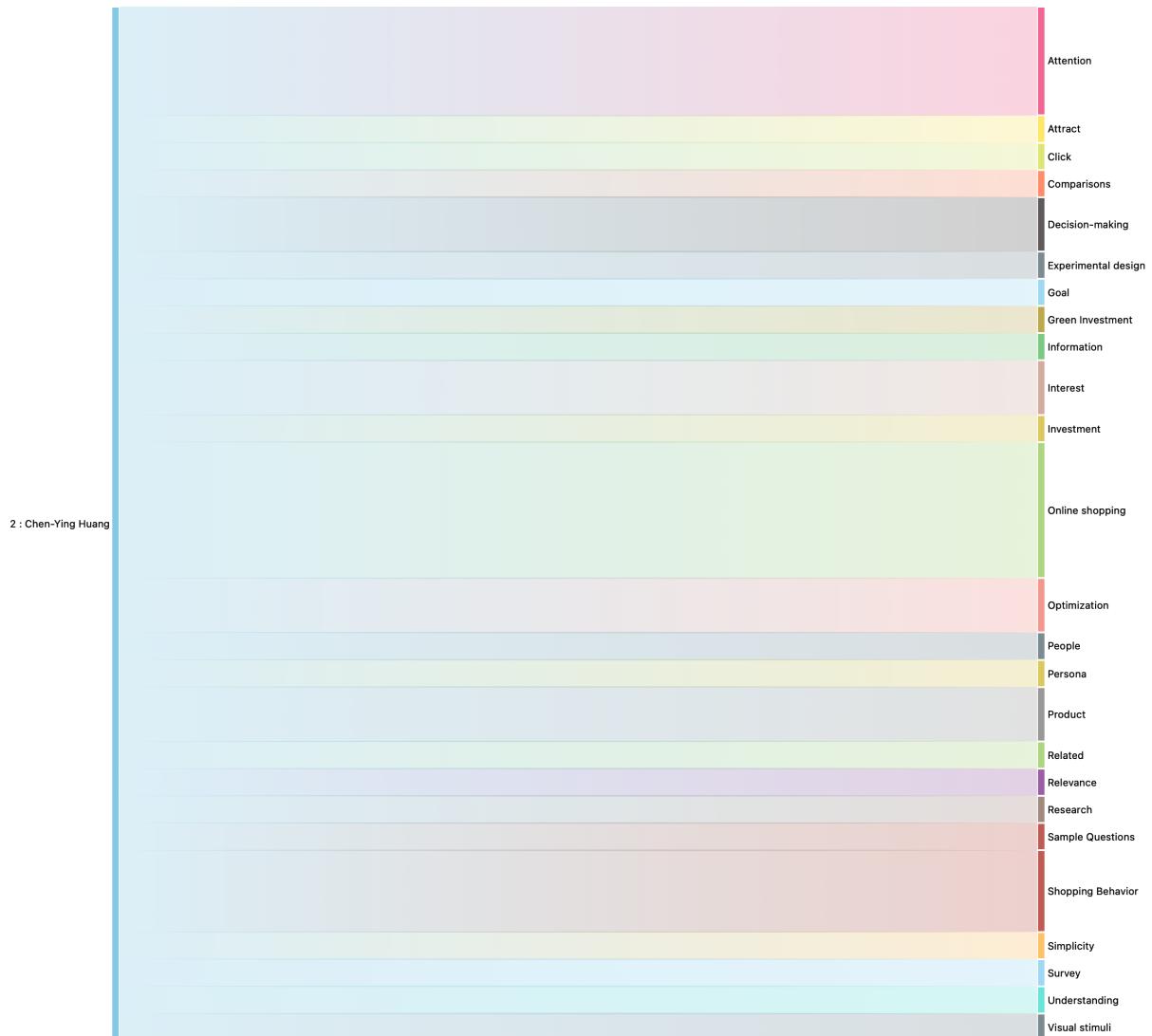


Figure 130: Chen-Ying Huang

12.16.5 Interview 5: Economist - Yuping Chen

Date: 2024-06-04 Expert: Yuping Chen is an economist and professor at National Taiwan University with a focus on marketing and online shopping. Country: Taiwan Topics: Economics, Online Shopping.

Key learnings: "I think you are targeting experts instead of a general consumers"

“I tried the Green Filter by myself and I find the information was overwhelming... I cannot pay attention to every detail.” - Yuping Chen

Thematic Analysis.

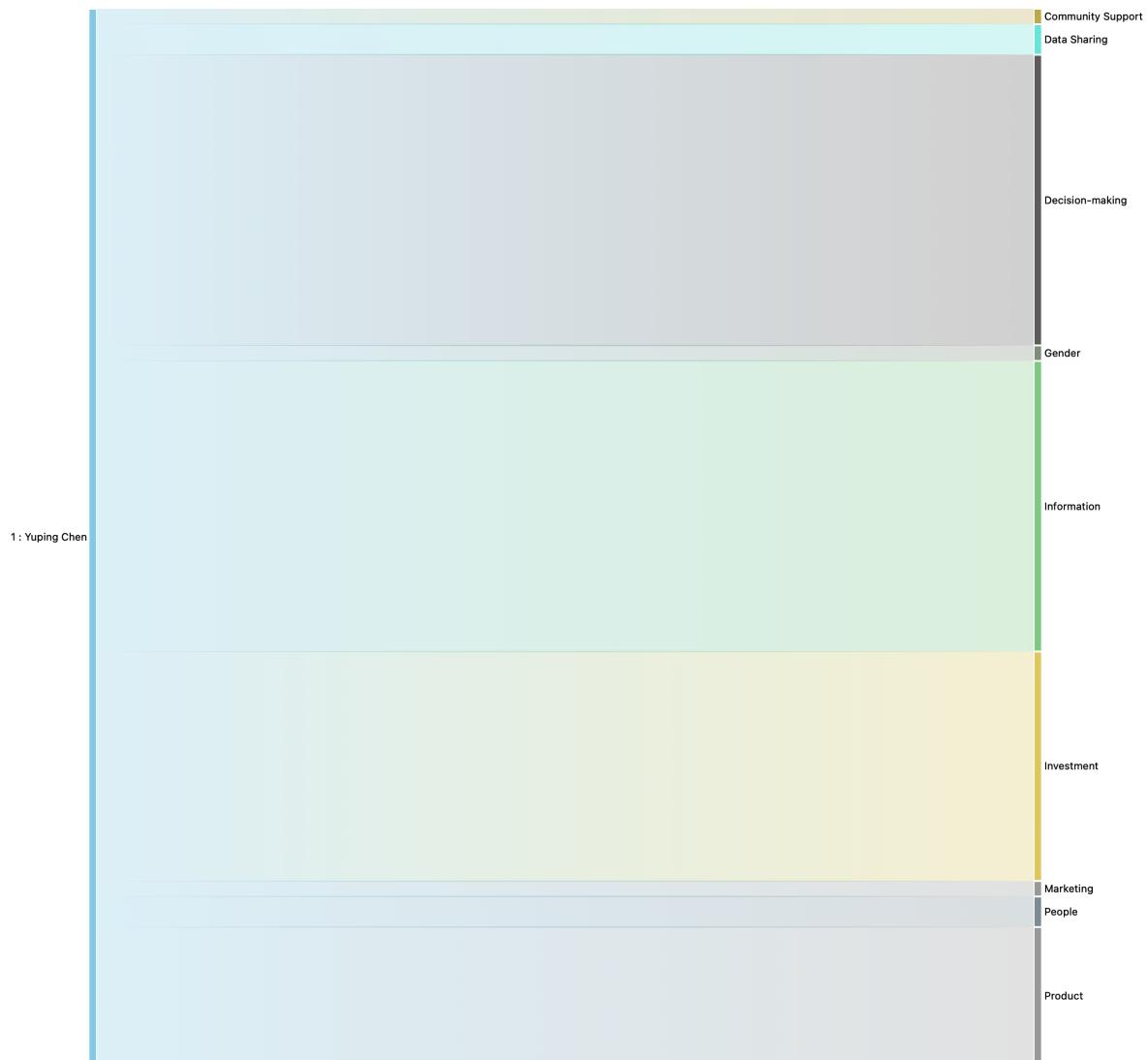


Figure 131: Yuping Chen

12.16.6 First Wave Expert Feedback Summary

Common topics between all the first wave conversations become visible in the overall Sankey Diagram.

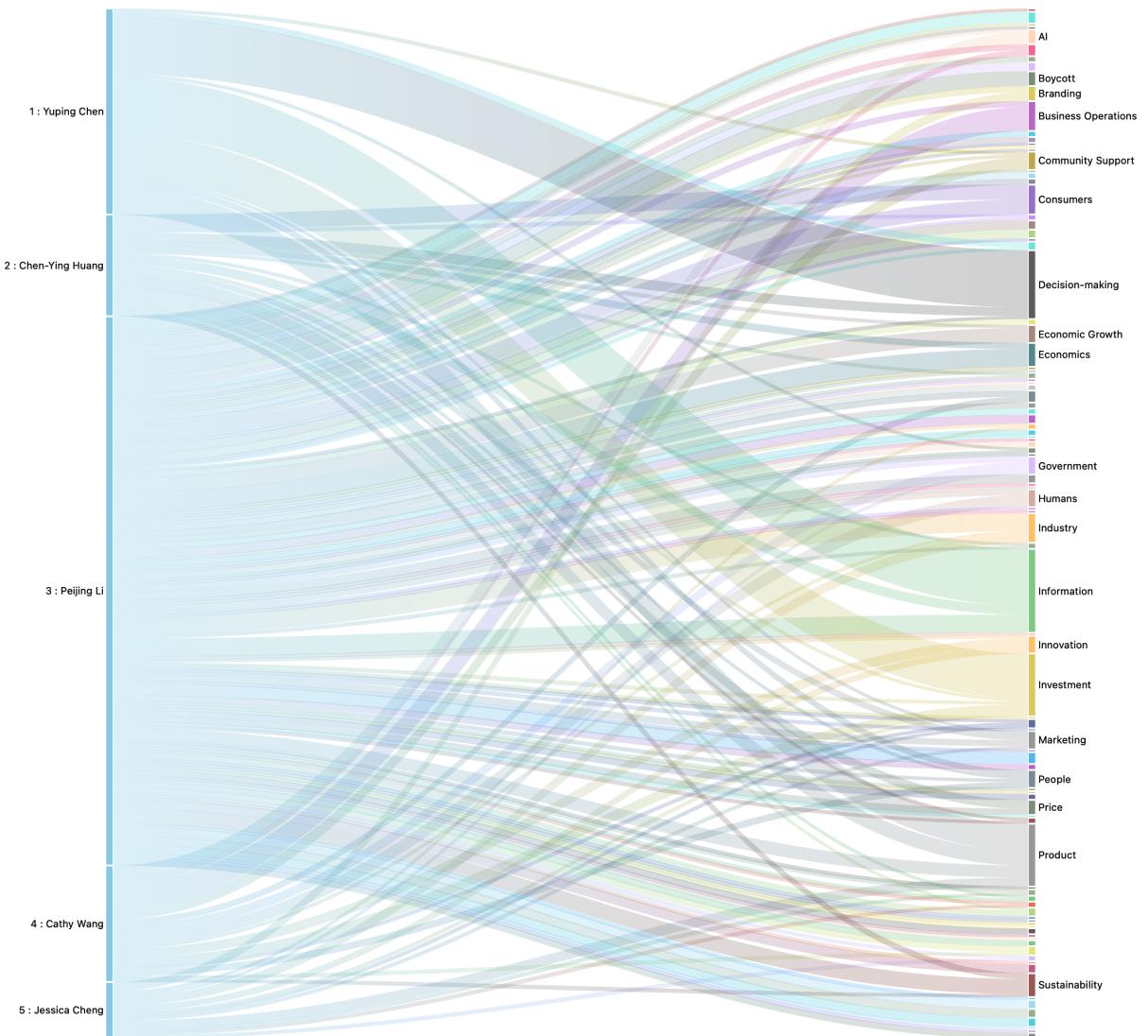


Figure 132: Common Topics Between All Experts in the First Phase

Key actionable takeaways from the first wave include:

- Provide alternatives
- Simplify text
- Use images
- Put a “New Feature” ad on the front page
- Change 繼續討論 to something more actionable (I tried changing to “see alternatives”)

12.17 Second Wave of Experts (2025)

12.17.1 Interview 1: Technology Expert - Audrey Tang

Date: 2025-02-28 Expert: Audrey Tang is a technology expert and former digital minister of Taiwan. Country: Taiwan. Topics: Sustainability, digitalization.

