

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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May 2025

1 ABSTRACT

Taiwanese college students are concerned with environmental issues, yet they are hindered by the attitude-behaviour gap and lack simple tools to affect systemic change. At the same time, strengthening environmental policy from the European Union includes the concept of *digital product passports*, which aims to help distinguish *eco-designed* products made by *circular economy* companies striving to be zero-waste from companies that simply engage in *greenwashing*. Tracking product data from the source materials, until the consumer purchase decision, and finally post-purchase recycling, facilitates building *transparency* into opaque global supply chains. *Data-driven interaction design, large-language models, and artificial intelligence assistants* translate complex environmental data into human-comprehensible language.

The emerging field of *planetary health* recognizes profound interconnections between our economic behaviors, ecosystem services such as clean water, air, soil, the climate crisis, and human health. As of 2025, Earth's natural environment is being heavily degraded by the extractive business practices of companies that make many of the products and services we buy every day. The way we use our money to interact with companies - through shopping as consumers and saving / investing as investors - has an effect on the life-supporting biosphere we rely on to keep our planet inhabitable. In essence, from an ecological perspective, every financial action is either an investment decision to support more environmentally-friendly companies - or to support polluters. By democratizing financial markets, young adults can gain greater access and influence over where their money goes, enabling them to support sustainable and environmentally responsible companies.

My research addresses the need for tools to make sustainable financial action more convenient, focusing in particular on college students. I leverage *design research* to find design concepts for *simple AI-based user interfaces* - also known as *generative UIs* - to help young adults participate in *sustainable financial activism*. A survey of 900 students across 20 universities in Taiwan was conducted, enhanced by 6 expert interviews providing industry insights. The major contribution of the study is an interactive AI-assistant prototype.

Keywords: Human-AI Interaction, Digital Sustainability, Transparency

2 摘要

台灣的年輕人，特別是大學生，關注環境問題，但因缺乏簡單的工具來影響系統性改變而受阻。同時，歐盟加強的環保政策引入了「數字產品護照」的概念，旨在區分由努力實現零廢棄的「循環經濟」公司製造的「生態設計」產品，與僅從事「漂綠」的公司。從原料開始追蹤產品數據，直到消費者的購買決策，最後到購後的回收，促進在不透明的全球供應鏈中建立透明度。「數據驅動的互動設計」、「大型語言模型」和「人工智慧助理」將復雜的環境數據轉換成人類可理解的語言。

新興的「地球健康」領域認識到，我們的經濟行為、生態系統服務（如清潔的水、空氣、土壤）、氣候危機和人類健康之間存在著深刻的相互聯繫。截至 2024 年，由於生產我們日常購買的許多產品和服務的公司進行的開採性商業行為，地球的自然環境正被嚴重破壞。我們用金錢與公司互動的方式——作為消費者的購物和作為投資者的儲蓄/投資——對我們賴以維持地球宜居性的生命支持生物圈產生影響。從生態學角度來看，每一個財務行動不是支持更環保公司的投資決策，就是支持污染者。透過民主化金融市場，年輕人可以獲得更大的權限和影響力，控制他們的資金流向，使他們能夠支持可持續和對環境負責的公司。

我的研究針對了需要工具來使可持續的財務行動更便捷的需求，特別關注大學生。我利用設計研究來尋找簡單的基於 AI 的使用者介面的設計概念，也稱為生成式 UI，以幫助年輕人參與可持續的財務行動主義。在台灣 10 所大學進行了涵蓋 700 名學生的調查，並透過 5 次專家訪談提供行業見解。研究的主要貢獻是一個互動式 AI 助理原型。

關鍵詞：人機互動、數字可持續性、透明度

The abstract was translated on May 22, 2024 using the Claude 3 Opus model. Translation quality was checked with OpenAI GPT4, Google Gemini, Mistral Large, Meta Llama, as well as human reviewers, and further refined with the OpenAI o1-preview model in November 2024. In case of any discrepancies, please refer to the English text.

3 ACKNOWLEDGMENTS

Thank you mom. Aitäh.

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4 LIST OF SYMBOLS AND ABBREVIATIONS

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

- AI - Artificial intelligence, a field of computer science and an umbrella term focused on a wide range of approaches to automation
- UX - User experience, a field of study and operational approach focused on how humans experience using systems
- AX - Algorithmic experience, a proposed category of user experience, that is focused on interfaces between AI algorithms and humans
- UI - User interface, such as in a mobile app, however increasingly audio, video, etc
- XAI - AI user experience, interaction design applied to AI concerned with how does a person or a group of people interact with the AI
- Fintech - Financial technology, the application of technology (usually AI), to classic financial services, such as payments
- 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
- AI Assistant - software system providing the user with personalized suggestions based on machine learning algorithms
- Financial Advisor - a human financial specialist providing customized financial advice, including investment advice and services to a client
- 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)
- HCI - Human-computer interaction, a field of study to improve human experience with information technology
- OEM - Original equipment manufacturer, a company making products for another company that markets and sells such products under their own brand
- API - Application Programming Interface, a method for software agents to exchange information in various forms of data: the basis for contemporary online services
- EPR - Extended Producer Responsibility
- SDGs - Sustainable Development Goals, a set of targets agreed upon by the nations of the world
- LLM - Large Language Models
- Vector Databases - specialized data storage for mathematical language embeddings in multi-dimensional space helpful for clustering similar concepts

- CO₂e - CO₂ equivalent greenhouse gases
- GHG - Greenhouse gases
- PD - Participatory Design
- VCM - Voluntary Carbon Markets
- Hedge Fund - pooled investment fund
- DAO - Decentralized Autonomous Organization
- 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)
- ESRP - Ecodesign for Sustainable Products Regulation
- NFRD - Non-Financial Reporting Directive
- CSRD - Corporate Sustainability Reporting Directive
- EUDR - European Union Deforestation Regulation
- Product Stewardship
- 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.

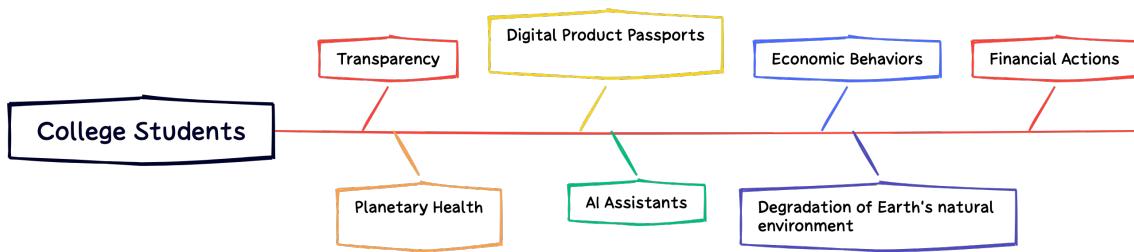


Figure 1: College Students

5.1 Relevance

The research addresses the “*attitude-behavior gap*” among Taiwanese college students in taking sustainable financial action. Convergence of the following 5 trends makes my research timely in 2024.

Table 1: Trending narratives.

Trend	Direction
Environmental degradation	Worsening
Interest in sustainability among young people	?

Trend	Direction
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

Criteria	
Population Count	College Students 700

Experts (finance, design, sustainability).

Criteria	
Location	Global
Population Count	Experts 5

5.6 Research Questions

My research answers the following questions.

Table 4: RQs.

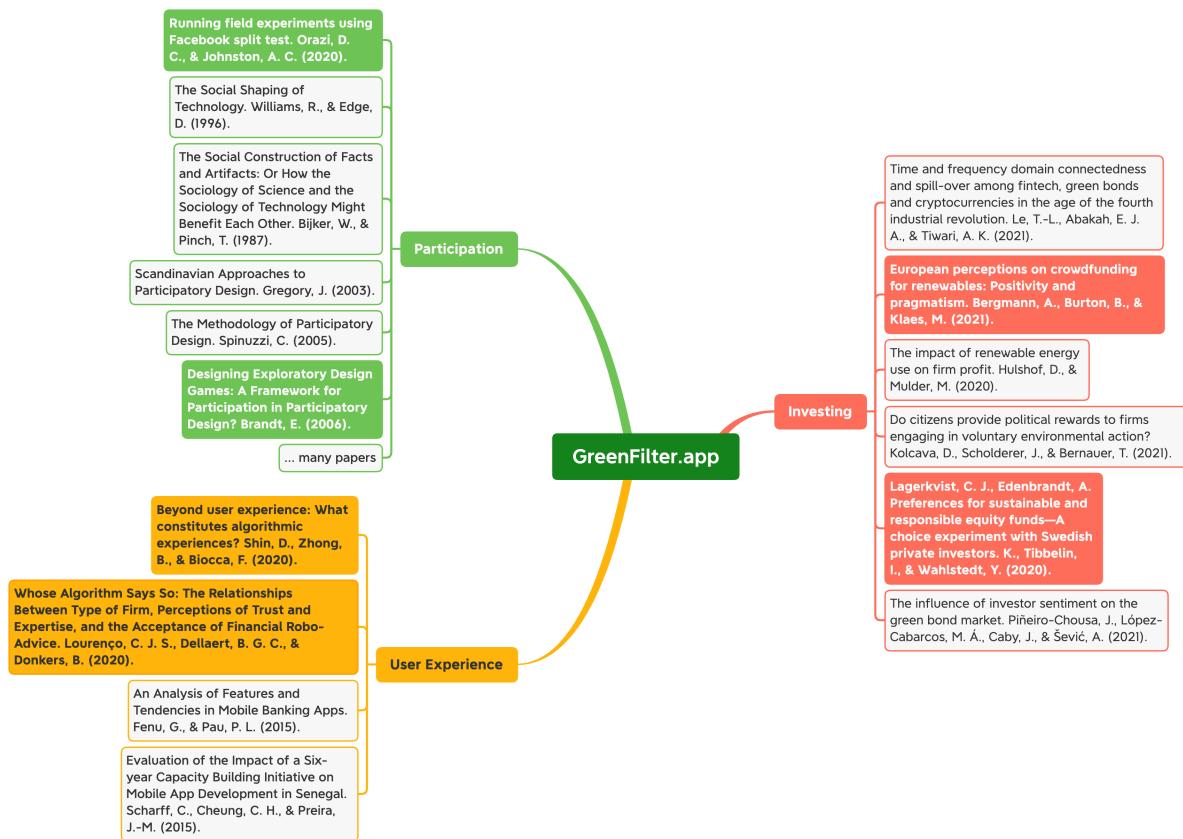
Question	Methods
What design considerations should be addressed when designing an AI companion for college students integrating sustainability and finance?	Literature Review
How can AI companions support college students with sustainability knowledge in the context of financial decisions?	Literature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

5.7 Literature Review

5.7.1 Goals

Given the goal 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.

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.



Presented with xmind

Figure 3: Example papers from the Literature Review

5.7.2 Sources

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

- ScienceDirect
- Nature
- the Lancet
- Oxford Academic
- Semantic Scholar
- JSTOR
- Google search.

5.7.3 AI Usage in Research

I'm a long time AI-assistant user. AI was used for

- search
- data comparison
- data science
- chart-building
- translation
- feedback
- editing
- ranking citations' relevance to existing body of writing

AI was *NOT* used for writing.

a visualisation of incremental changes to the thesis can be seen on the github repository as update commits as well as in the visualisation below.

6 YOUNG ADULTS AND COLLEGE STUDENTS

6.1 Student Protests for Climate Justice: Around the World and In 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 of 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 4: 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).