“The 17 and the 70-year-olds are the natural allies... because they care more about the long term. They don’t care about the next quarter.” - Audrey Tang

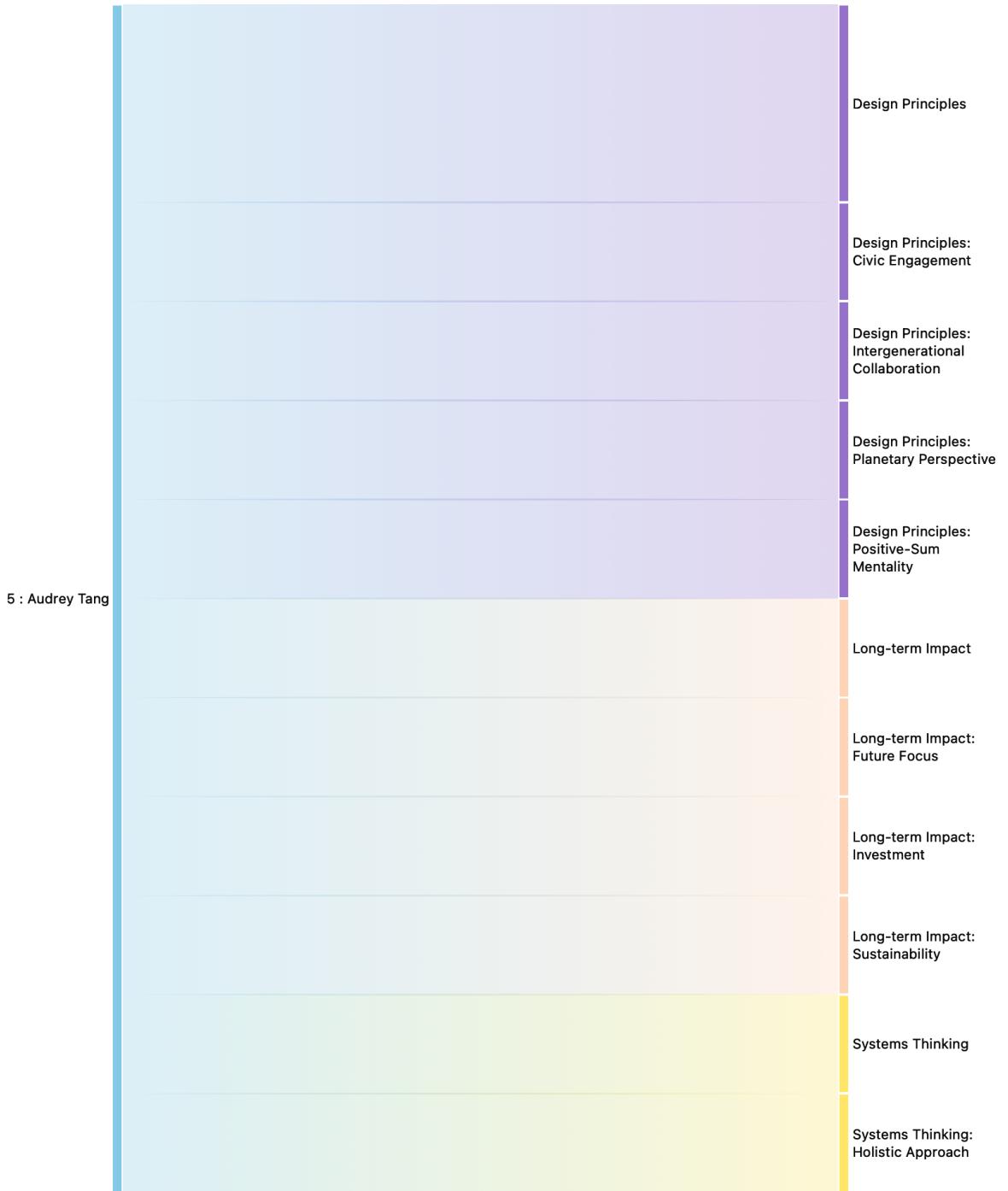


Figure 133: Yuping Chen

12.17.2 Interview 2: Sustainability Expert - Carlos Serra

Date: 2025-06-30 Expert: Carlos Serra is a sustainability expert and zero waste activist. Country: Mozambique. Topics: Sustainability, corporate responsibility.

"I believe certification is, obviously, a powerful means of providing positive visibility, motivating, encouraging, and even creating an attraction for eco-friendly, sustainable businesses." - Carlos Serra

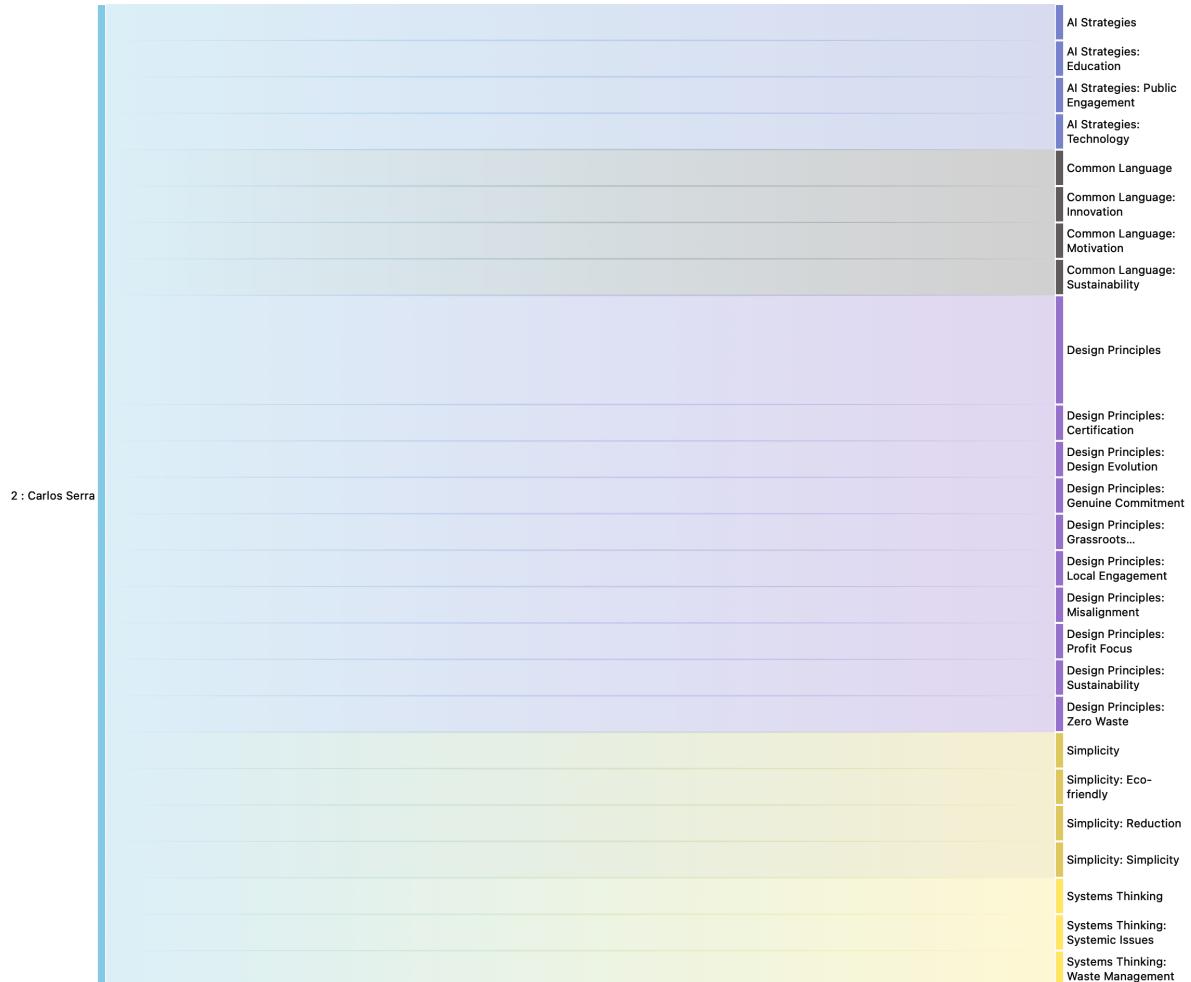


Figure 134: Yuping Chen

12.18 Thematic Codes

Category	Code	Frequency
AI Strategies	→ Technology	8
	→ User Engagement	6
	→ User Interaction	6
	→ Data Collection	5
	→ AI Tools	4
Common Language	→ Engagement	7

Category	Code	Frequency
Design Principles	→ Transparency	7
	→ Accessibility	6
	→ User Engagement	5
	→ User Experience	5
	→ User Engagement	13
	→ Sustainability	12
	→ Collaboration	10
	→ Integration	10
	→ Transparency	9
Feedback Loops	→ Continuous Improvement	6
	→ Refinement	5
	→ User Feedback	3
	→ User Experience	2
	→ User Testing	2
	→ Sustainability	9
Long-term Impact	→ Sustained Engagement	6
	→ Long-term Impact	5
	→ Consumer Behavior	2
	→ Continuous Improvement	2
	→ Simplicity	10
Simplicity	→ Accessibility	7
	→ Clarity	7
	→ Straightforwardness	4
	→ User Engagement	4
	→ Interconnectedness	31
Systems Thinking	→ Holistic Approach	15
	→ Integration	12
	→ Consumer Behavior	5
	→ Systemic Approach	5
	→ Transparency	8
Transparency	→ Clarity	7
	→ Clear Communication	7
	→ Visibility	4
	→ Product Origin	3

12.19 Overall Expert Feedback Summary

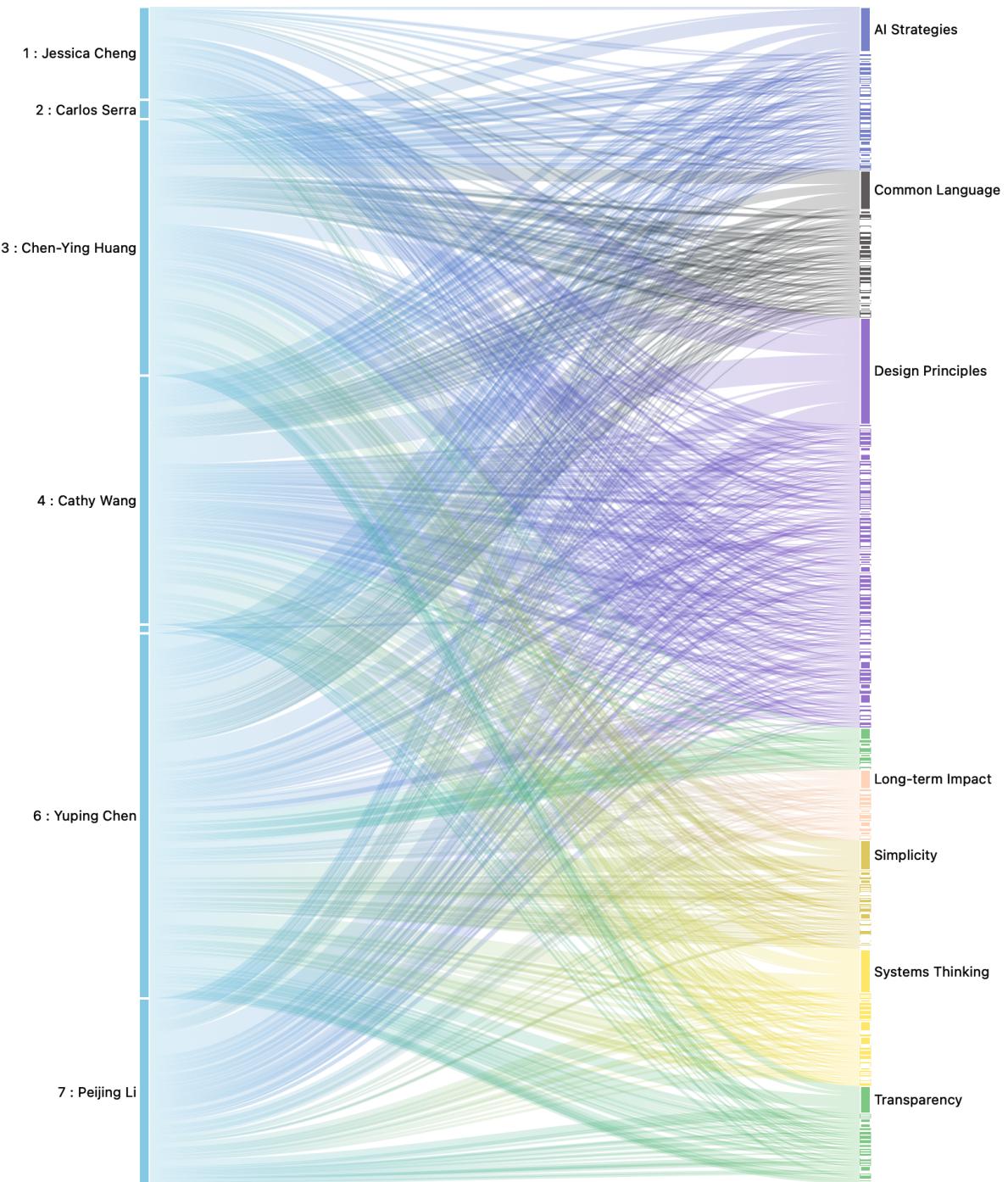


Figure 135: Common Topics Between All Experts in the First and Second Phase

The following summaries were generated by Atlas.ti for each of the 8 thematic keywords, combining insights from all of the interviews, then heavily edited for brevity and formatted into

tables.

1) AI Strategies

This line of discussion focuses on digital AI tool design and preferred functionality to enhance consumer awareness of product origins and sustainable consumption and investments.

Topic	Key Points
User Engagement Challenges	Difficulties in attracting user attention to features in apps like Momo; suggestions include curiosity-driven prompts, quizzes, and intuitive design
Sustainability Focus	Shared need for transparent product info, especially on environmental impact; desire for clear labeling on sustainability and investment value
Improving User Experience	Tactics to boost click-through rates, such as eye-catching visuals and smart contextual prompts to encourage feature exploration
Technical Constraints	Discussion of platform limits (e.g., Chrome) on tracking; proposes tracking once users enter a more controlled environment
Educational Perspectives	Need to educate users on sustainable investing; propose accessible metrics and user flows that guide them from casual to informed consumers
Cultural Insights	Taiwan-specific views on sustainability; food safety concerns seen as a gateway to broader sustainable practice awareness
Future of AI in Design	AI can simplify design and personalize interfaces; discussion includes ethical use of AI and its role in user engagement
Collaborative Approach	Importance of collaboration among designers, developers, and businesses to overcome user resistance and data challenges

In this line of discussion on AI strategies, experts provide ideas to build a framework for developing a sustainable consumer application while addressing user engagement, technological limitations, and the educational aspects of sustainability.

2) Common Language

Challenges in user engagement and data collection, particularly how to move users from initial engagement to deeper interactions with the app.

Topic	Key Points
User Engagement	Users show initial interest but rarely go deeper; main issue is the analysis button being overlooked.
App Features and UX	Proposed adding a personality quiz and refining button design/colors to boost curiosity and clicks.

Topic	Key Points
Data Analysis and Personas	3 user personas guide feature customization, aligning content with differing sustainability interests.
Testing and Iteration	Emphasis on refining testing, possibly using a control version to compare user behavior and preferences.
Sustainability Metrics	Aim to show clear, simple info about product origins and sustainability to sustain user interest.
Technological Integration	Suggestions include using tech to track and visualize sustainability data, enhancing transparency and usability.

This line of discussion seeks practical solutions to enhance the app's functionality and ensure it resonates with its users more effectively; the discourse focuses on a complex interplay between user experience design, data utilization, and the overarching goal of promoting more sustainable consumer habits through increased awareness and engagement.

3) Design Principles

This line of discussion centers around environmental sustainability, the influence of AI and technology in business, and the interface of design thinking with social and economic changes.

Topic	Key Points
Emotional Connections in Digital Content	AI can mimic emotional presence, creating bonds (e.g., with digital personas), especially for older users.
ESG Reporting and Corporate Responsibility	ESG affects investment decisions; there's a need for clearer, more honest sustainability communication.
Design Thinking and User Engagement	UX must reflect user emotions; feedback and intuitive interfaces are key to engaging digital products.
Personalization in Consumer Platforms	Users expect tailored content; platforms like Momo and Shopee benefit from adaptive recommendations.
Impact of Grassroots Movements	Youth-led efforts (e.g., against plastic straws) can influence corporate behavior and policy shifts.
Access to Information and Accountability	ESG data must be more transparent and consumer-friendly to foster trust and real accountability.
The Role of Design in Social Change	Design drives social impact when aligned with emotional storytelling and community needs.
Holistic and Systemic Perspectives	Solving big issues (e.g., climate change) requires integrated, cross-sectoral thinking.

Topic	Key Points
Practical Applications of Research in Design	Design theory should lead to action; involve users and students in real-life design practice.
Future Directions in Sustainability	Emphasis on youth-led activism, intergenerational collaboration, real-time transparency tools, personalized user journeys, and regulatory pressure (e.g., EU ESG mandates) as drivers of future sustainability innovation. Experts highlight the need for planetary thinking, upstream design changes, and grassroots movements enabled by accessible digital technology.

4) Feedback Loops

This line of discussion focuses on the challenges in user tracking, specifically on the Momo platform. Initial testing has shown that many can't find critical buttons, highlighting design flaws that need to be addressed. Yuping Chen provides insights on user engagement and suggests ways to improve the visibility of new features. They discuss user funnels, the difficulty of capturing attention from users, and the importance of clear communication about new features.

The conversation explores the concept of persona-driven design and generative UI, noting that understanding user preferences (like product origins) can help in tailoring the app's offerings. The need for simplicity and engagement in user interfaces to keep users interested.

Feedback is exchanged on testing methods, where Yuping provides suggestions for effective user surveys and experimental designs to gauge user satisfaction, especially regarding product origins. The discussion emphasizes the need for user-friendly features and clear communication to enhance user interaction and retention within the app. They conclude that making the app's intentions explicit and engaging users interactively is crucial to success.

Topic	Key Points
Continuous Improvement Refinement	Improving visibility of key features on Momo; clearer prompts and in-app guidance can boost engagement.
User Feedback	Early tests showed users overlooked important buttons; need for redesigning layout and color to capture attention more effectively.
User Experience	Yuping shares tips on using surveys to collect actionable input; user responses help guide feature prioritization and messaging clarity.
User Testing	Simplicity and visual cues are essential; persona-driven design helps match product info (like origin) to user preferences.
	They emphasize A/B testing and user observation; tracking interaction data can help improve app flow and retention strategies.

5) Long-term Impact

This line of discussion revolves around the development of an app focused on transparency in product origins and investments, exploring various user personas and their interests, emphasizing the importance of product origin in attracting users, particularly college students, sharing insights about user testing, highlighting challenges in engagement and visibility of app features.

Yuping Chen suggests strategies for improving user interaction, such as making buttons more noticeable and providing explicit information about new features, reflecting on changing consumer behavior regarding sustainability and the importance of communicating the ethical dimensions of products. Cathy Wang adds to the discussion by highlighting the emotional aspects of consumer behavior and the regulatory environment impacting businesses, especially in relation to sustainability. Exploration of concepts like “sunrise” and “sunset” industries, touches on the implications of economic growth versus sustainable practices.

Topic	Key Points
User Personas & Engagement	Outline of personas focused on product origin, especially for college students; highlights issues in feature visibility and drop-off.
Interface Design & Feedback	Yuping suggests clearer buttons and upfront prompts to guide users; the use of surveys to link feedback with app interactions.
Sustainability & Business Impact	Cathy emphasizes emotional drivers in consumer behavior and how sustainability is reshaping business, especially under new regulations.

Overall, the conversation navigates the intersection of technology, consumer behavior, and sustainability, emphasizing the need for innovative approaches to engage users effectively while addressing their concerns about product origins and environmental impact.

6) Simplicity

This line of conversation discusses the origins for the research, stemming from a desire to create a product that allows users to easily access information about the sustainability of products they purchase, inspired by the science fiction show Star Trek, indicating a wish for a scanner-like tool that could provide instant information on product quality.

Topic	Key Points
Sustainability Tools	The concept originated from a desire for a tool that instantly reveals the sustainability and origins of products, inspired by sci-fi ideas.
Sustained Engagement	Maintaining user interest requires visual design, gamified features, and clear prompts that simplify sustainability insights.
Long-term Impact	The goal is to transform casual purchases into informed, value-aligned decisions that support long-term sustainable habits.

Topic	Key Points
Consumer Behavior Continuous Improvement	Users often avoid detailed reports and prefer quick, intuitive visuals; simplifying data presentation is key to influencing decisions. Iterative feedback from testing helps refine design and communication; using familiar product types makes sustainability info more relatable.

The experts brainstorm ways to enhance the user interface and make it more intuitive, such as using *familiar product categories* for testing purposes.

Chen-Ying Huang highlights the role of AI in analyzing products and providing insights, emphasizing that users often prefer quick, easy-to-understand visual representations over detailed reports and the importance of gathering user feedback to refine the product, particularly regarding the clarity and relevance of information about product origins and sustainability.