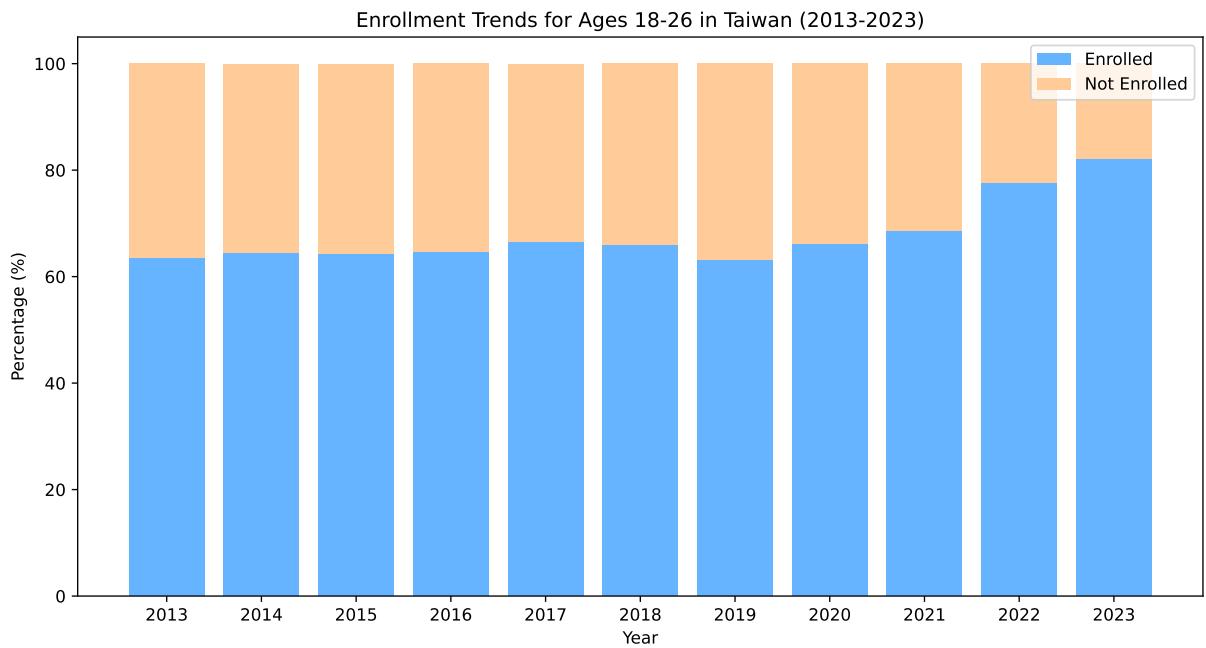
Figure 5: Climate protest in Taipei in May 2019 in front of the Democratic Progressive Party (DPP) headquarters

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

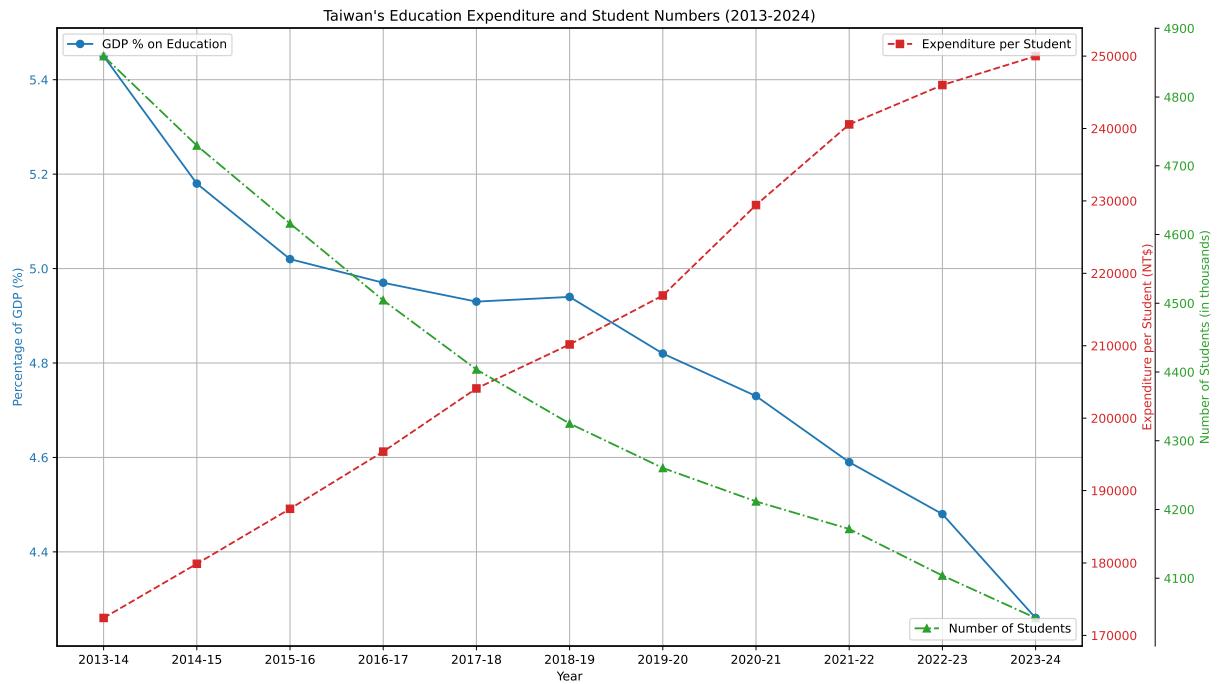
“climate actions,” exercising agency within those limits. In addition, both Confucianism and Daoism, the prevalent belief systems in Taiwan, affect education to be *teacher-centered*, where traditionally the role of students is to listen and absorb knowledge; in today’s society, there’s space to open 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).

6.2 Taiwanese Educational System in Numbers

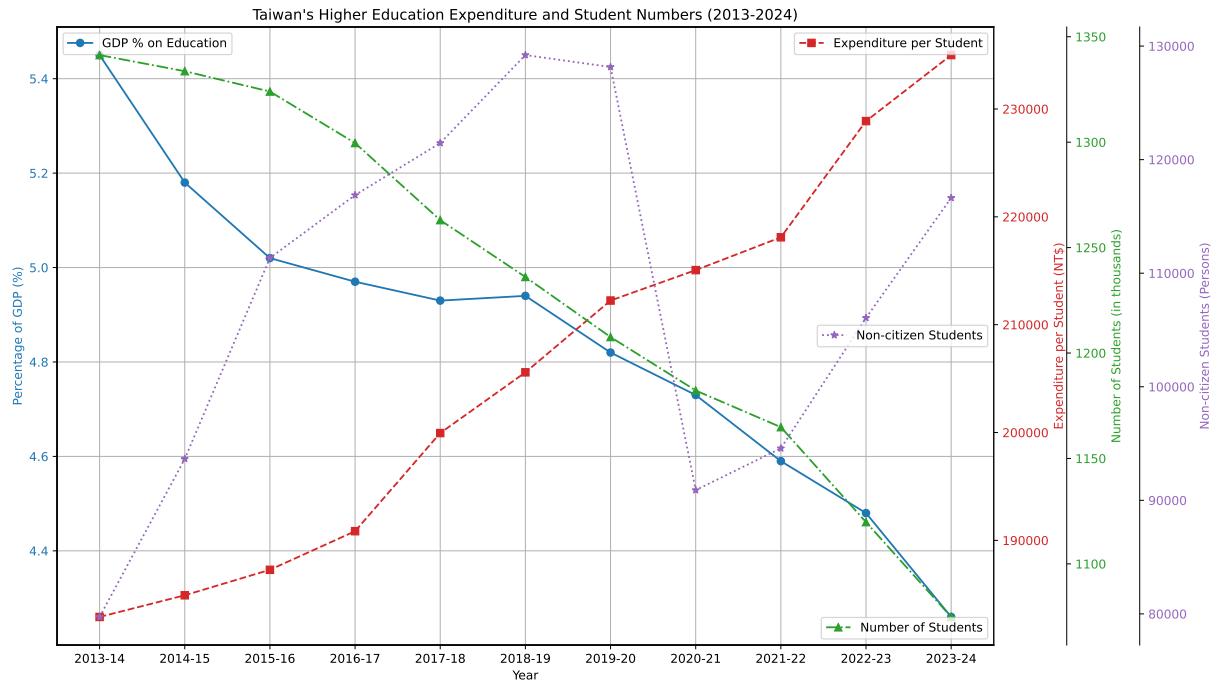
Taiwan has approximately 2 million young adults (Gen-Z, 18-26), and 73% percent of them are students attending tertiary education as of 2023, with a slow increase of enrollment over the past decade (Ministry of Education of Taiwan, 2024b).



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.



6.3 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 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).

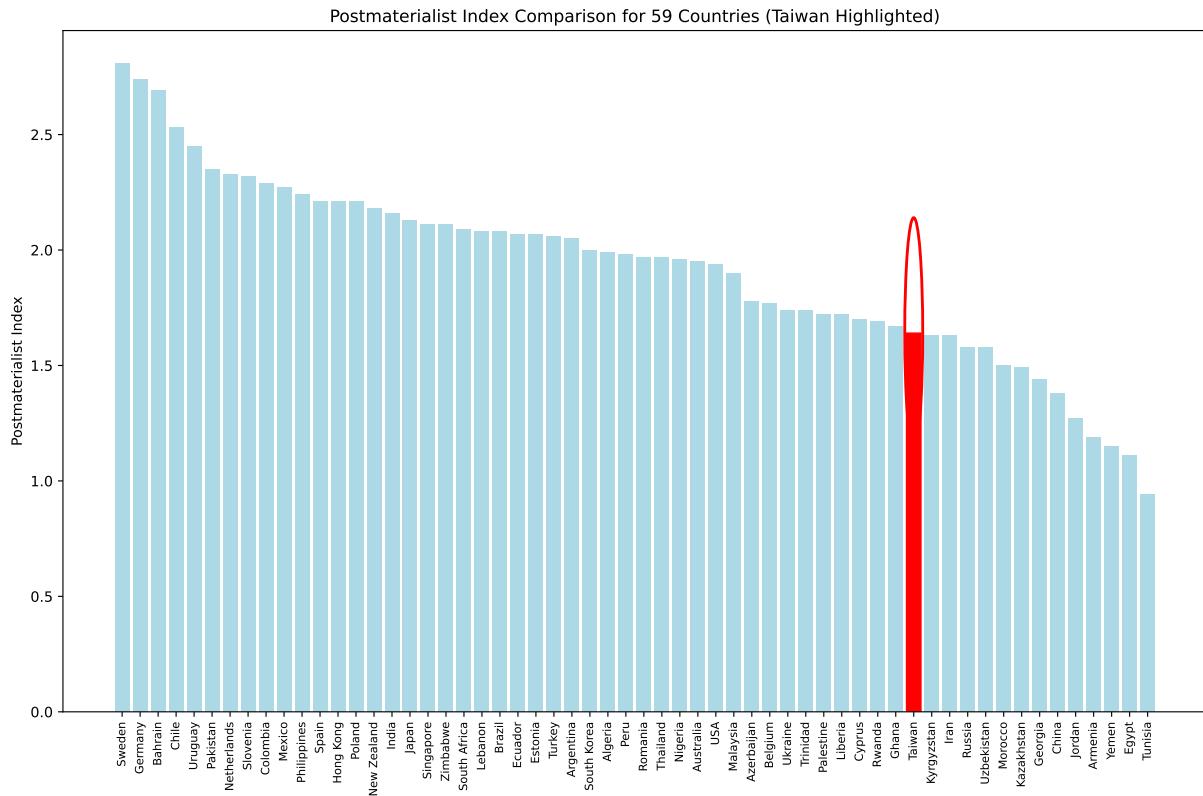
Designing for College Students: Developing Personas. User research makes extensive use of user *personas* to represent a group of people with similar attributes. Designers use personas to *articulate assumptions*, which, if used well, is useful for *user-centered design*, to create better products. Personas 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.

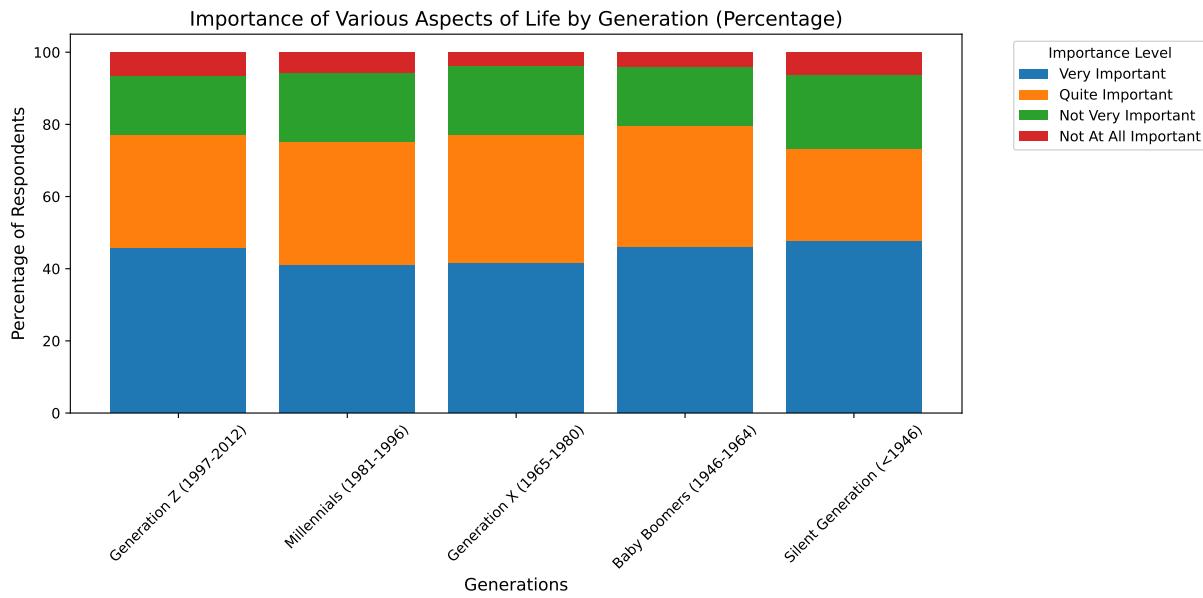
6.4 Taiwanese Youth in the Global Context: Attitudes Towards Sustainability From Eco-Friendly Diet to Climate Action

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.