The dialogue also touches on the need to adapt existing technology to improve user experience, especially focusing on the limitations of platforms like the Apple app ecosystem compared to more flexible ones like Google Chrome, exploring various strategies to encourage users to engage with the application, such as gamifying the experience or providing attractive prompts.

Throughout the conversation, there is a focus on how to make the initiative relevant to the general public, addressing their concerns about sustainability and helping them make informed purchasing decisions. The discussion implies a significant challenge ahead in creating a compelling, user-friendly tool that can bridge the gap between consumer behavior and sustainable practices.

7) Systems thinking

This lengthy discussion primarily revolves around sustainability, consumer behavior, and technological solutions aimed at improving transparency in the marketplace, when it comes to products and their environmental impact.

Topic	Key Points
Economic Impact and Externalities	Peijing Li highlights the importance of considering external costs in economics, using the example of cigarette smoking, where the price does not reflect the full societal harm caused.
Sustainability and Consumer Awareness:	There is a focus on how consumers perceive products, particularly regarding sustainability. Many college student survey participants express a lack of trust in “green” claims, suggesting that they want more transparency in product origins and environmental impacts. Consumer skepticism toward green claims signals demand for clearer, verifiable data on product origins and environmental impact.

Topic	Key Points
Tech-Driven Transparency	Technology (such as apps, AI, blockchains, etc) can be used to enhance consumer understanding of products. There's a vision for real-time data on product origins, manufacturing practices, and company sustainability scores.
Behavioral Insights	How consumers interact with sustainability-related information reveal that many are overwhelmed and confused. Thus, there's a need for simplified, engaging communication about sustainable practices.
Behavioral Economics	The idea of "sunrise" (growing industries) and "sunset" (declining industries) companies is raised, emphasizing that consumers might change their habits out of risk avoidance rather than a genuine commitment to sustainability.
Marketing Strategies	Recommends using curiosity-based prompts, interactive features, and clear messaging to drive sustainable user engagement.
Research, Testing & Experimentation	Advocates for A/B testing of sustainability labels and features, linking product origin data to user satisfaction.
Community Collaboration	Community-based actions and local engagement can strengthen sustainable habits and promote systems-level change.

Altogether, the conversation emphasizes the intersection of technology, consumer behavior, and economic theories in shaping a more sustainable market environment, while identifying the ongoing challenges in achieving greater transparency and consumer engagement in sustainability efforts.

8) Transparency

Finally, the discussion on transparency centers around the concept of improving consumer awareness of sustainability and ethical practices in products through the "*Green Filter*" app.

Topic	Key Points
Consumer Awareness	The app aims to reveal hidden layers behind products, empowering users through simple, trustworthy insights into ethical practices. Users who understand product origins and company ethics are more empowered to make informed, sustainable choices.
Feature Design and User Interaction	Simplify the user journey while boosting user engagement with playful interactions. Test UIs to make sustainability information more intuitive and accessible.
Investment Education	Connects purchases with green investing, teaching users how spending links to broader financial and environmental outcomes.

Topic	Key Points
Data and Trust	Recognizes challenges in ESG data reliability; seeks transparent reporting standards users can trust.
Research and Testing	Uses user testing and analytics to refine features, identify pain points, and improve click-through.
Label Skepticism	Questions the credibility of existing sustainability labels; calls for clearer, more accountable rating systems.

The conversation revolves around creating an informative AI-based tool that empowers consumers to make more sustainable choices while addressing the realistic challenges in obtaining and presenting such information effectively.

12.20 Interview Template

This is the basic interview script, which was used with small modifications at each interview.

On Momo:

- What is a brand that you like'd or would like to buy - search - please pick a product (or search again)
- After reaching Momo product page: what do you notice on this page?
- What kind of information is important for you on this page?
- Do you notice anything else?
- (If the user doesn't notice the green filter, direct their attention to it and ask: what do you think this does?)
- Would you click on it - if the user says yes, continue - if the user says no, make note and continue
- As the extension generates a response: what do you think about this content?
- Is there any information that you consider important?
- Anything else you see that you think looks special
- Do you see anywhere you can click?
- Would you click on it? - if yes, continue - if no, make note, and continue
- Explain: due to the limitation of the prototype, the test will continue on a separate page where you can ask questions
- Is there anything you would like to ask the helper?
- Notice if the user picks from sample questions
- Remind the user they can come up with their own question
- As the AI is generating content ask: do you see any information in this content
- Did you know this before or is there any info you didn't know before? make note.
- Front page: explain the helper takes into account your personal info and goals.
- Ask: what kind of information do you think important to share with the helper?

12.21 2nd Wave of Testing (Fall 2024 - Spring 2025) - Prototype

Interviews and testing survey were conducted anonymously in hopes to have more honest responses from the responders.

- 32 anonymous Gen-Z participants in face-to-face interviews at 7 universities
- Over 100 anonymous self-testing participants at over 20 universities
- Testing is anonymous

Below you can see some of the images testers uploaded from their own devices (there were too many to be displayed here fully).

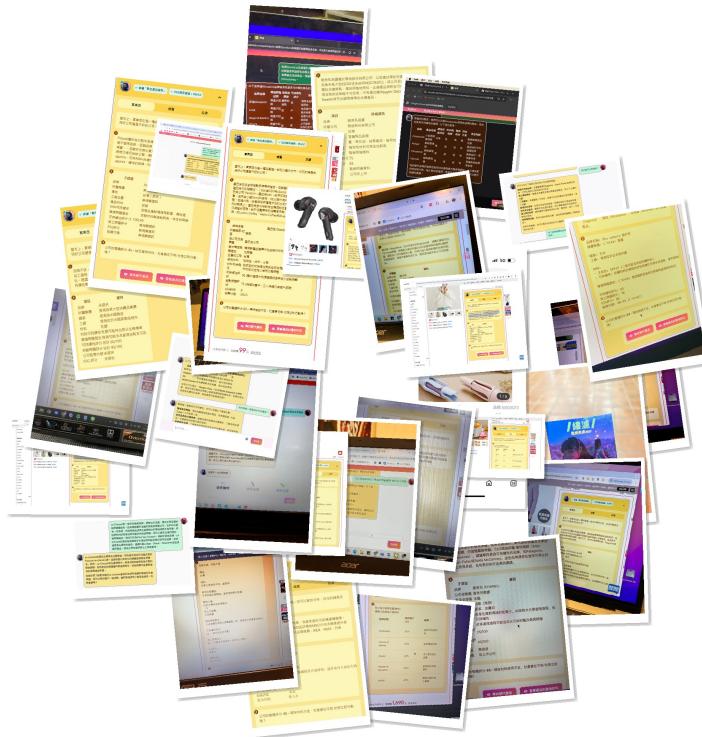


Figure 136: User-uploaded screenshots of the Green Filter prototype

12.21.1 Testing Summary

In-person interviews highlighted that participants generally appreciated the transparency provided by the Green Filter app regarding sustainability of products. Interviewees mentioned that the visibility of “*Material Sustainability*” and the historical and environmental impact of products influenced their perception and purchasing intentions, sometimes causing them to reconsider previously unquestioned consumption habits. Participants were particularly intrigued by the comprehensive information on carbon emissions, labor issues, and potential health risks from certain ingredients, emphasizing that such details were rarely accessible in typical shopping experiences. Additionally, participants valued AI-generated comparative data that offered alternative sustainable brands and products, which helped them better understand environmental impacts and make more informed choices.

However, usability issues surfaced regarding terminology and interface clarity. Some users misunderstood the labeling related to financial savings and carbon emission reductions, indicating the importance of precise and intuitive wording in Chinese.

12.21.2 Known Issues

- The Green Filter (Ziran) Chrome Extension is unable to record activity due to browser security restrictions for plugins.
- Meanwhile, the web-only version at “ai.ziran.tw” (without direct access to user’s screen), can record user activity.

12.21.3 Notable Quotes from In-Person Testing

“But I didn’t think that maybe the facial mask could contain some unknown plant extracts and chemical preservatives.”, anonymous student at Tainan Chang Jung Christian University (CJCU)

“Since I was young, they often said... if something is made locally, the carbon footprint won’t be as high.”, anonymous student at National Pingtung University of Science and Technology (NPUST)

“It gives me more choices.”, anonymous student at Tainan Southern Taiwan University of Science and Technology (STUST)

“I hadn’t thought that the final use and disposal... would also affect carbon emissions.”, anonymous student at Tainan University of Technology (STUST)

“What I see now is that it has listed the carbon footprint... it listed it very detailedly.”, anonymous student at Tainan National Cheng Kung University (NCKU)

“I don’t care, I just look at the price, see what else there is, and then buy it directly.”, anonymous student at Chiayi National Chung Cheng University (CCU)

“You can understand the product better. Before buying, you’ll know its info in more detail and what happens after you buy it...”, anonymous student at Tainan National Cheng Kung University (NCKU)

12.21.4 Example Interview: 25 December 2024

Location: Taichung, National Chung Hsing University (NCHU) Anonymous Tester Code: [3G1RL]

Speaker	Content
Interviewer	This app is part of my thesis about sustainability. First, may I record our conversation?
Participant	Uh, yes.
Interviewer	Have you used Momo before?
Participant	Yes.
Interviewer	Which platform do you use most, Momo or Shopee?

Speaker	Content
Participant	I use Shopee more often.
Interviewer	What kind of things do you usually buy online?
Participant	On Momo I once bought a set of speakers.
Interviewer	Anything you want to shop for right now?
Participant	Maybe some movies... but let me browse shoes instead.
Interviewer	Sure, pick any item.
Participant	(Searches) Found a pair of Timberland boat shoes.
Interviewer	Why that model?
Participant	I have eyed this pair for a long time and it looks good when others wear it.
Interviewer	Let us open my prototype overlay. What do you notice first?
Participant	The company score says forty five, which feels low, so maybe it is not very eco friendly.
Interviewer	The green tab shows "Reduce carbon emission thirty eight percent". What does that mean to you?
Participant	It lists brands with lower carbon footprints so I could choose them instead. I have tried Timberland before; the others are new to me.
Interviewer	The purple tab suggests investment options. Thoughts?
Participant	It looks like I could invest in companies similar to Timberland, check stock prices and trends. I have never bought stocks though.
Interviewer	If Apple scored badly on the environment, would you switch brands?
Participant	I would research alternatives. Environmental impact matters to me.
Interviewer	Try the "Ask AI" button.
Participant	(Types) "How much carbon does this product emit?" The answer breaks down production, packaging, transport, even end of life disposal. I never considered water and electricity used during use.
Interviewer	Which part of the overlay feels most useful?
Participant	The detailed material and ESG section, environmental and labor issues, plus the alternative brands list.
Interviewer	Any information missing before you decide?
Participant	Safety data and warranty, especially for products used near the face; also clearer brand logos and Chinese names.
Interviewer	At the top there is a code. Please read it aloud.
Participant	Three G one R L.
Interviewer	Could you take a photo of the most important screen and write that code on the card?
Participant	(Takes photo and writes code) Done.
Interviewer	Last question, will the sustainability data change your purchase?
Participant	I might still buy these shoes if I really love them, but I will think twice and compare with greener options first.
Interviewer	Great. Thanks for your help today.
Participant	No problem.

12.22 1st Wave of Testing (Spring 2024) - Prototype

Semi-structured interviews were conducted in Chinese. The interviewer (me) took notes of the interviews. Some gaps in the data exist due to the limited Chinese language skills of the interviewer (me).