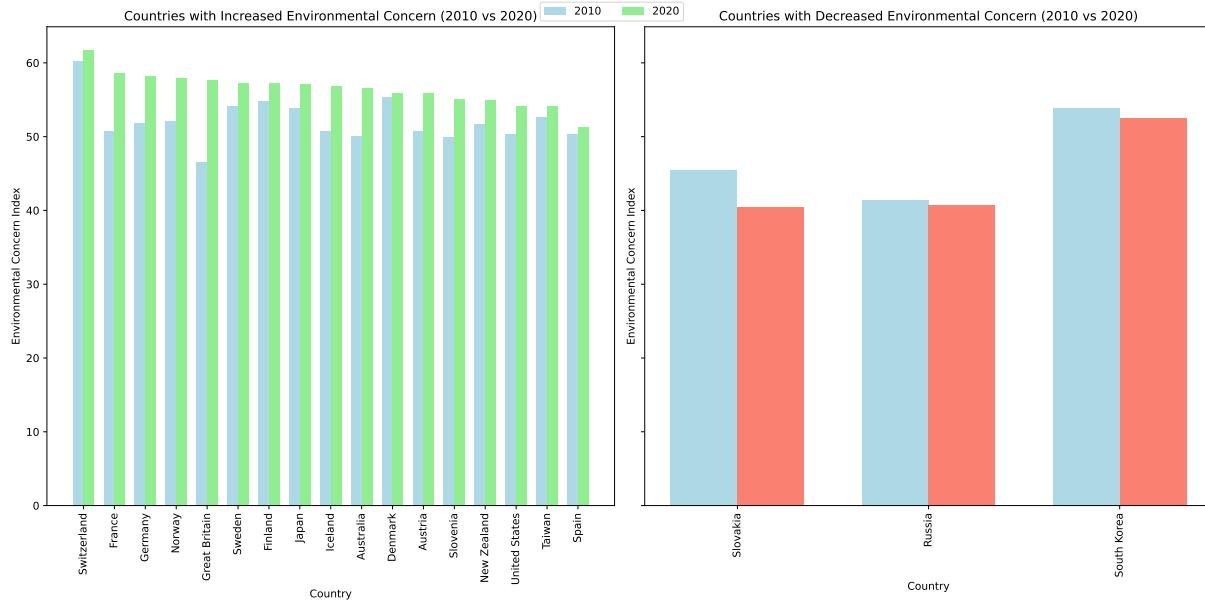
World Values Survey



(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-scale global 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).

Table 5: 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%

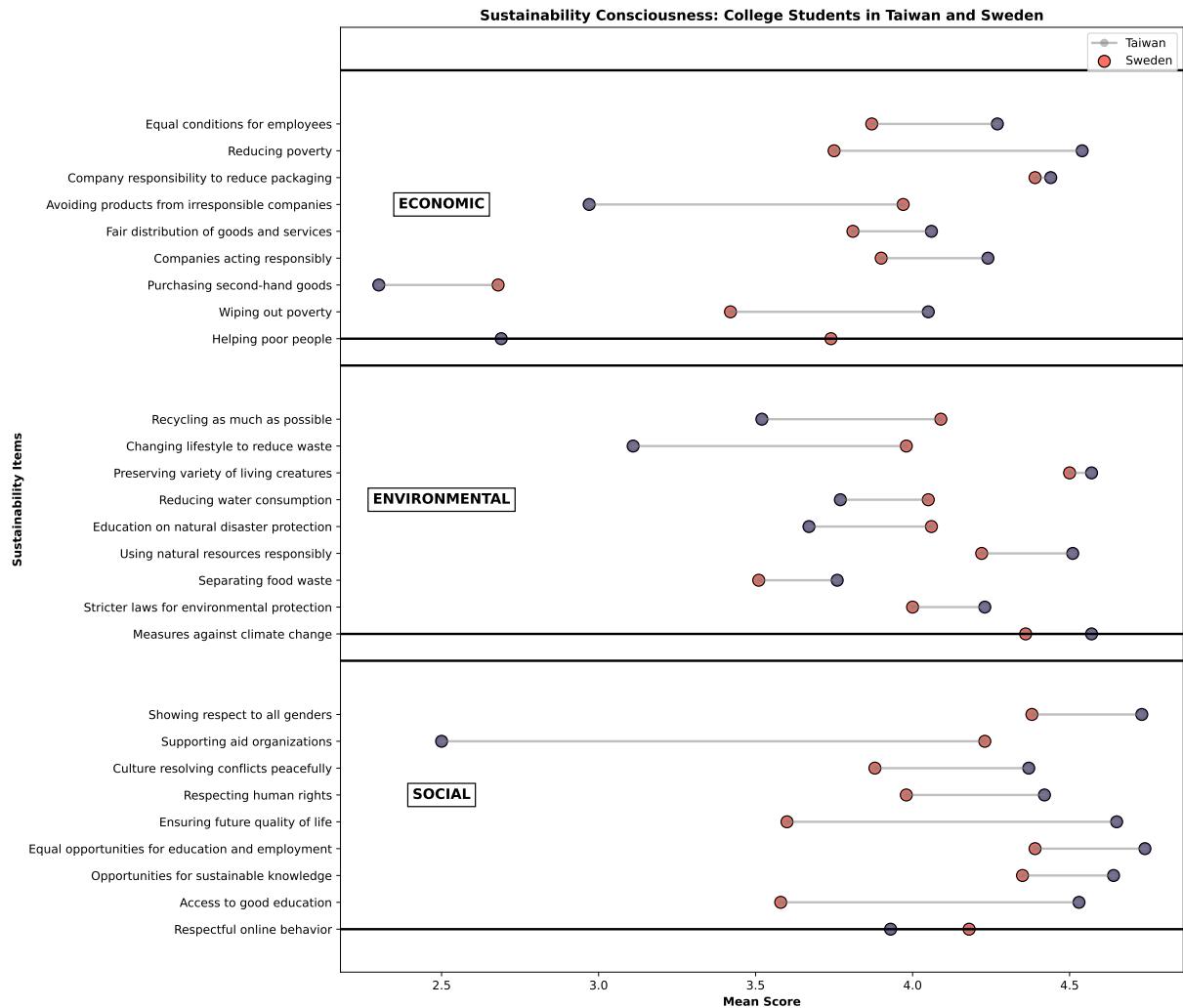
At the pre-university level, Taiwanese government has been promoting environmental education through a green school network; however surveys at middle school and high school level suggest there is no impact on *sustainability consciousness* among students in comparison with regular schools (Olsson et 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 environmental 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 concluded, Taiwanese students and teachers at all levels of education have a positive attitude towards sustainability, 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).

Internationally, there is extensive research on the attitudes of U.S. college students towards climate change. (American Press Institute, 2022) reports only 37% percent of U.S. Generation-Z and Millennials follow news related to environmental issues. (Schwartz et al., 2022) reports some adult US 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 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.

6.5 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 CO₂e 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 PM_{2.5} 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 Xiang 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 µg/L in contrast to the average river concentration of <0.1 µg/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 6: Examples of large industrial polluters in Taiwan as reported in academic papers and the media.

Company	2023 Mt CO ₂ e	Notable Problems	Data Source
台電 Taipower	93.33	A single power plant in Taichung produces 26 Mt CO ₂ e	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 e emissions come from 1 steel mill in Kaohsiung	蕭婷方 (2021); 環境資訊中心記者 (2022)

Company	2023 Mt CO ₂ e	Notable Problems	Data Source
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)
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、水污裁罰金榜首 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 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)

6.6 Climate Anxiety and How to Respond

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

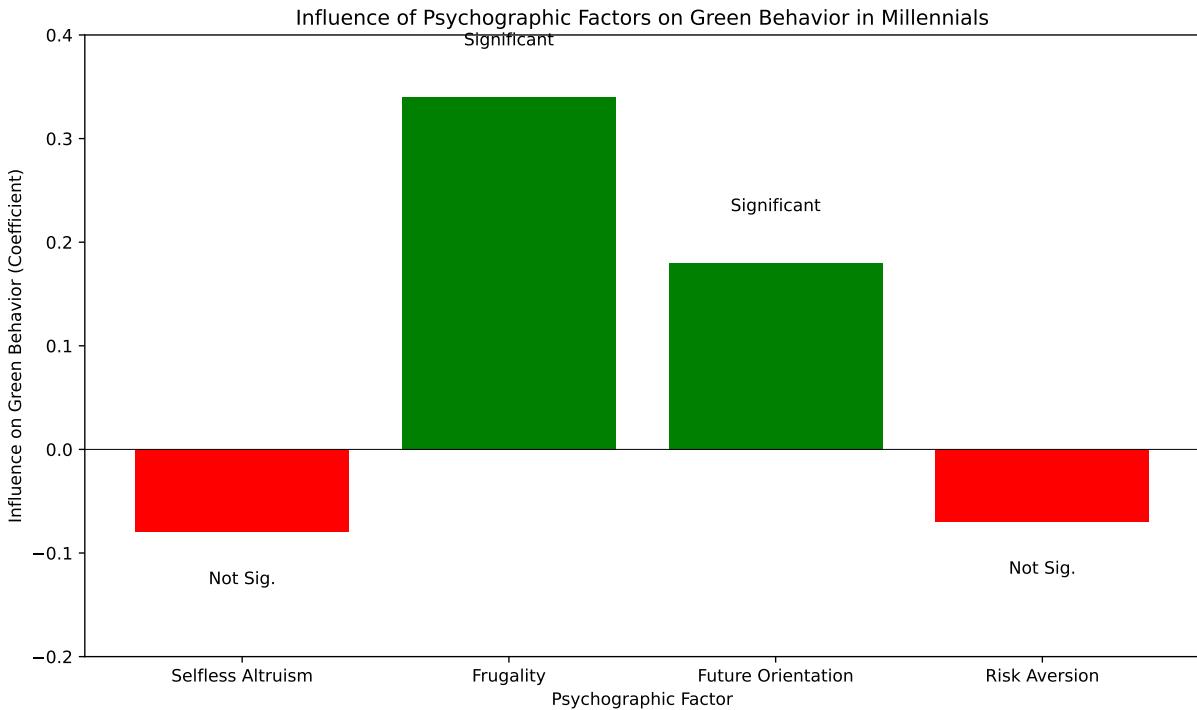
young people and is a possible motivator for climate action. Additionally, (Ogunbode et al., 2022) finds climate anxiety in 32 countries and also supports the idea that climate anxiety leads to climate activism. (Thibodeau, 2022): “In 2021, the BBC polled 1,000 people in Scotland to understand the barriers 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 millenials to engage with sustainability (Naderi & Van Steenburg, 2018)



6.7 The 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 says people want eco-products but aren't willing to pay more.
- Willingness to pay research.

6.8 Sustainability Tools in the Taiwanese Context, Digital Sustainability: Taiwan's Digital Receipt System

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.

6.9 Trends in Taiwanese Companies from Industry to 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 CO₂ was largely a prerequisite for economic growth in Taiwan (T. Chang et al.,

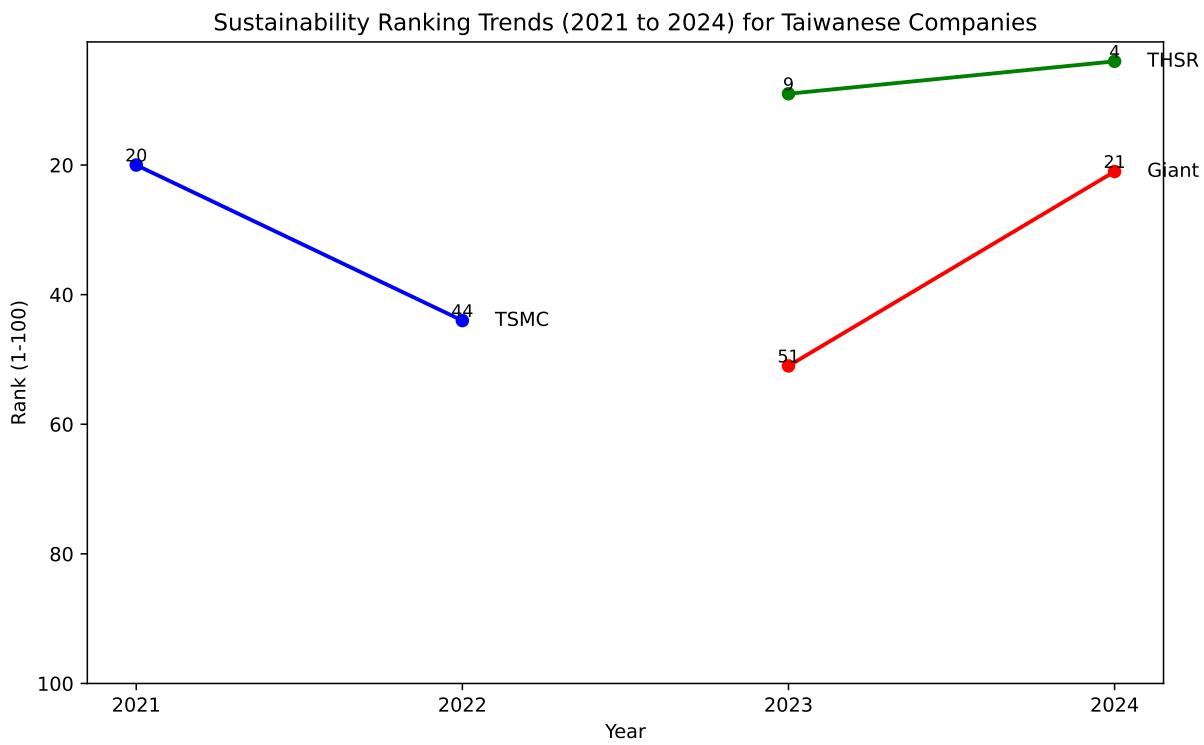
2023). Since the 1990s, Taiwan is a net CO₂e exporter through emissions embedded in the industrial production oriented economy (Huang et al., 2020). Starting in 2023, Taiwan's Financial Supervisory Commission's (FSC) added "requirements for Taiwan's corporates to disclose their carbon emissions," (Reformosatw, 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).

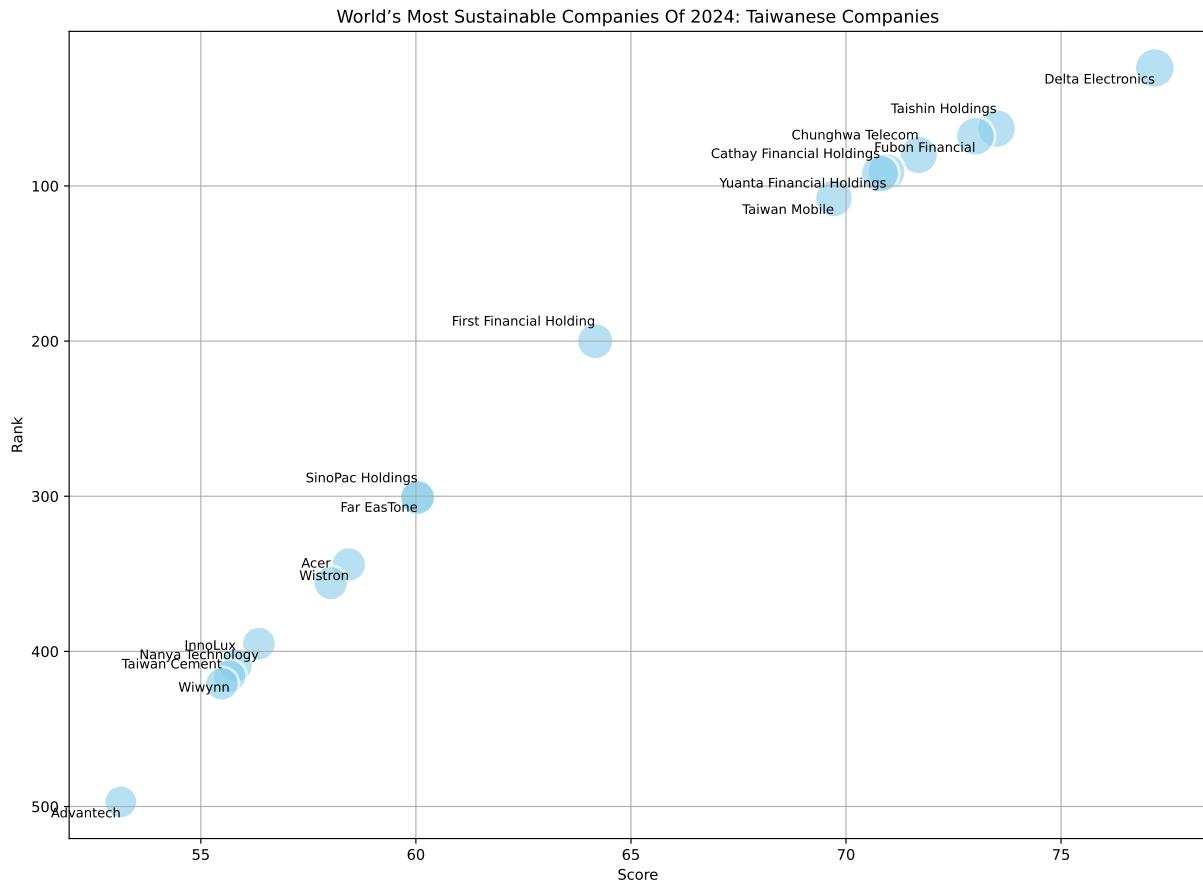
Table 7: Data from (Alana Semuels, 2024).

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



6.10 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 8: Compiled table of respondent account ownership, familiarity with financial products, and preferred payment methods, as reported in (陳美君, n.d.).

<u>Banking</u>	<u>% of Respondents</u>
Have at least one financial account	80%
<u>Familiarity</u>	<u>% Unfamiliar</u>
Savings accounts	70%
Mutual funds	63%

Banking	% of Respondents
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 Millennials 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 9: 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%
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 10: 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).

【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：FINLEA...



【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 6: 財金智慧 FINLEA YouTube Channel

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 11: Data from millennial investors (Calastone, 2020).

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

6.11 Social Media Usage, Trends, Memes, Media Currents, 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 12: As reported by (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 %

Metric	18–29	30–39
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.

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).

6.12 AI Usage 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).

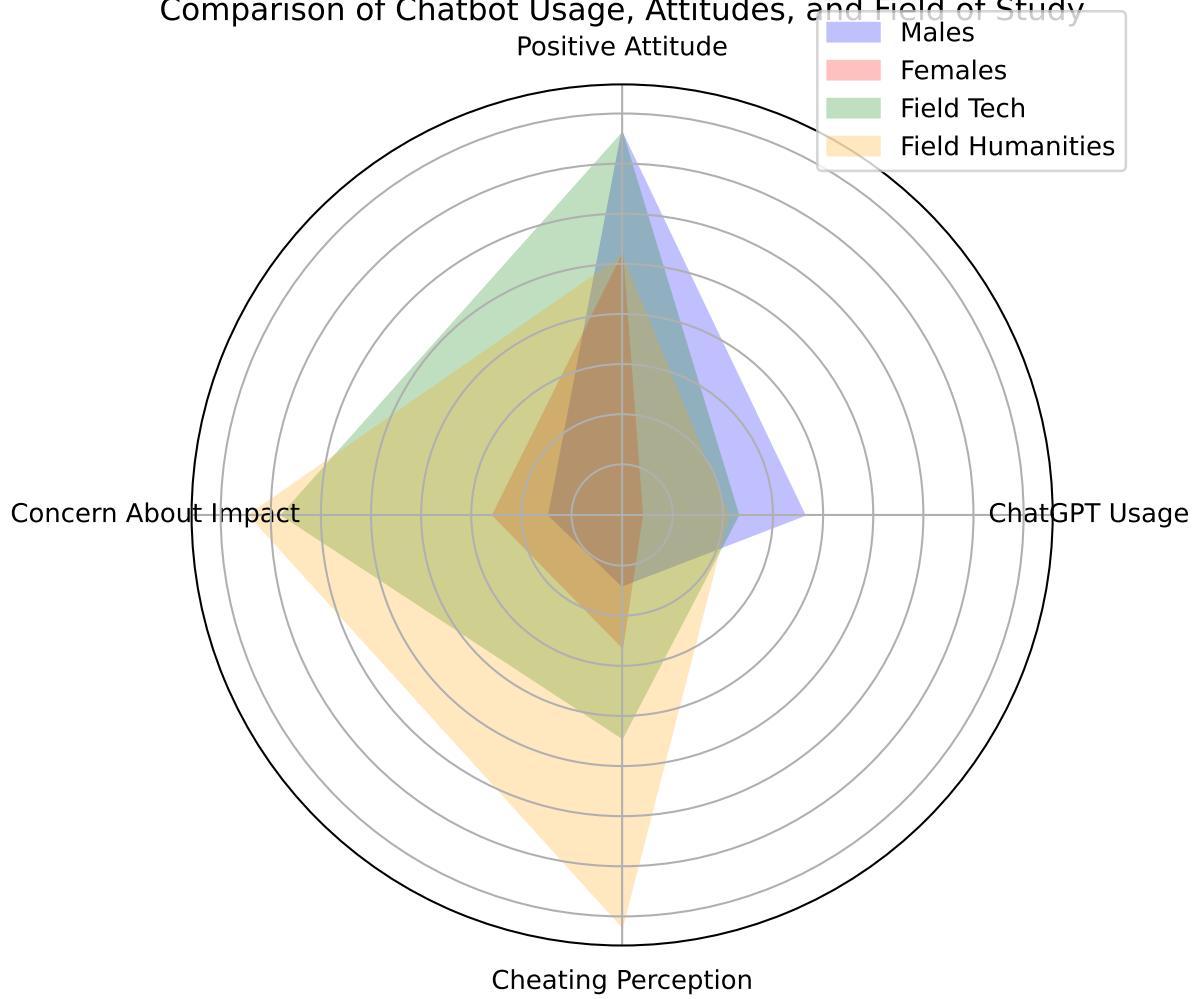
In a more recent large-scale survey focusing on AI literacy administered to the general public ($n = 2174$) found that only 26% of the respondents had used ChatGPT in the past 3 months (in comparison with the 25% from a similar survey administered in the previous year); younger

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).

Comparison of Chatbot Usage, Attitudes, and Field of Study



7 SUSTAINABILITY

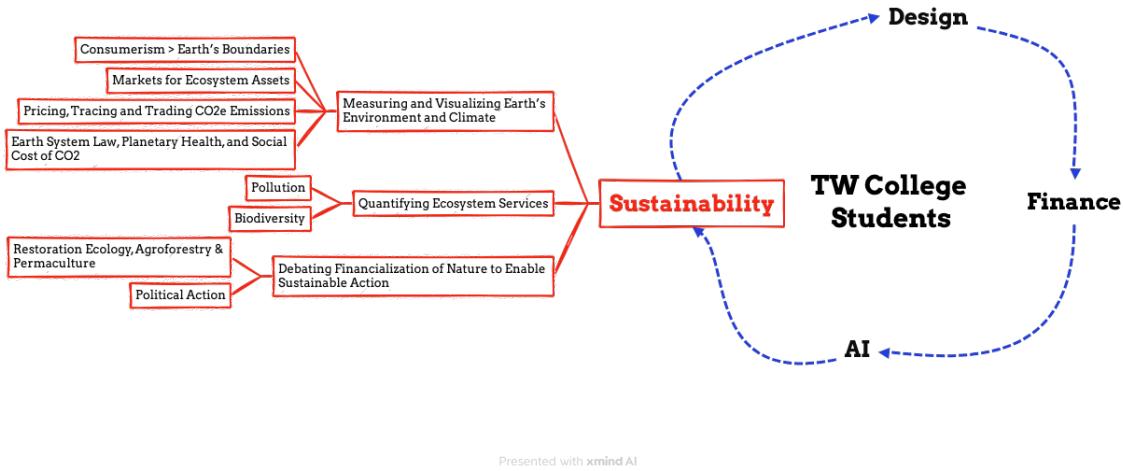


Figure 7: Visual abstract for the sustainability chapter

7.1 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.

7.2 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 (T. R. 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 (T. R. Anderson et al., 2016).

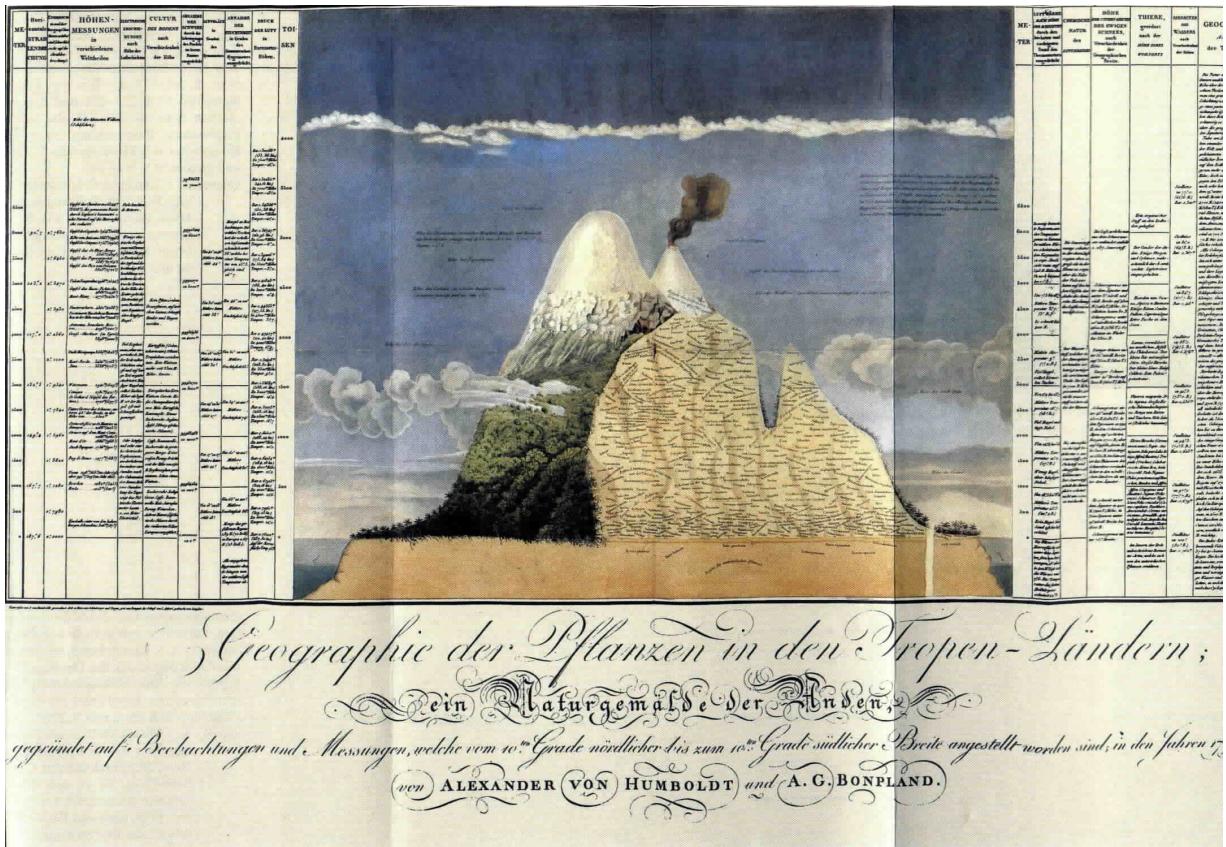


Figure 8: Humboldt's Naturgemälde, early data visualization of ecology, rain, temperature, elevation, etc

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 CO₂ in the air. It also has an advanced calibration system where it makes measurements in air with a known quantity of gases (Worthington, 2025b).