12.22.1 1st Wave Interview Samples

Sun, 14. April 2024, 22h at D24

User Profile: NCKU student, Gen-Z. Anonymous Tester Code: [REDACTED]

- Searches for *Lancome* brand.
- Chooses LANCOME 蘭蔻 小黑瓶 100ml (買一送一/超未來肌因賦活露國際航空版) Link to Momo page.
- Notices 買一送一 (buy one, get one free).
- Doesn't notice the analysis button at first.
- Would only click on this button if the product is really expensive.
- Would not click on "continue chat button"
- Asked "why is it so expensive in taiwan".
- Considers the report result useful.

Note: There's dropoff on every step of the user journey. Note 2: Add carbon indicators, other labels to the analysis, add report code, calculate report code from URL? Save as KV. Note 3: Make use of the Chinese term: 有意識的消費主義

RQ: To what extend can shopping become an entry point for saving and investing. RQ: Can shopping serve as an entry point for sustainable saving and investing?

May 8

User Profile: NCKU student, Gen-Z. Anonymous Tester Code: [CZUTA].

On Momo: * Investment help is useless.. * Needs a simpler introduction * Wants to see real cows [in the product source view] * Very curious about companies * Wants to see the company profit and margin percentage. Why is margin so high if pollution is bad? * Wants to see the real environmental impact of the company.

May 6

User Profile: NCKU student, Gen-Z. Anonymous Tester Code: [REDACTED]

On Momo: * Is concerned that seeing factory photos is useful only if they are trustworthy photos. Who will provide them?

May 5

User Profile: NCKU student, Gen-Z. Anonymous Tester Code: [REDACTED].

On Momo: * Does not find the Green Filter AI at all. * User: it looks like an ad

May 3

User Profile: NCKU student, Gen-Z. Anonymous Tester Code: [REDACTED].

User first does an online Search: - Uses Google to look for “fashion brand eco friendly” - Thinks “goodonyou.eco” looks like a brand website.

On Momo: - first looked for NET clothes but Momo doesn’t sell it - Looked for Sony camera lens

May 1

Notes: *Professor Feedback*: 1st of May Prof. suggestion - make connection between biodiversity and production and consumption clearer - what is the incentive for companies to share their data?

my own idea: like the switch of going from traditional banking with ATM machines on the street (or even the physical bank office) to online banking with mobile payments.

Hypothesis: ESG accessibility can push companies to increase production standards.

What if you can see ESG in near-realtime such as the stock market price?

I can imagine ESG derivative product like siemens gamesa

AI can help integrate esg derivatives into daily life to drive esg adoption

“effective altruism (EA)”

“Blockchain technology can improve price transparency in product distribution by allowing consumers to know the exact pricing from raw materials to distributors to suppliers.”

Tuesday 30. April 14:05-14:45

User Profile: NCKU student, Gen-Z. Anonymous Tester Code: [7CYQ6]

On Momo: - Looks for Levis pants - Looks for recommendations on the sidebar - Looks at the photos - Looks at the price and options - Didn’t notice the helper as it looks like an ad - When helped... - Ignores 社區支持: 購物 69% 儲蓄 80% 投資 65% as doesn’t know what these mean

On ai.ziran: - Shares personal info: 四年後想考研究所，還不想工作，所以不會存到錢，希望可以考到台北的學校，每個月有兩萬生活費。

On DJmoney: Link to DJmoney page - Still didn’t notice the helper - Doesn’t understand investing (Understands it’s Taiwanese stocks) so the helper is useful for explaining new concepts

Monday 29. April 10:10-10.25

User Profile: NCKU student, Gen-Z. Anonymous Tester Code: [REDACTED]

On Momo: * Wants to buy New Balance sneakers

On DJmoney: * Wants compare EFTs

Monday 29. april 14:50-15:10

User Profile: NCKU student, Gen-Z. Anonymous Tester Code: [REDACTED]

On Momo: * Wants to buy an Apple iPhone (older model). * Bad internet (very slow) * App was slow * App crashed

Note: Green Filter analysis on DJmoney seems more trustworthy than the other 2 ETF sites
2: Button placement is important (too low on sites other than djmoney)

Sunday 28. april 16:00

User Profile: NCKU student, Gen-Z. Anonymous Tester Code: [REDACTED]

On Momo: * Wants to buy ice cream

12.23 Early Feature Ideas

The following early feature ideas occurred to me during the literature review process. They are naive and meant to allow thinking in terms of *what-if* a particular user experience was possible. These prototypes were not tested with users directly and rather formed a basis for directing the questions asked in a potential user survey.

12.23.1 Susan (Sustainability Conversation)

What if I could have a chat like this at the supermarket? Imagine what questions I would ask before buying a product. AI: “Kris, do you still remember Coca Cola’s packaging is a large contributor to ocean plastic? You even went to a beach cleanup!” Me: “That’s so sad but it’s tasty!” AI. “Remember your values. Would you like to start saving for investing in insect farms in Indonesia instead? Predicted return 4% per year, according to analysts A and B.” If I’m not so sure, I could continue the conversation. Me: “Tell me more” AI: “A recent UN study says, the planet needs to grow 70% more food in the next 40 years. Experts from 8 investment companies predict growth for this category of assets.” Me: “Thanks for reminding me who I am” ... Moments later. AI: “This shampoo is made by Unilever, which is implicated in deforestation in Indonesia according to reporting by World Forest Watch. Would you consider buying another brand instead? They have a higher ESG rating.”

Example Suggestions of the AI companion:

- “*Don’t buy a car; use a car sharing service instead to save XYZ CO₂eq. Services available near you: Bolt, Uber, Line Taxi*”
- “*Use a refillable shampoo bottle to save XYZ plastic pollution*”
- “*Call your local politician to nudge them to improve bicycle paths and reduce cars in your neighborhood. Over the past 2 years, your city has experienced an increase of cars from 290 cars per capita to 350 cars per capita.*”

Speculative scenario of an interaction between a human user and a robo-advisor through the interface of chat messages in the context of retail shopping for daily products.

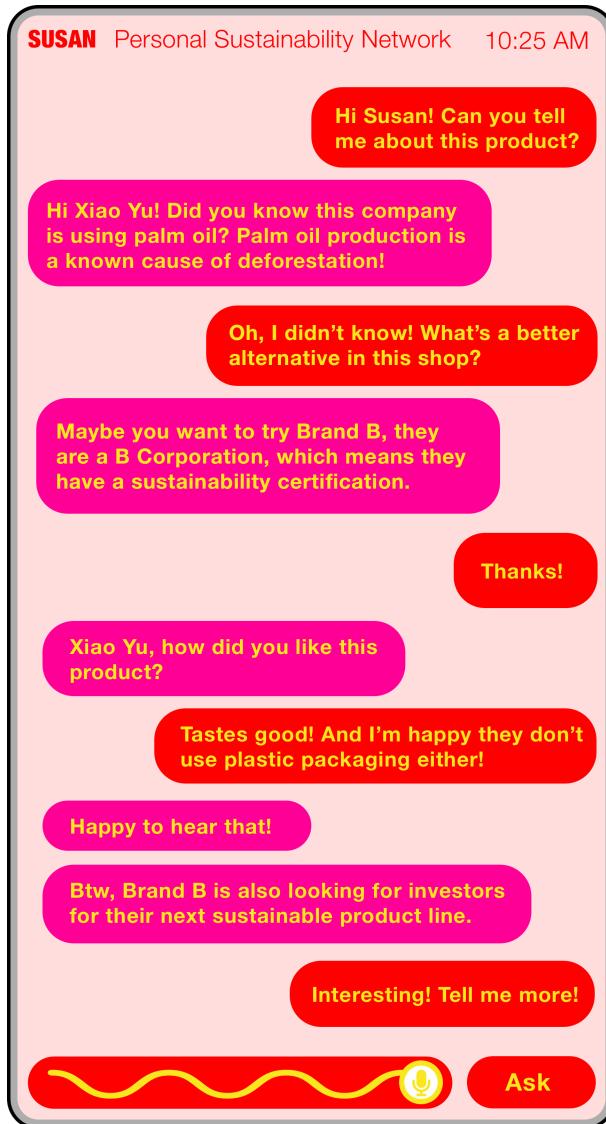


Figure 137: Early prototype of my Sustainable Finance AI Companion (Nov. 2020)

12.23.2 Sunday Market

What if I could go to the Sunday market with other people who care about sustainability? First prototype (based on literature review) called HappyGreen's for going to the organic Sunday Market with friends. Choose industries of focus? Fashion, Food, etc?

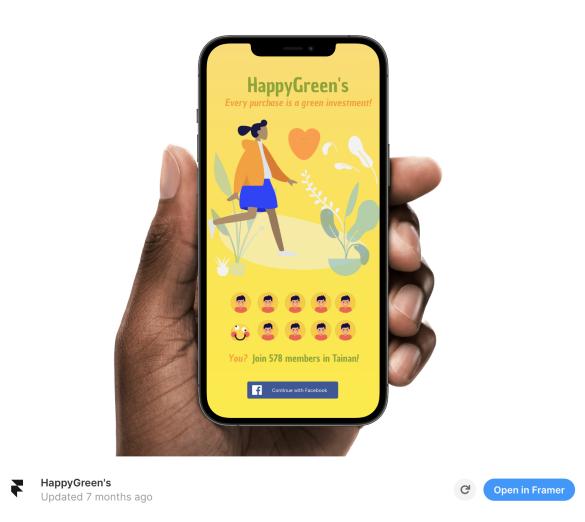


Figure 138: Feature idea: community app for shopping with eco-minded friends (Nov. 2020)

12.23.3 True Cost

What if I you could see the actual cost of each product including externalities?

Product	Price	True Cost
Coca Cola (0.5L)	3€	18€
Wella Shampoo	5€	30€

Figure 139: Feature idea: True Cost (Nov. 2020)

12.23.4 How Far?

What if the exact distance traveled by a product to reach me was clearly displayed during shopping? Seeing precise transportation distances and associated emissions could immediately clarify the environmental impact of buying local versus imported goods. Such transparency might encourage consumers to prioritize local and sustainable sourcing.

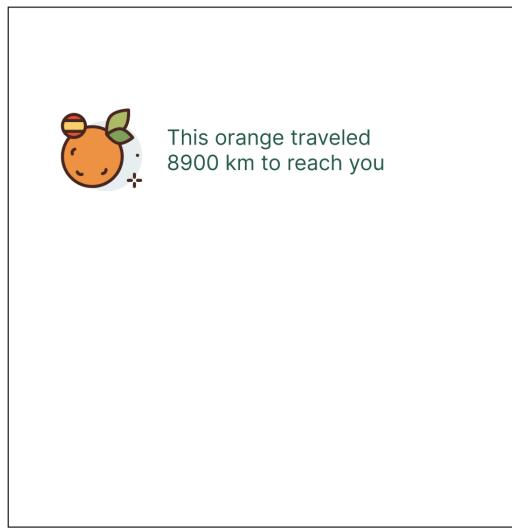


Figure 140: Feature idea: How far? (Nov. 2020)

12.24 Country Profiles

What if I knew my country's top pollution sources? I could instantly access detailed insights into my country's primary sources of pollution? Having clear, accessible data on national environmental challenges might empower consumers to support policies, businesses, and lifestyle changes that address critical sustainability issues.