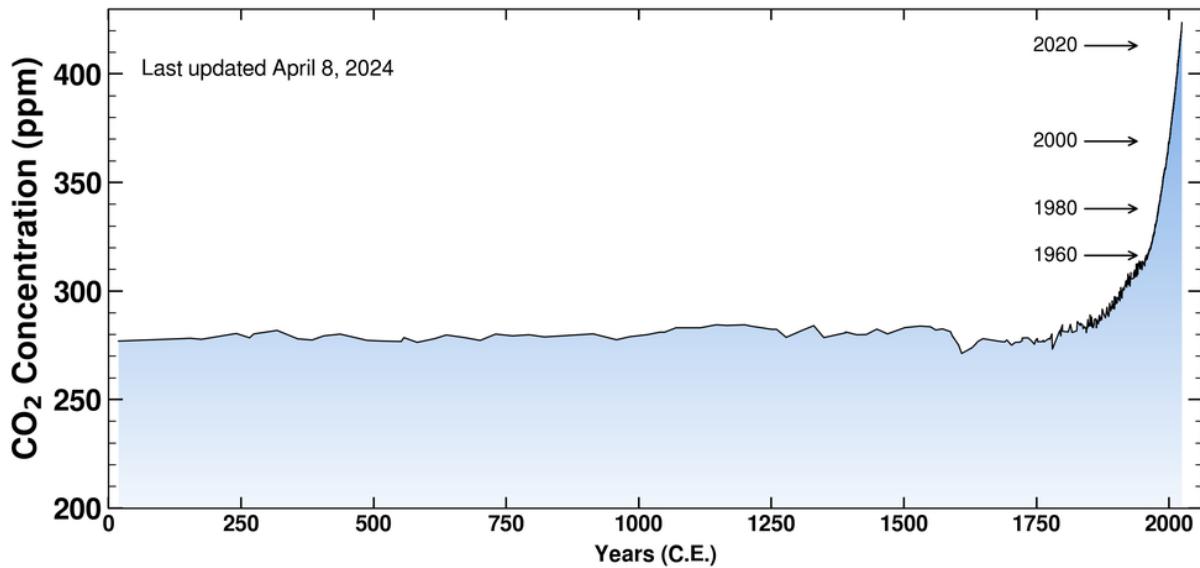


Figure 9: CO₂ concentration in the atmosphere as of Ap. Image Credit: Scripps Institution of Oceanography at UC San Diego.

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 CO₂e emissions have exceeded 1.5 trillion tonnes globally or when expressed in CO₂e for all green house gases, total historic emissions would reach roughly 1.7 trillion tonnes CO₂e 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, Germany, Italy, Japan, United Kingdom, United States) are heading for 2.7 °C of warming by 2050 (CDP, 2022).

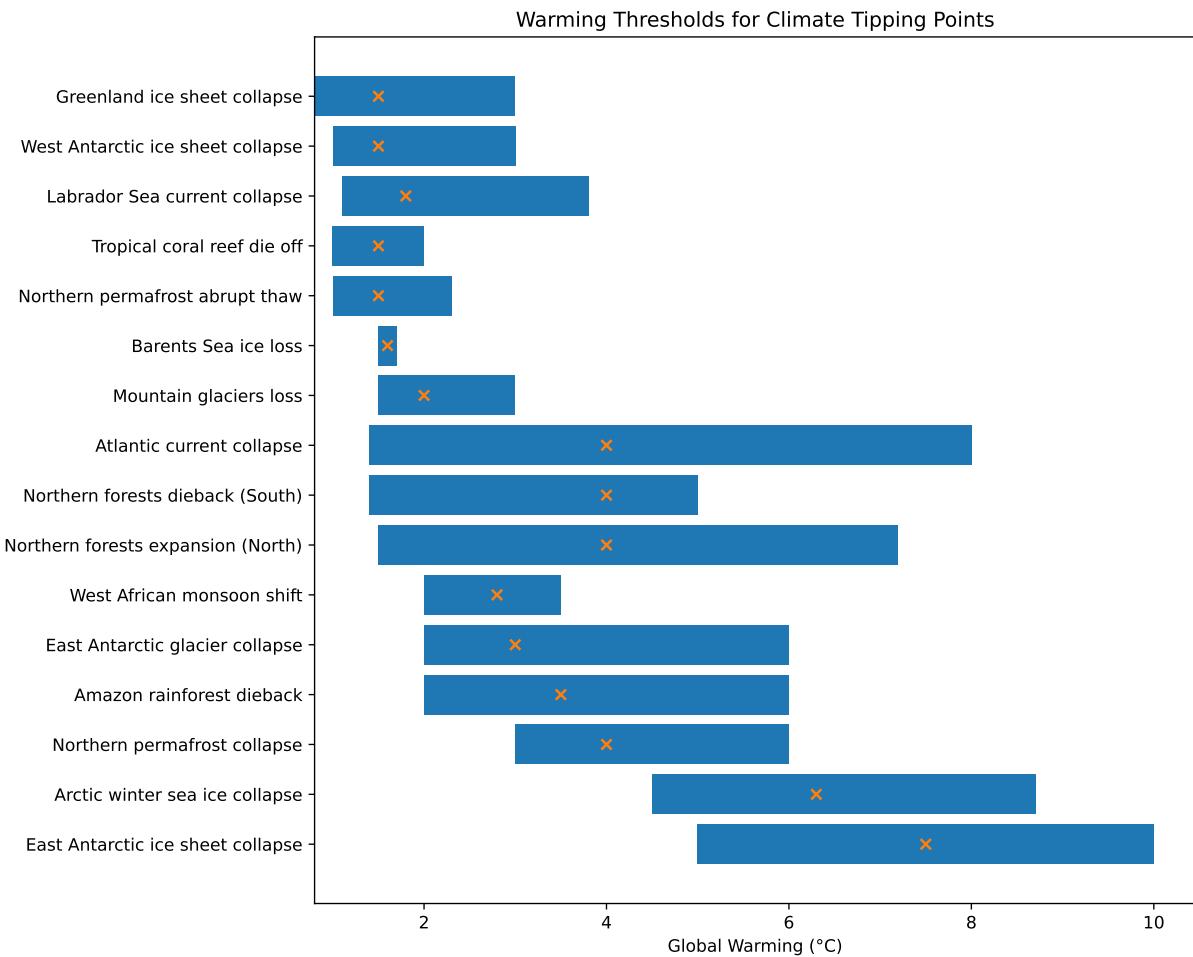
(United Nations Environment Programme (UNEP), 2021) reported as of 2021 updated national climate pledges (NDCs) and other mitigation measures are projected to lead to a global temperature increase of approximately 2.7°C by 2100, significantly surpassing the Paris Agreement's aspirational goal to keep 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.

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7.2.1 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 “[near-real time updates of key global climate variables”*(The Copernicus Climate Change Service, 2024).

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 CO₂ 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).

Table 13: Comparing highest per capita CO₂e emissions (mostly from oil producers) vs regional average per capita CO₂ emissions vs total CO₂ emissions(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 CO₂e emissions into 4 main categories helps to organize calculating CO₂e 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.).

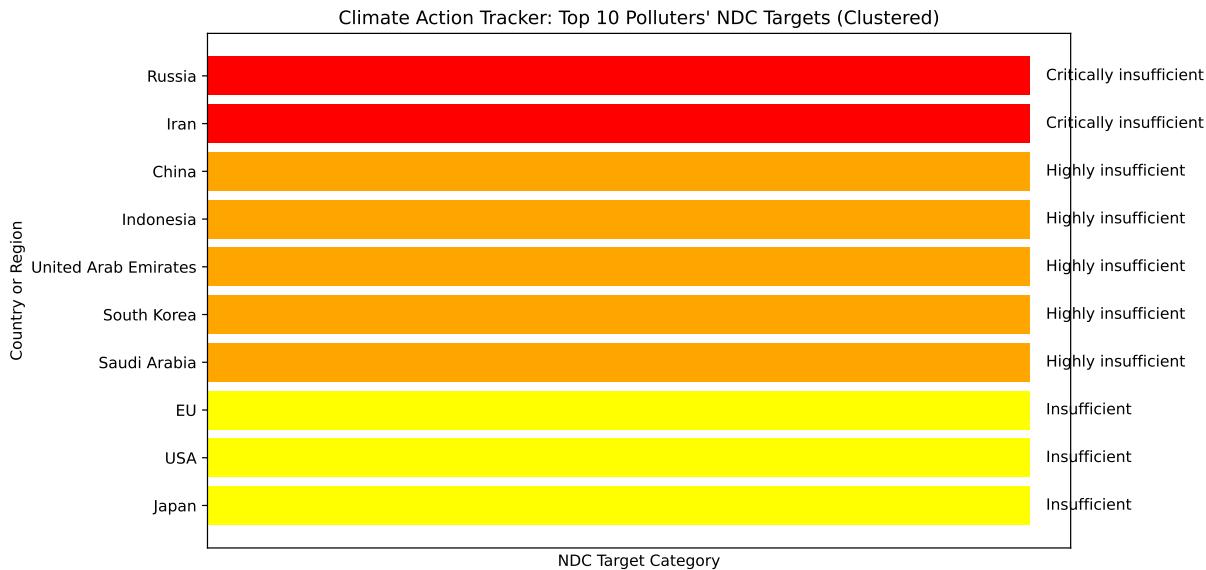
Table 14: Definition of Emission Scopes From (National Public Utilities Council, 2022). One's scope 3 emissions are someone else's scope 1 emissions.

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 15: 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 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, 2025).

7.2.2 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 16: 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).

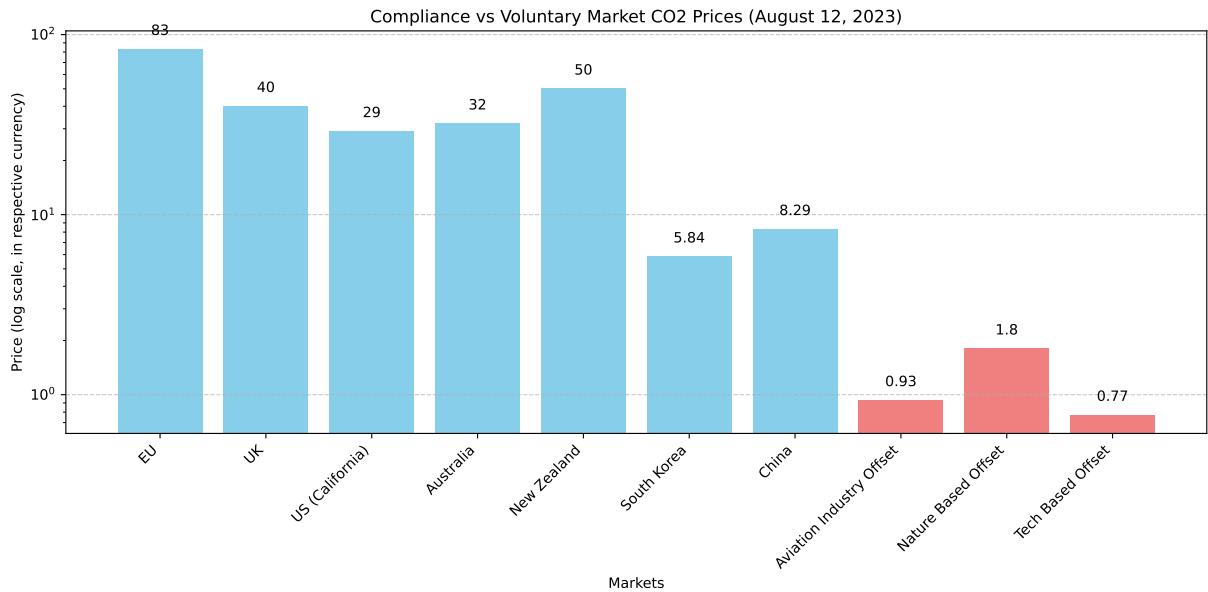
The prices between compliance and voluntary markets differ substantially.

Table 17: Compliance market CO₂ prices on August 12, 2023; data from (CarbonCredits, 2023; Ember, 2023; Trading Economics, 2023).

Compliance 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 18: Voluntary market CO₂ prices on August 12, 2023; data from (CarbonCredits, 2023).

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



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 CO₂ 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 19: 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 CO₂ 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 CO₂ emissions has caused several high-profile pollution events. Large ones that got international news coverage include Exxon Valdez and Deepwater Horizon.

7.2.3 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 20: Types of nature-backed assets and tradable 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 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
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)

7.2.4 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 CO₂e, in Africa and the Middle East 1.7t CO₂e; 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 CO₂e 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 21: 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 22: Data from (Hannah Ritchie, 2020; US EPA, 2016).

Sector	Share	Description
Energy Use (inc. electricity, heat and transport)	73.2 %	Total CO ₂ 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 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.