Figure 141: Feature idea: Country Profile (Nov. 2020)

12.25 Know Your Company (KYC)

What if I could KYC the companies I interact with? This is a common practice for banks, they need to KYC “Know Your Client”. As a consumer, could I approach companies in a similar way to banks - using “Know Your Company” (KYC) for daily interactions with businesses? Possibly detailed transparency about corporate sustainability, ethics, and practices would enable consumers to engage only with companies whose values align closely with my own. Similary, *What if* I could “Speak Truth to Power”, affecting companies with truth? Consolidate user feedback for companies.

12.25.1 CO₂eq Flex

What if I could show off how much CO₂eq I have retired? What if I could showcase my contributions to reducing carbon emissions, similar to how fitness achievements are shared? A visual display or “badge” reflecting my environmental impact could encourage others, creating a ripple effect of positive behavior and raising community awareness about personal sustainability efforts.

12.25.2 Sustainability Watch

What if I could see all my sustainability data on a wearable device in the right context? My wearable device could provide instant, contextually relevant sustainability data throughout my day? Imagine checking my watch during shopping or commuting and instantly seeing personalized, actionable insights that help me make more eco-friendly decisions seamlessly integrated into my daily routine.

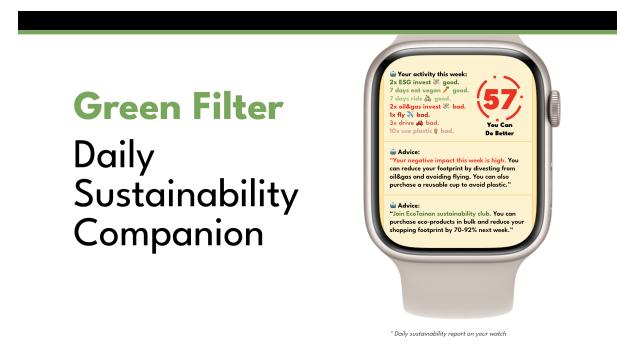


Figure 142: Feature idea: Sustainability Watch (Nov. 2020)

12.25.3 Narrative Layouts

What if I spent 5 minutes every day with a guide who could help me make more eco-friendly choices? How should the layout storyline be structured? Well it's like Strava (that running app)

for sustainability... or if you have heard of Welltory. I believe sustainable choices that would improve my life.. be it what I consume, save, invest, etc.. so I'm trying to design an app around this idea. I'm basically building the UX of AI.. focused on sustainability. How should the layout storyline be structured? Well it's like Strava (that running app) for sustainability... or if you have heard of Welltory. I believe if I spent 5 minutes every day with a guide who could help me make more eco-friendly choices that would improve my life.. be it what I consume, save, invest, etc.. so I'm trying to design an app around this idea.



Figure 143: Feature idea: Narrative Layouts (Nov. 2020)

12.25.4 Shopping Divest

What if I you could build a community based on what I buy? Or join existing communities based explicitly on sustainable consumption habits? By sharing my purchasing choices and sustainability experiences with others, perhaps we could collectively amplify the positive impact of our eco-conscious decisions.

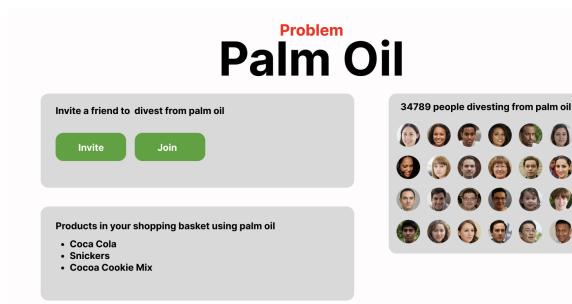


Figure 144: Feature idea: Narrative (Nov. 2020)

12.26 Prototype Development

The interactive prototype is publicly available at the Google Chrome extensions store and separately at the website: <https://ai.ziran.tw/>

12.26.1 Prototype architecture

- Google Chrome browser extension
- API microservice
- Ziran AI
- AI backend
- Ratings API
- Redis testing AI results
- Redis Page cache / from page / separate scraping service
- Documentation: GreenFilter: thesis website / github
- AI API got / Claude
- Stock ratings API
- Community ratings API

70 Questions - Use report ID to do anonymous testing - Page tracking to track the usage - 7 app questions - 63 personality questions

Other Tools Used: - QR generator in Canva - Postman for API testing

12.26.2 Google Chrome Extension App Installs

While Google is the most popular browser with over 3.45 billion users (“Google Chrome Statistics for 2024,” 2023), extensions are a relatively less known feature of the browser. Most popular extensions are Grammarly, for Taiwanese students End Note is familiar. However, it’s only available for computers (extensions don’t run on phones and tablets).

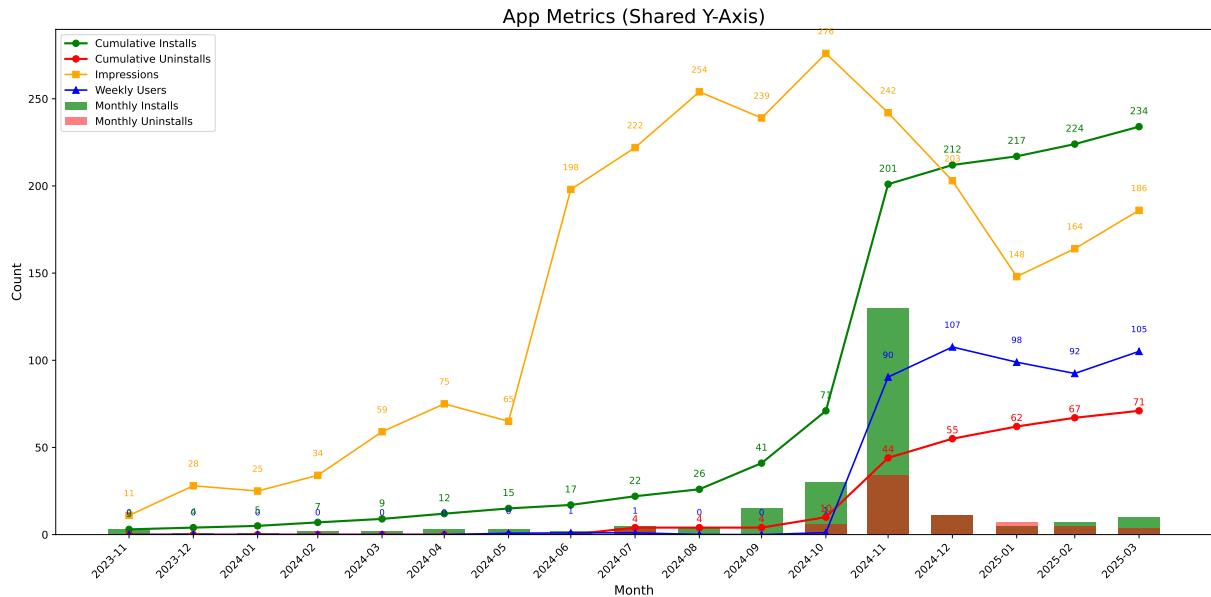


Figure 145: Green Filter Google Chrome Extension Installs

13 DISCUSSION

The success of interaction design depends on human psychological underpinnings. In the following tables I've used the *Theory of Planned Behavior* to categorize each feature according to what psychological state they aim to affect. To have any chance to impact human behavior towards sustainability, the nudges should be delivered in-context, and at the right time, using effective language. This section will focus on key findings that could be relevant for designing the right context - i.e. inside particular *Features* of the experience.

13.1 Design Implications

The following findings from *Literature Review*, *User Survey*, and *Prototype Testing*, have been categorized by chapter and list some of the key implications which can lead to *Feature Ideas*.

13.1.1 College

College students need tools for action. General theory about Taiwanese society suggests that it's low-context and people need groups to do activities. But my survey about my sustainability app shows that people don't pick the features for joining groups. Joining groups was one of the least interesting choices in the survey.

TPB	Design Factors	Potential Explanation for Group-Related Features
Attitude	Survey Framing Effect	Survey respondents may feel the way I framed the survey question for “joining groups” made it sound like an extra commitment they didn’t want to make.
Perceived Control	Group Fatigue	Survey respondents may already have too many group obligations to attend to (school, work, family, etc). Joining another new group may feel like a burden, not a benefit.
Perceived Control	Fear of Awkwardness	Survey respondents may feel joining strangers in online group is risky, uncomfortable or unnecessary.
Attitude	Desire for Personal Achievement; Changing Cultural Trends	Survey respondents may be more motivated by <i>individual achievement</i> to personally feel they are making a difference instead of waiting for the group. Possibly they are more individualistic than my expectations in their behavior (particularly in a digital context) and the traditional “group society” stereotype is weakening.
Subjective Norms	Are “Group” and “Sustainability” Concepts Related?	Survey respondents may not clearly understand the benefit for sustainability from their joining a group.

Environment shapes action.. how to create an environment where college students can influence companies.

Table 108: Design implications arising from the college chapter.

TPB	Human Interface	Findings and Roles	Design Implications
Subjective Norms	Community	Taiwanese students are highly influenced by the actions of their peers. People exist in relation to other people.	The app should show what other people are doing. In terms of a specific Feature, this could become “Group Purchases”, “Find Your Composting Community”, “Create a Group Chatroom”.

TPB	Human Interface	Findings and Roles	Design Implications
Perceived Control	Investing	Psychology of ‘fundraising clubs’ vs individual investing differs greatly.	Provide a community for pooling money with like-minded investors.

13.1.2 Sustainability

Design implications arising from the sustainability chapter.

Table 109: Design implications arising from the sustainability chapter.

TPB	Human Interface	Findings and Roles	Design Implications
Attitude	Shopping / Transparency	Realtime ESG is a building block to enable consumers and investors make more accurate, real-world purchase decisions.	Build technologies and practices that enable <i>real-time ESG</i> : up-to-date transparent information about how our products are produced.
Perceived Control	Shopping / Actionability	Start with the most polluted regions as priority?	Simplify action towards a “triple turn”: environmental, social, governance.
Perceived Control	Shopping / Pollution	People living in polluted areas are so used to it.	What app to wake them up? “You live in a highly polluted area. Here’s the TOP 10 companies causing pollution. Here’s what you can do.”
Perceived Control	Saving / Health Tracking	Blood testing and biomarkers allow people to track their health.	I’m introducing the concept of ‘eco-markers’ to follow the sustainability of human activities.
Attitude	Circular Economy	AI can help us make sense of the vast amounts of sustainability data generated daily.	Sustainability is part of product quality. If a product is hurting the environment, it’s a low quality product.

TPB	Human Interface	Findings and Roles	Design Implications
Perceived Control	EPR	There is a lot of new legislation (especially in Europe) encouraging sustainable design.	EPR and CDP data should be part of Green Filter.
Perceived Control	Eco-Design	As a consumer, eco-designed products are hard to find.	Provide clear labeling to find eco-designed products.
Subjective Norms	Governance	Politics matter and lack of transparency is intentional.	Make it easy to support policies that call for transparency.

13.1.3 Design

This chapter has the following design implications.

Several superapps already contain features for payments (shopping), savings, and investing. Yet none thus far integrate Digital Product Passports to understand the products' journey, including the origin and manufacturing conditions, materials, components, CO₂e footprint and environmental impact, post-consumer repair, recycling, and end-of-life disposal guidelines.

Table 110: Design implications arising from the design chapter.