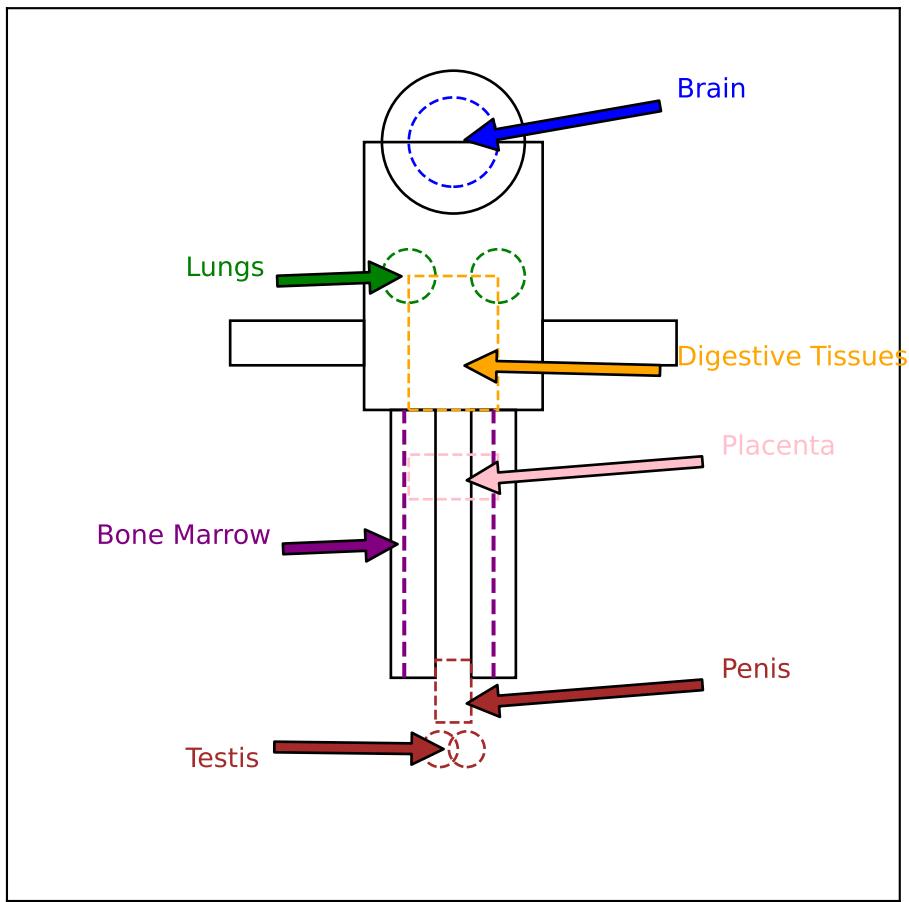
Earth's growing population reached 8 Billion people In November 2022 and population projections by predict 8.5B people by 2030 and 9.7B by 2050 (The Economic Times, 2022; United Nations Department of Economic and Social Affairs, Population Division, 2022). Indeed, making *anything* consumes natural resources, 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."*

7.2.5 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



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).

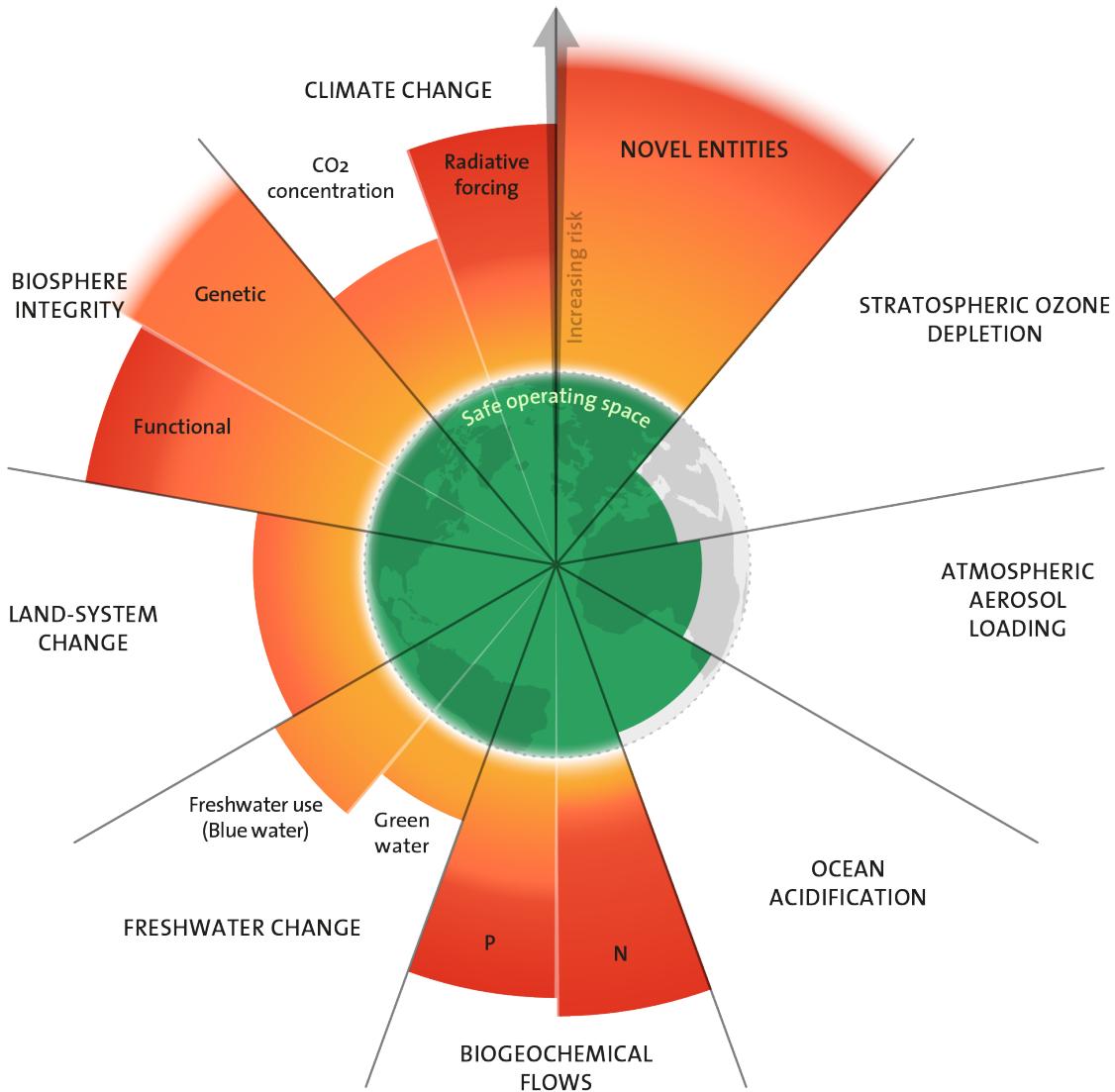


Figure 10: Planetary Boundaries 2023 update. Azote for Stockholm Resilience Centre, based on analysis in Richardson et al 2023

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 renown 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).

7.2.6 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 civilisation: *“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 levelled-up to planetary scale, concerned with the health of ecological life-support systems: 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, (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.

7.3 Ecosystem Services: Quantifying Human Benefits from Nature

Ecosystem services measure the benefits humans receive from the biosphere. Put most simply, *ecosystem services* enable human life on Earth. 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-Baggethun 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). 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.

7.3.1 The Biosphere: 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).

7.3.2 Using Ecological Indicators to Track Environmental Health

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).

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).

AI is being used to map icebergs and measure the change in size (European Space Agency, 2023).

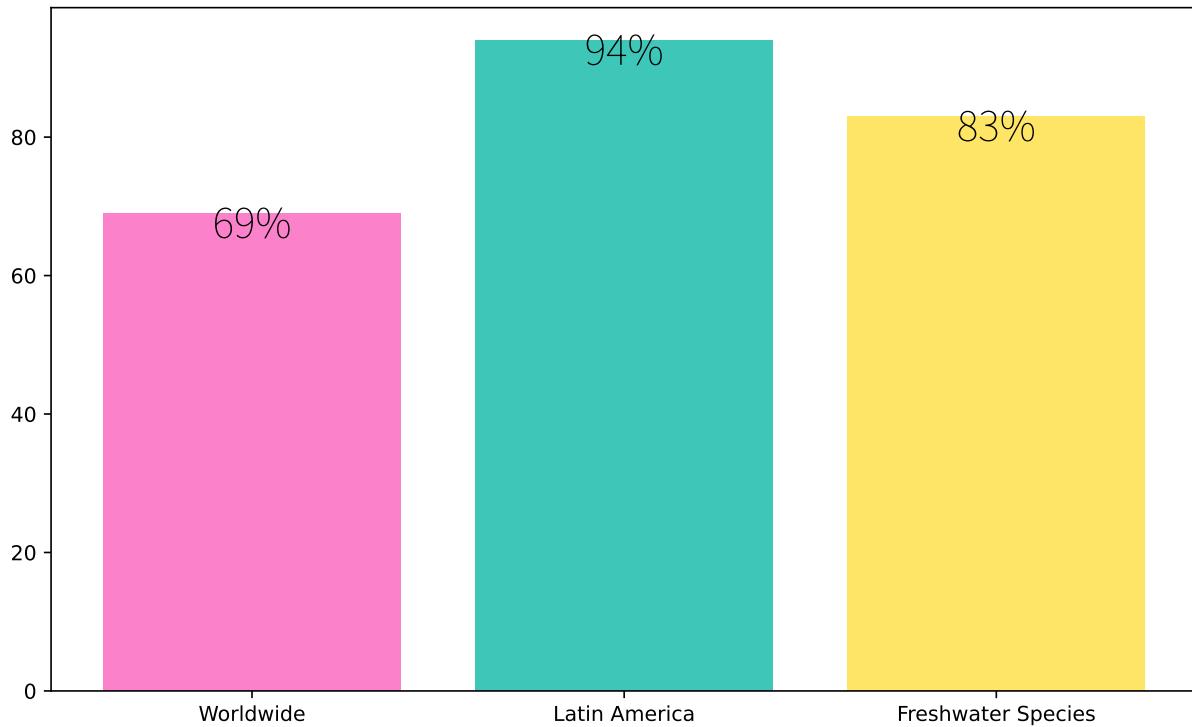
7.3.3 Measuring Biodiversity Loss and Environmental Degradation

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%).”

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 23: 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



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 & Alvarez-Etxeberria (2023).

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

Table 24: Concepts 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)

7.3.4 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).

7.3.5 Forests: Carbon Sinks and Biodiversity Reservoirs

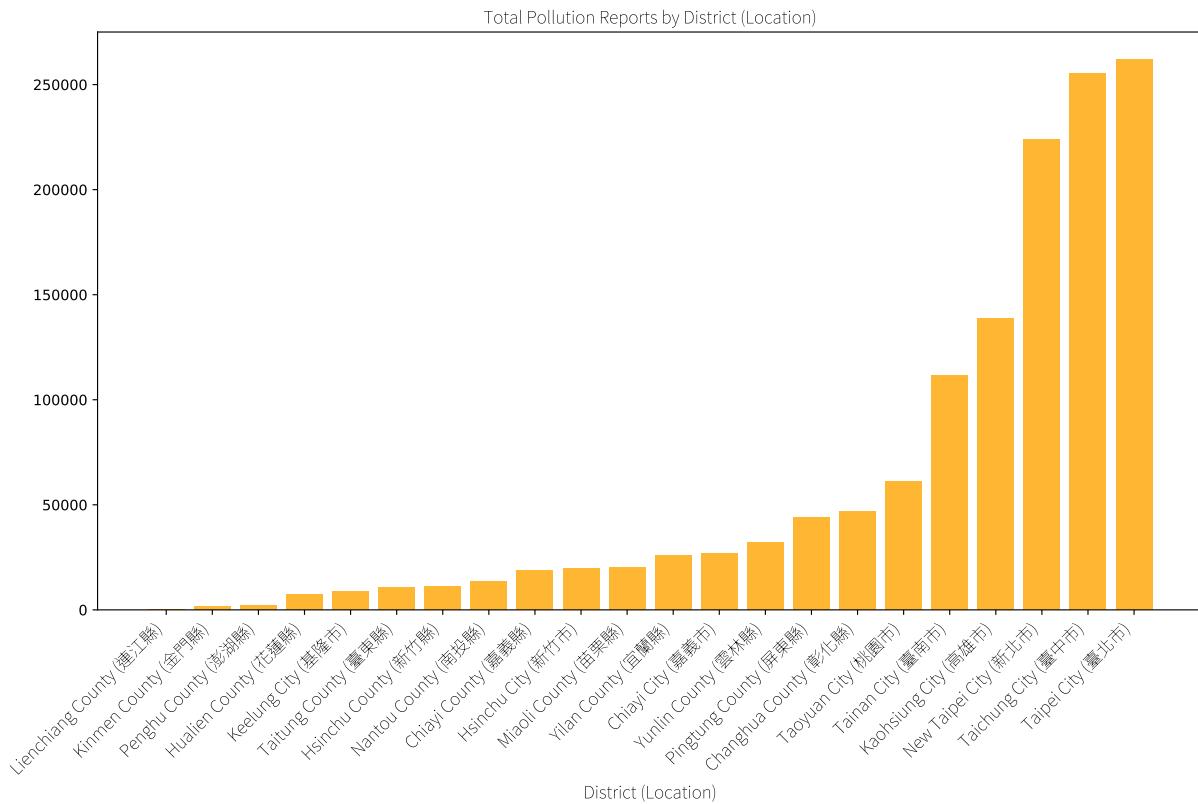
Forests are a crucial part of Earth's carbon cycle and the main natural CO₂ capture system; due to deforestation, Europe rapidly losing its forest carbon sink (Frédéric Simon, 2022). Beyond their role in locking away carbon, recent field work shows forest actively scrub methane from the air as tree bark 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