TPB	Human Interface	Findings and Role	Design Implications
Perceived Control	User Interface	AI now enables generative UIs, which can dynamically change the layout and content as needed and fitting to the data.	It's a balance: while there's potential, users also need some type of stability (think: text input stays in the same place but different types of interfaces appear within a clearly defined space).
Attitude	Health	Many respondents express concerns about health.	Show health-related alerts in addition to sustainability. For example, Aspartame has not been banned or reduced after 2 years of findings; provide warnings for possible cancer-causing ingredients in the AI assistant.

TPB	Human Interface	Findings and Role	Design Implications
Subjective Norms	Greenwashing	Personal CO ₂ eq tracking is ineffective and the focus should be on systematic change towards circular design and zero waste practices.	Provide tools to influence companies instead of only personal lifestyle changes.
Perceived Control	Goal-setting	Users feel bored if there's no updated information.	As a student, I can set an <i>Intention</i> for myself, such as cutting plastic waste or building a climate positive investment portfolio.
Perceived Control	Accountability	Consumers lack tools to affect change.	Help consumers to demand more by integrating tooling into the shopping experience. Perhaps this could be called “embedded sustainability”, inspired by the “embedded finance” trend documented in literature.

13.1.4 AI

This chapter looked at AI in general since its early history and then focused on AI assistants in particular.

Table 111: Design implications arising from the AI chapter.

TPB	Human Interface	Findings and Roles	Design Implications
Perceived Control	Ambient Computing	AI companions could combine sensor data from human bodies with the ability to reason about human speech, to provide increasingly relevant, in-context assistance.	Because of the conversational nature of LLMs, they are very useful for affective computing. OpenAI is developing such a device.

TPB	Human Interface	Findings and Roles	Design Implications
Perceived Control	Voice Assistants	There are many distinct ways how an algorithm can communicate with a human.	From a simple search box such as Google's to chatbots, voices, avatars, videos, to full physical manifestation, there are interfaces to make it easier for the human to communicate with a machine.
Attitude	Sustainability	While I'm supportive of the idea of using AI assistants to highlight more sustainable choices, I'm critical of the tendency of the above examples to shift full environmental responsibility to the consumer.	Sustainability is a complex interaction, where the producers' conduct can be measured and businesses can bear responsibility for their processes, even if there's market demand for polluting products.
Attitude	Sustainability	Personal sustainability projects haven't so far achieved widespread adoption, making the endeavor to influence human behaviors towards sustainability with just an app – like it's commonplace for health and sports activity trackers such as Strava – seem unlikely.	Personal notifications and chat messages are not enough unless they provide the right motivation. Could visualizing a connection to a larger system, showing the impact of the eco-friendly actions taken by the user, provide a meaningful motivation to the user, and a strong signal to the businesses?
Attitude	Cuteness	Cuter apps have higher retention. Literature suggests adding an avatar to the AI design may be worthwhile.	Design the app to be cute and ask the user for their favorite animal.

Subjective Norms	Anthropomorphism	People lose trust in AI if it lies.	AIs should disclose they are AIs. Understanding algorithm transparency helps humans to regard the AI as a machine rather than a human.
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13.1.5 Finance

Design implications results from the literature review on finance.

TPB	Human Interface	Finding and Role	Design Implications
Perceived Control	Legislation	As a consumer, legislation does not always protect me from being complicit in pollution, even if unintended.	As a consumer, I can get notified by the app about highlights of poor legislation refuted by science.
Attitude	Greenwashing	As a consumer, sustainability is fragmented and greenwashing is widespread: how can I feel trust, honesty, and transparency?	As a consumer, I can make use of Green Filter, a sustainable shopping, saving, and investing companion.
Attitude	Greenwashing	As a consumer, while reading the EU Commission's proposals shared in the news, I might think the politicians have everything under control, I can relax and continue the same lifestyles as before, the reality is emissions keep rising, while they should be falling.	As a consumer, I need proper tools to understand what's sustainable. I want to know it's possible to curb greenwashing.

TPB	Human Interface	Finding and Role	Design Implications
Attitude	Education	As an interaction design student who cares about the environment, I ask myself how can interaction design contribute to increase sustainability?	I make the assumption that investing is inherently “good” for one’s life, in the same way, that doing sports is good, or eating healthy is good. It’s one of the human activities that is required for an improved quality of life as we age. To start investing sooner, rather than later, because of compound interest. Nonetheless, investment also includes higher risk than sports or food. ?
Attitude	Education	As a designer for a financial product, I need to communicate the risk of investing effectively while educating the users.	
Perceived Control	Metrics	As an investor, I want to know where my money is going.	As an investor, I can visualize what happens with the money.
Perceived Control	Metrics	ESG can’t be trusted. ESG-reporting alone is not a sufficient metric to prove sustainability of a company.	ESG needs to be accompanied by other metrics.
Subjective Norms	Governance	As a consumer or investor, I can’t trust the people running the company.	Show company board membership in the app product view.

13.2 Research Limitations

First, this work is focused on integrating sustainability into user experience design and does attempt to make a contribution to economics, finance, or any related technical field - in the context of this work, these fields are sources of inspiration for design.

Second, finance is a highly regulated industry and the proposed user experience designs may be limited by legal requirements. This study does not take such limitations into account, rather focusing only on the user experience.

Third, up to date ESG data is expensive and thus couldn't directly be used in this research. ESG needs data to give us an accurate understanding of the realities inside companies and the user experience design does not address the underlying data quality problem further than by providing a link to the data source.

Fourth, I don't have access to users' financial data, which would be useful for design research.

13.3 Future Research

Some ideas for fruitful research directions:

- Perceptions of pollution levels among Taiwanese college students.
- Does the specialized interface for AI offer any advantages of a general-purpose UIs such as ChatGPT, Claude, Gemini, Mistral, and others?
- While many people are working on AI models, there's a lack of people working on Human-AI interaction in the context of sustainability.

If you do decide to pursue any of these questions or were otherwise inspired by my thesis, please do reach out. As I have interest in these areas of research, I would happy to help in any way I can. Thank you.

14 CONCLUSION

A survey of over 900 students from over 48 universities across Taiwan (21 of which I personally visited to hand out flyers for my survey and get a sense of the students' daily context), confirms that Gen Z college students do care about environmental damage, yet they are held back by scattered information and a lack of practical tools. As an interaction design student, I began my research by trying to understand my potential users' mental model. If my design system meets that model, change becomes possible.

According to the *Theory of Planned Behaviour*, **attitudes**, **subjective norms**, and **perceived behavioral control**, drive intentions and behavior. My findings align with these constructs and inform how Green Filter supports them. My prototype "*Green Filter*" app introduced here is an AI companion that translates raw environmental and financial data into plain language, revealing facts like the ESG record and CO₂ eq emission of a product, the materials used, the factory where it came from, etc. It aims to nudge users toward greener shopping, treating purchases as a type of investing – i.e., "Shopping-as-Investing". In-person prototype testing with 32 students across 7 campuses uncovered everyday hurdles still matter: slow Wi-Fi, aging laptops, and dying batteries, all became challenges, stopping the users from achieving their goals. Yet, these problems are a reminder to design a lighter, mobile, more resilient version of the app, thereby increasing **perceived control**.

Nonetheless, the prototype helped students imagine how everyday spending could become a form of financial activism, shifting budgets toward green products, and pressuring companies to share honest ESG numbers. Giving young adults a convenient digital ally equips them to fold sustainability into daily life, empowers them to advocate for stronger legislation (**subjective norms**), and pushes both markets and policymakers toward greater transparency, accountability, and a healthier Earth. A comprehensive literature review in the interconnected economic behavior and ecological sustainability underscores the critical role that financial decisions play in impacting the planet's health. Literature shows that for high ESG performance, Governance, Board Diversity, Board Experts on Climate, and Fintech Adoption (Digitalisation) matter. These are the main predictors of high ESG performance and should be highlighted to the users who wish to buy sustainable products.

14.1 RQ1: What Design Considerations Should Be Addressed When Designing an AI Companion for College Students Integrating Sustainability and Finance?

The goal of this question was to give the widest understanding, mapping out the design space: transparency, sustainability, accessibility, data ethics, integration with campus tools, cultural tone, etc. The deliverable is a set of "design commandments" that every future sprint has to respect.

Data From Literature Review, User Survey, Expert Interviews, and User Testing the Prototype.

Design Principle	Design Implications	Actionable Design Advice	TPB
<i>Design for Visibility & Simplicity</i>	<p>Testers often overlooked the AI analysis feature, thinking it was part of the website, not a 3rd party service.</p> <p>The interface must make key actions obvious. Use prominent announcements to announce new features (e.g., a pop-up tour highlighting what's new). Minimize extra clicks: as one expert (Huang) noted, "people are lazy... if it's easier to get the information that I don't have to click a button, I will pay attention".</p> <p>In short, design a streamlined UI with clear one-step interactions and in-context prompts, thereby strengthening positive attitudes.</p>	<p>Make key actions obvious, use pop-up tours, cut extra clicks; boosts positive feelings toward using the tool.</p>	Attitude
<i>Design for Intuitive Visuals & Feedback</i>	<p>Replace dense text with clear graphics and simple ratings. Huang observed that users tune out long reports but immediately grasp an icon or "eco score" (e.g., a polar bear or 0–100 scale).</p> <p>Similarly, testers noticed numeric eco-scores more than textual features. Thus, represent sustainability metrics as concise visuals or scores, with brief tooltips explaining meaning to bolster attitudes.</p>	<p>Replace dense text with icons and scores; quick comprehension lifts perceived value.</p>	Attitude
<i>Design for Engaging Tone & Fun Elements</i>	<p>Use approachable language and interactive cues. Experts advised avoiding jargon: e.g., change button text from "Continue discussion" to a playful prompt to spark curiosity and intrigue user interest.</p> <p>Gamification (e.g., progress bars, "unlocking" sustainable tips) may sustain engagement, given users' limited patience for lengthy explanations.</p>	<p>Gamified language and progress bars spark curiosity and enjoyment.</p>	Attitude

Design Principle	Design Implications	Actionable Design Advice	TPB
<i>Design for Trust and Transparency</i>	<p>Students expressed moderate trust in AI (survey results show many neutral-to-skeptical responses). To build credibility, the companion must cite verifiable data (certifications, carbon labels, etc.) rather than vague claims. For example, testers distrusted offsetting alone (“I still feel like I’m not really doing it right” when just buying carbon credits), so the app should provide concrete evidence of impact. Avoid taking ESG scores at face value – include context (e.g., B Corp or supply-chain data) to align with perceived behavioural control over accurate information.</p>	Cite verifiable data and give context so students feel info is credible and actionable.	Perceived Behavioral Control
<i>Design Mobile-First</i>	<p>For technical reasons the prototype testing was done using laptop computers (Apple does not allow adding 3rd party overlays on iOS apps the same way Google allows with Chrome Browser Extensions).</p> <p>However, given 96% of students use smartphones (majority iOS), mobile-first is a must, even given all the technical limitations. The design should favor a mobile app or browser extension that integrates with their existing shopping/payment tools.</p> <p>Survey clustering suggests leveraging daily habits (shopping/savings apps) as entry points. Ensure compatibility (notably, iOS imposes browser restrictions) and consider platform-specific design (e.g., integrating with Momo app interface as envisioned). Shopee was consistently mentioned by testers and could serve for the next round of testing instead of Momo.</p>	Meet students on their primary device and integrate with familiar apps, reducing friction.	Perceived Behavioral Control

14.2 RQ2: How can AI Companions Support College Students with Sustainability Knowledge in the Context of Financial Decisions?

The goal of this question was to zoom into *how* the green filter app moves the needle on sustainability when money is on the line: when does the AI surface eco-facts, what modes (chat, visual score) stick, what UI patterns are effective?

Data From Literature Review, User Survey, Expert Interviews, and User Testing the Prototype.

Feature	Design Implications	Actionable Design Advice	TPB
Contextualized Information at Point-of-Decision	Embed sustainability data into shopping and investment flows. In prototype testing, participants valued seeing hidden product info (ingredients, manufacturing “history”) that they normally don’t encounter. For example, revealing that a facial mask contained problematic chemicals led a student to switch to an aloe-based alternative. This suggests the AI should surface concise ecological/health facts (e.g. “contains X chemical linked to...”) whenever users view a product. Similarly, in the investment context the AI showed company ESG scores and stock info. Users reacted positively: one noted, “Buying things is also an investment... I can help you analyze if the money spent is good or bad”. Thus, frame purchases as “investments” in sustainable companies to link finance and ecology.	Surface hidden ingredients, ESG scores, frame purchases as “investments”.	Attitude and Perceived Behavioral Control

Feature	Design Implications	Actionable Design Advice	TPB
Sustainable Alternatives and Comparisons	<p>Provide actionable recommendations. Testers frequently clicked a “Find Alternatives” feature, and Cathy Wang confirms that students want alerts on “the most dangerous products” to avoid. Accordingly, the companion should automatically flag high-impact products in the user’s list and suggest greener options or categories. In finance mode, it should compare companies’ performance (e.g. “Company X is high-ESG, Company Y is not”) so students can weigh investment choices. Survey data underscores this: roughly one-third of respondents want pre-investment checks of company eco-credentials (31% for certifications, 26% for consumer reviews) and comparisons (26%) of environmental performance. The AI can fulfill these by summarizing third-party eco-reports or consumer sentiments on companies.</p>	Auto-flag high-impact items and show greener options or stock comparisons.	Perceived Behavioral Control
Personal Sustainability Dashboard	<p>Many students expressed interest in tracking their own impact (25% wanted a monthly “eco-score” of spending). Building on this, the app can maintain a simple personal report (e.g. “Your spending this month saved X kg CO₂” or “you’re now 20% greener”). This aligns with providing “carbon score” feedback that testers noticed. The dashboard should be succinct, using visuals (progress bars, infographics) rather than verbose text, so students quickly grasp progress (Huang’s scale idea).</p>	Monthly eco-score and progress visuals reinforce learning and self-efficacy.	Attitude and Perceived Behavioral Control

Feature	Design Implications	Actionable Design Advice	TPB
Educational Nudges & Explanations	<p>Use the AI chat (or chat-like prompts) to elaborate on sustainability concepts as needed. Although few testers clicked the “Chat with AI” button during prototyping, it can serve as a fallback for curious users. For example, when a student sees a product’s green score, they could ask “Why?” and the AI could briefly explain (“This brand was rated low because it uses high-carbon packaging”, sort of like in the earliest prototype). Encouraging exploration without overwhelming users aligns with Audrey Tang’s insight that youth are eager to engage but need clear, relatable contexts (e.g. connecting a bubble-tea straw ban to personal habits). Overall, the AI should act as an informed guide: contextualizing data, answering “what-if” questions, and helping students internalize how their financial choices affect sustainability.</p>	<p>Chat prompts explain the “why” behind scores, linking knowledge to choices.</p>	Attitude

14.3 RQ3: What AI Companion Features do College Students Prioritize as the Highest?

The goal of this question was to directly understand the users’ voice: a list of features that the users would crave.

Data From User Survey, Expert Interviews, and User Testing the Prototype.

Feature	Design Implications	Why Students Want It?	TPB
1) Eco-Impact Product Filters	<p>The highest-priority feature is product-level sustainability comparison. In the survey, 63% of students wanted to “see which products are most polluting so I can avoid them,” far above other categories. This aligns with testing observations: Wang notes “the main feature...was to avoid the most...dangerous products” via an alert on the shopping list. Accordingly, the companion should prominently offer “sustainability filters” (e.g. sort products by carbon footprint or toxin content) and alternative suggestions, just as users clicked the “Find Alternatives” button in our prototype.</p>	Lets them avoid polluting products quickly, aligning with personal values.	Perceived Behavioral Control
2) Supply Chain Transparency	<p>Other top features relate to sourcing. About 41% of respondents want to check product origin (e.g. local vs. imported) and 40% want to know how eco-friendly the production process is. Designing a simple icon or tag for “local” or “certified eco-friendly factory” (as Chen-Ying Huang recommends using recognizable symbols) would meet these needs. Similarly, one-third favored an “organic” product search. The prototype’s green-colored “Analysis” tab (showing carbon emissions by product type) was also used by testers, indicating interest in seeing how choices impact emissions cumulatively.</p>	Origin tags and factory eco-labels give socially accepted proof of ethics.	Subjective Norm and Perceived Behavioral Control

Feature	Design Implications	Why Students Want It?	TPB
3) Personal Eco-Score and History	A quarter of students (25%) expressed interest in a monthly report of their own eco-score. In testing, participants took screenshots of the carbon-reduction analysis, suggesting value in recording progress. We should include a lightweight “eco-dashboard” feature: an overview of past decisions, scores, and tips. Crucially, it must be eye-catching and concise (e.g. a single visual per month) so students will actually review it.	Visible progress boosts motivation and perceived capability.	Attitude and Perceived Behavioral Control
4) Sustainable Investing	Roughly 26–32% of respondents wanted to see company eco-scores, certifications, or performance comparisons before investing. Testers saw company ESG ratings and stock info (they asked “what is this company’s stock code?”) and even got recommendations for similar sustainable companies. Thus, the feature set should include an investment tab with clear “sustainability ratings” for companies alongside stock data, and suggestions of alternative stocks aligned with the student’s values.	Company eco-scores inform responsible investment, meeting peer expectations.	Subjective Norm and Perceived Behavioral Control
5) Lower-Priority Features	Given the high usage of social media in Taiwan, I was surprised community-related and social features ranked low in the survey. Only around 12% of the respondents wanted social networking with eco-peers, and indeed testers rarely engaged even with the AI’s chat option to ask more questions. These findings suggest focusing development effort on concrete decision aids (filtering, scoring, recommendations) rather than social networking or open-ended chat.	Ranked low, so less impact on key TPB levers for now.	(n/a)

14.4 Final Takeaway

By building the Green Filter prototype, combining Digital Product Passports (DPPs) with data-driven interaction design, large-language models, and AI agents that translate complex data into plain language, tracking data across the entire product lifecycle (source materials → purchase → recycling), injecting transparency into otherwise opaque supply chains, I have demonstrated the potential of software to close the *attitude-behaviour gap*, making it obvious which products are truly circular and which are just greenwashing.

In my research, I have integrated quantitative survey trends with qualitative insights from testing and interviews. For instance, strong survey interest in product comparisons (63%) is consistent with testers clicking the “*Find Alternatives*” feature and the experts (Huang, Wang) emphasizing clear eco-indicators. By aligning the AI companion’s design closely with the above patterns: favoring concise visual info, high discoverability of features, and actionable eco-insights, I can better meet student needs, providing sustainable financial decision support exactly at the right context and the right time.

By mapping my findings onto the *Theory of Planned Behaviour*, I have ensured that the Green Filter app strengthens **attitudes**, leverages **subjective norms**, and enhances **perceived behavioral control**, paving the way for sustainable financial actions among Gen Z students. With the right tools at hand, college students can demand for increased ESG accessibility (a higher baseline for sustainability). For college students, influencing business governance is the main point of leverage; in essence, Governance -> Social -> Environment.

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- 台灣設計研究院 (TDRI) on Instagram: ”■ 北歐循環設計論壇 | 開放報名中 - 近幾年，全球的極端氣候造成各地災害頻傳，人們更加意識到要珍惜地球資源，丹麥從 10 幾年前就開始推行低碳生活，哥本哈根海洋上成排的風力發電機供應丹麥 20%以上的能源，哥本哈根的學校建造出全世界最大的太陽能板，甚至丹麥的設計團隊進行設計皆從永續環境為本心出發，在丹麥，每一個生活環節都是循環設計！- 但丹麥談的循環永續不只是不具經濟效益的理念，循環經濟對丹麥來說不僅具有環境層面的效益，還可提升企業的競爭力，對資源生產力、就業機會、資源供應安全和自然資源的可持續利用都有極正面的回饋。- 本次國際論壇，我們邀請來自丹麥的設計師 Ditte Lysgaard Vind 從循環經濟策略、Rosa Nøss Bendixen 從產品設計、Helene Jensen 從時尚產業、更有台灣的團隊奇想創造、光寶科技、REnato Lab 從不同產業類別，以跨領域的思維，分享他們循環再造的創意點子！- ■ 北歐循環設計論壇 Nordic Circular Design Forum 活動日期 | 11 / 12 (五) 16:00 ~ 18:20 講座方式 | 線上直播與線下參與講座費用 | 免費 報名 | 請至個人檔案點選 □ #TDRI #台灣設計研究院#設研

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16 APPENDICES

16.1 Appendix 1: Research Tech Stack

For anyone who would like to repeat this research, here's a table with the software that this research project made use of.

Tool/Service	Category
Matplotlib	Data Visualization
NumPy	Scientific Computing
jupyter	Development Environment
seaborn	Data Visualization
Python	Programming Language
VSCode	Code Editor
GitHub	Version Control
fireflies.ai	AI Meeting Assistant
Google Meet	Communication
databricks	Data Platform
HuggingFace	Machine Learning
TypeScript	Programming Language
Tally	Form Builder
Zotero	Reference Manager
Quarto	Publishing/Documentation

Tool/Service	Category
Apache Parquet	Data Storage Format
Haystack	Search Framework
MongoDB	NoSQL Database
langchain	AI/ML Development
GitHub Copilot	AI Coding Assistant
Figma	Design Tool
Sketch	Design Tool
OpenAI ChatGPT	AI Assistant
Anthropic Claude	AI Assistant
Google Gemini	AI Assistant
Google Colab	Development Environment
Google Sheets	Spreadsheet
META Llama	AI Model
Mistral	AI Model
OpenAI API	API Service
Postman	API Testing Tool

Tool/Service	Category
Next.js	Web Framework
fullstory	Analytics
Polygon.io	Financial Data API
Hotjar	Behavior Analytics
Lottie	Animation Library
Docusaurus	Documentation
Google Analytics	Web Analytics
Google Maps	Maps/Location Service
vis.gl	Data Visualization Framework
Pinecone	Vector Database
Vercel	Deployment Platform
Vercel AI SDK	AI SDK
Radix UI	UI Library
highcharts	Data Visualization
React	Web Framework
Tailwind	CSS Framework
Markdown	Markup Language

16.2 Appendix 2: Further Reading

Some recommended books on the topics covered in this thesis include, but are not limited to:

- R. Buckminster Fuller “Operating Manual for Spaceship Earth”
- Victor Papanek “Design for the Real World”
- Jonathan Chapman “Emotionally Durable Design”
- Carlo Vezzoli “Product-Service System Design for Sustainability”
- Ezio Manzini “Design, When Everybody Designs”.