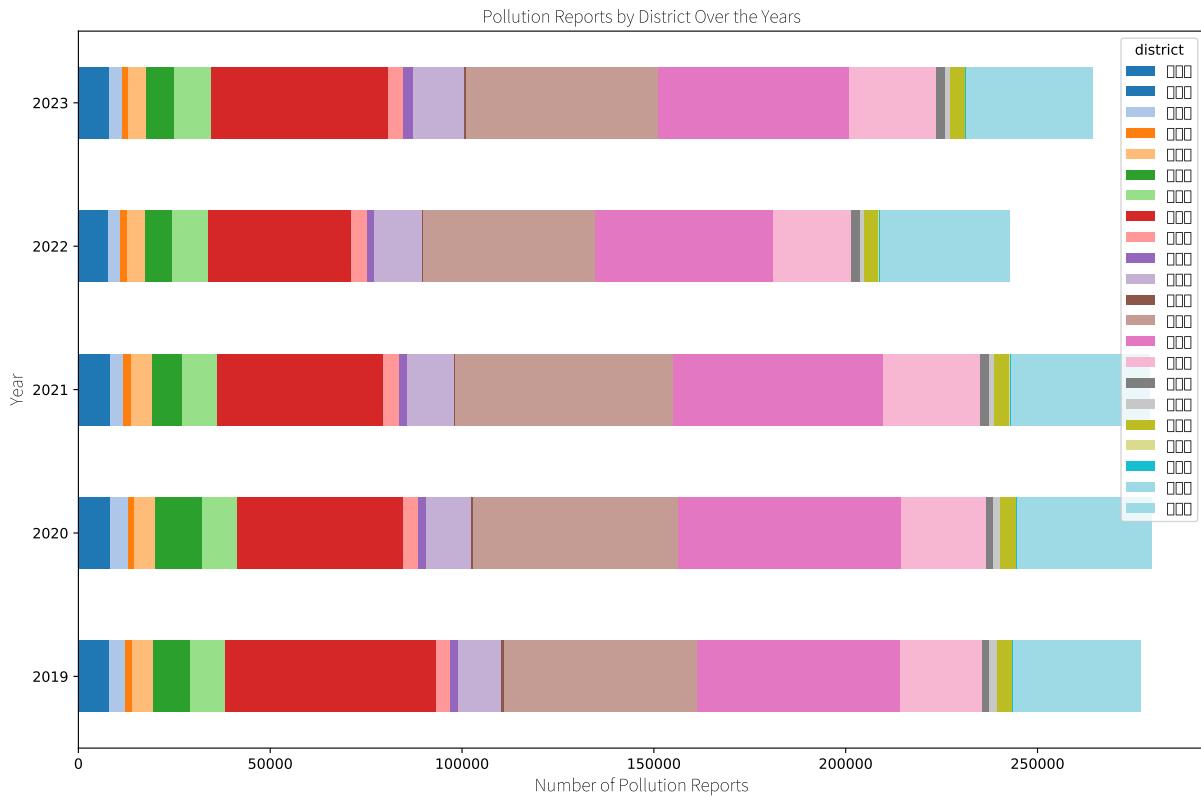
education, poverty and access to green jobs. Taking these aspect into account may be beneficial, for example (Bousfield et al., 2022) reports there's evidence paying landowners for the ecosystem services their forests provide may reduce deforestation.

7.3.6 Pollution: Air, Water, and Soil Degradation

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



<Figure size 3600x2400 with 0 Axes>



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).

Air Pollution

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 μm PM (PM2.5) air pollution as a *cause for lung cancer*. In (Hannah Devlin, 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.”

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, (Bouscassee et al., 2022) finds strong health and economic benefits across the board from air pollution reduction.

Water and Soil Pollution

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 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.

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.

7.3.7 Climate and Disaster Preparedness: Building Resilience to Extreme Weather

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 CO₂ 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 [ADD CITATION]. 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).

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).

7.4 Financialization of Nature vs Nature's Sacred Value: How to Scale Up Sustainable Action

There are 2 main approaches to protecting nature:

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 26: 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.

7.4.1 Ecological Restoration: Healing Damaged Ecosystems Through 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 27: 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 totalling 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 CO₂ 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 CO₂ 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 standardisation 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 industrialisation 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.

7.4.2 Energy Production: “Climatech”, Renewable Energy and Decarbonisation Pathways

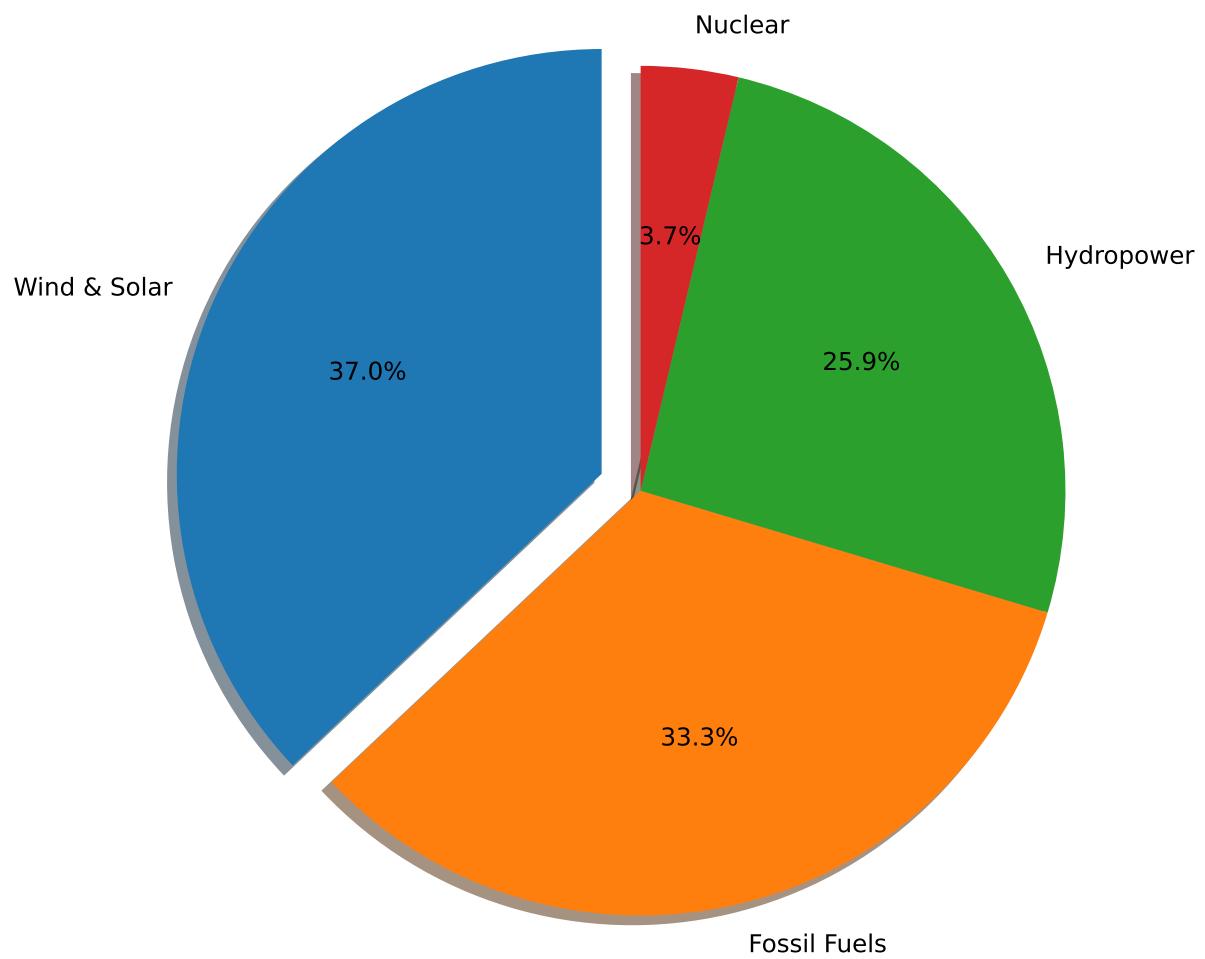
Globally, 34% of all emissions come from energy production (US EPA, 2016), making it the key sector to require innovation for reducing carbon emissions. The International Energy Agency’s (IEAs), “Tracking Clean Energy Progress” report on 50 distinct decarbonisation enablers and finds that only 3 components - 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) (Bonasia, 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).

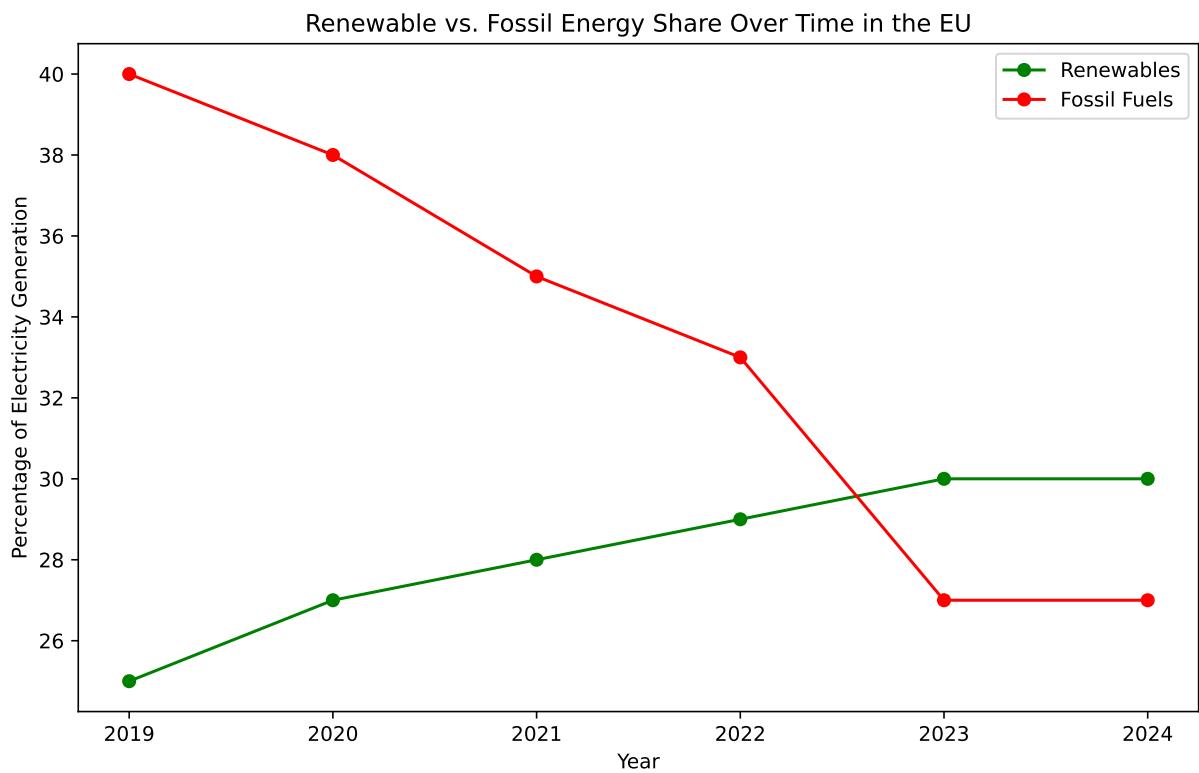
(Gaure & Golombok, 2022) simulate a CO₂ free electricity generation system in the European Union where “98% of total electricity production is generated by wind power and solar; the remainder is covered by a backup technology.”. The authors stipulate it’s possible to power the EU without producing CO₂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

EU’s energy mix in 2024:

EU Electricity Generation Breakdown (H1 2024)

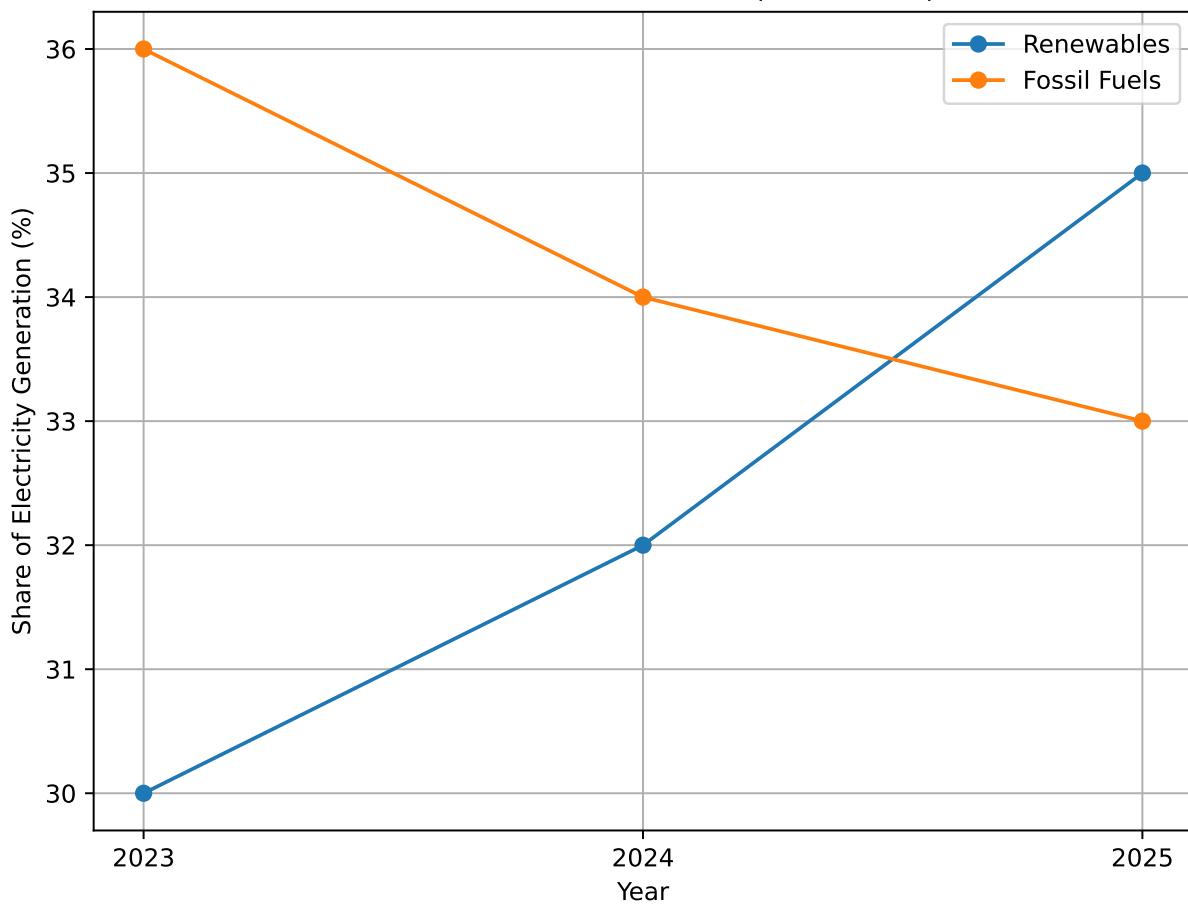


Wind and solar energy overtook fossil energy in Europe:

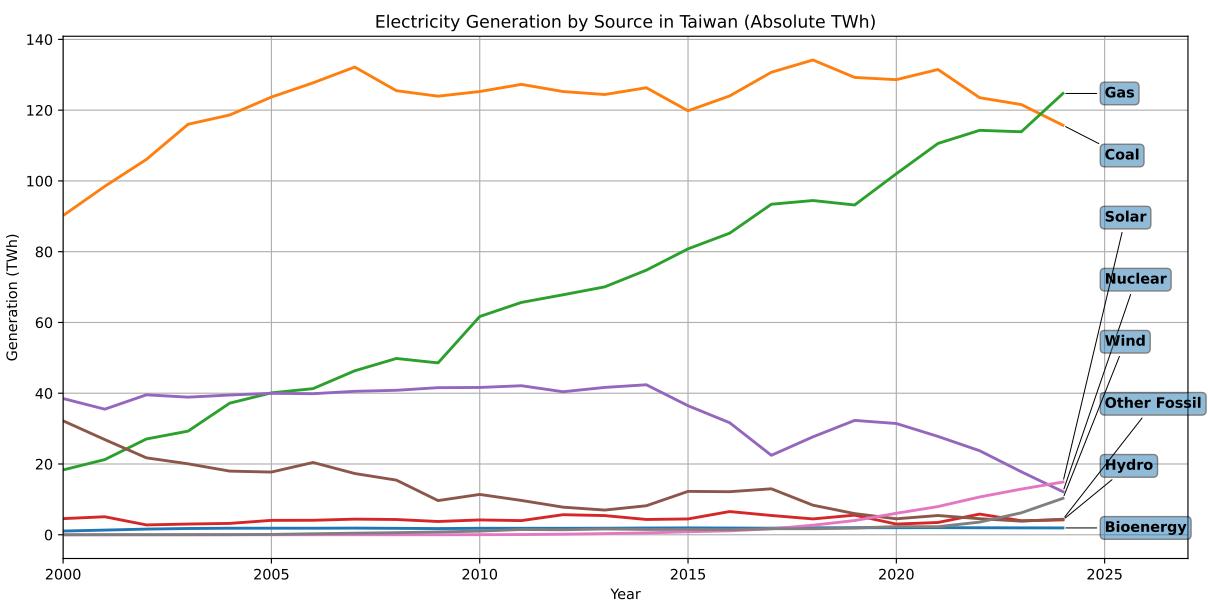
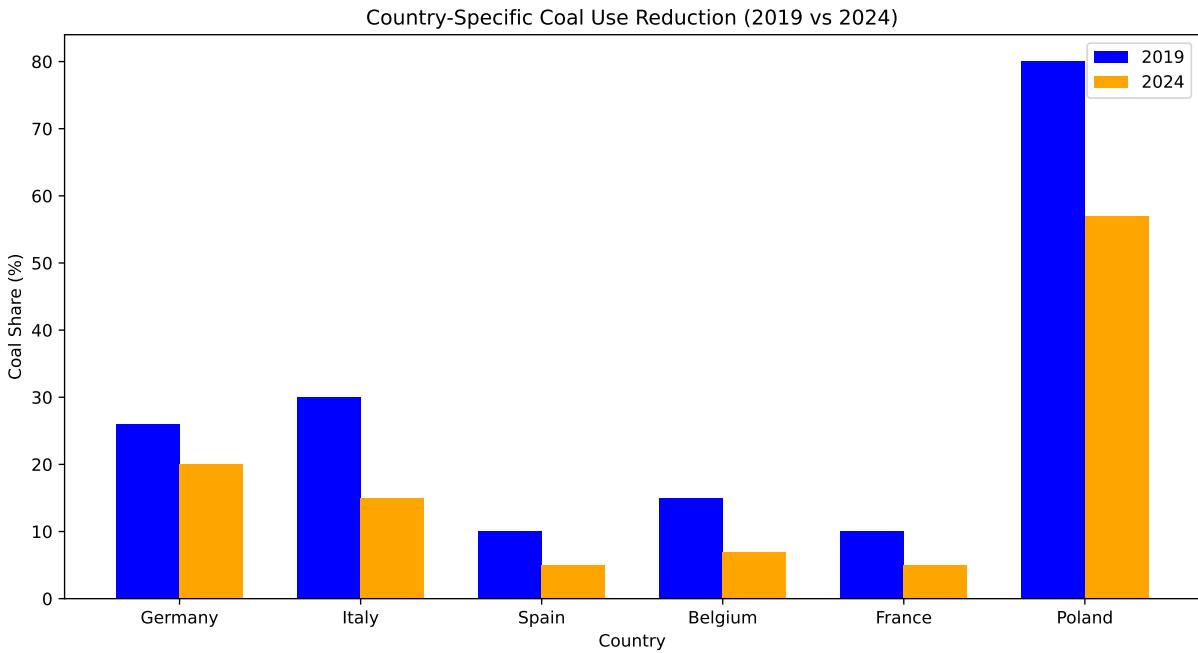


Globally, renewables also overtook fossil fuels (IEA, 2024):

Renewables vs Fossil Fuels (2023-2025)



Meanwhile, reduction in coal-power was also possible. Coal is a large CO2 emitter.



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 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 CO₂ reduction among nature- and technology-based methods are the most effective (S. Low et al., 2022).

7.4.3 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).

8 DESIGN

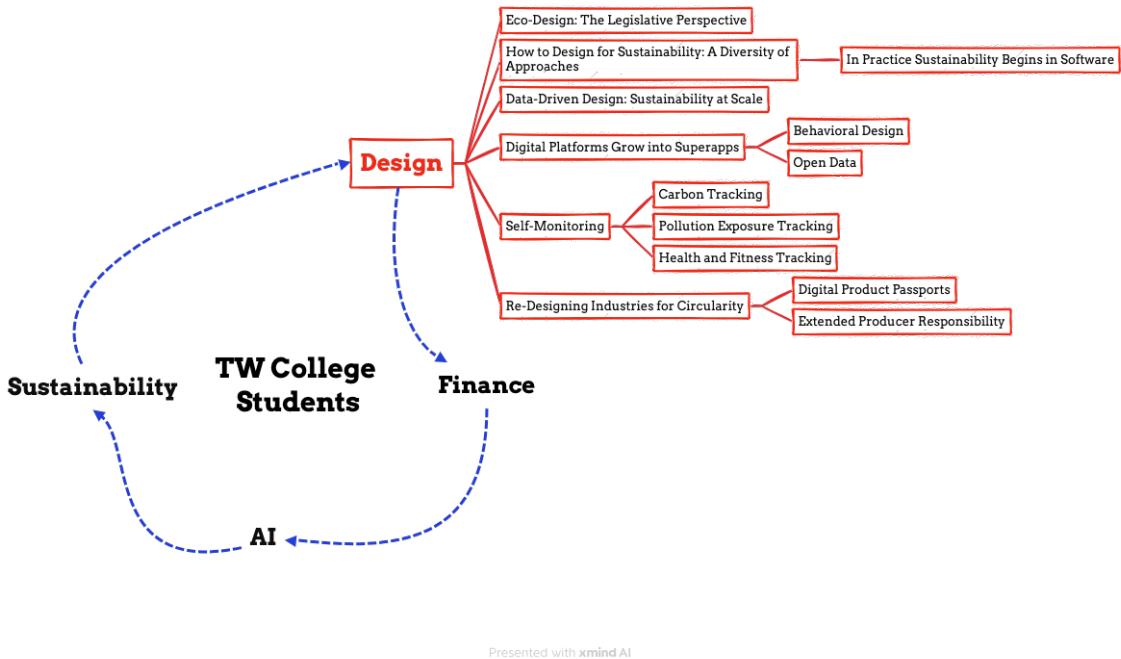


Figure 11: Visual abstract for the design chapter

- Design makes complexity comprehensible. Norman (2016)
- like the Helsinki chapel. there's either or a priest or a social worker present. it's the perfect public service. Limit the barrier of entry for people to discover. Elegant.

8.1 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). The monumental task of removing several gigatons of CO₂e from the atmosphere requires massive policy shifts and collaboration across countries and industries (Mackler et al., 2021).

We have an opportunity to re-imagine how every product can be an eco-product and how they circulate in our circular economy.

Designing the right legislative measures can be hugely impactful. 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). 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. The Ecodesign for Sustainable Products Regulation (ESPR) entered into force in July 2024 (European Commission, 2024) 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).

Europe has been on a path of transformation from 2023 to 2030.



Figure 12: EU Policy Context Timeline

The EU Commission has been releasing strategic foresight reports since 2020 (European Commission, 2023b).

Timeline of the Policy Context:

- In 2019 by the von der Leyen commission adopted the European Union (EU) Green Deal strategy.
- In 2021 the Commission proposed a goal of reducing CO2e 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 CO2e reductions compared to 1990. This proposal is set to become a binding law for all EU member countries (European Commission (2019c); European Commission (2019a); *EU Reaches Agreement on National Emission Reductions* (2022); 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). Each product covered by the policy 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. It's safe to say the large majority of products available today do not meet these criteria.

- European Commission (2022b) Ecodesign for sustainable products. The EU “Green Deal” legislative strategy is comprehensive. Eco-Design is a Key EU Sustainable Policy Design Tool.

Combined Concept Map of EU Green Deal Regulations and Categories



In the European Union (EU), a wide range of legislative proposals, targets, organizations, and goals have exists across diverse countries. It's not that the EU didn't have an overarching environmental policy before; rather it was more vague and filled with loop-holes. Upcoming laws 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.

Director of the French environmental NGO Pôle Eco-conception, eco-design is “[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 EU is also concerned with supply-chain deforestation. 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.

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).

The EU has a *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.).

Europe is transforming into a hotbed of sustainability. One of the EU goals is reducing careless consumption. Tacking our consumption habits can help support eco-designed products. It’s up to legislators to provide sustainable products on our marketplace... but until this happens, we can use the green filter.

8.1.1 Beyond Recycling: Return, Repair, Reuse

- There’s a growing number of companies providing re-use of existing items.
- *SmartSwap* (n.d.) For example, Swap furniture in Estonia
- universal recycling symbol creator Gary Anderson created the symbol when he was an architecture student in California, USC (uni southern california) in 1970 at the age of 23, inspired by Silent Spring, Earth Day, and Bauhaus, Buckminster Fuller, Spaceship Earth, printing presses, and the Woolmark logo for wool industry certification, and the Möbius strip, for a competition held by a packaging firm that was making paper containers for packaging Swap Society (2023)
- The power of defaults. Make the sustainable option the default Gigerenzer (2008) “simple heuristics built from basic rules; how heuristics are selected and structured in social and physical environments; concept of ecological rationality to identify the environmental conditions under which particular heuristics succeed or fail”

- standardising reuse across the globe, a body to create a reuse standard is holding a competition to create e reuse symbol

Table 28: 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
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 CO2 footprint and operating costs
Resource Efficient	Reduce product's use of raw materials and energy during production and life-cycle

8.1.2 Legislative Efforts Around the World

Europe is not the only region undertaking legislative efforts to promote sustainability. In the US, the *Inflation Reduction Act* provided funding to development of de-carbonizing technologies and includes plans to combat air pollution, reduce green house gases and address environmental injustices (Rajagopalan & Landigan, 2023).

Many other jurisdictions also have laws that aim to reduce the environmental impact of products throughout their life cycles.

For instance Australia has a Product Stewardship (PS) scheme, which 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 [ADD CITATION].

8.1.3 Eco-Modulation: Incentive Design for Extended Producer Responsibility and Product Stewardship

Eco-modulation means harder to recycle items are 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.

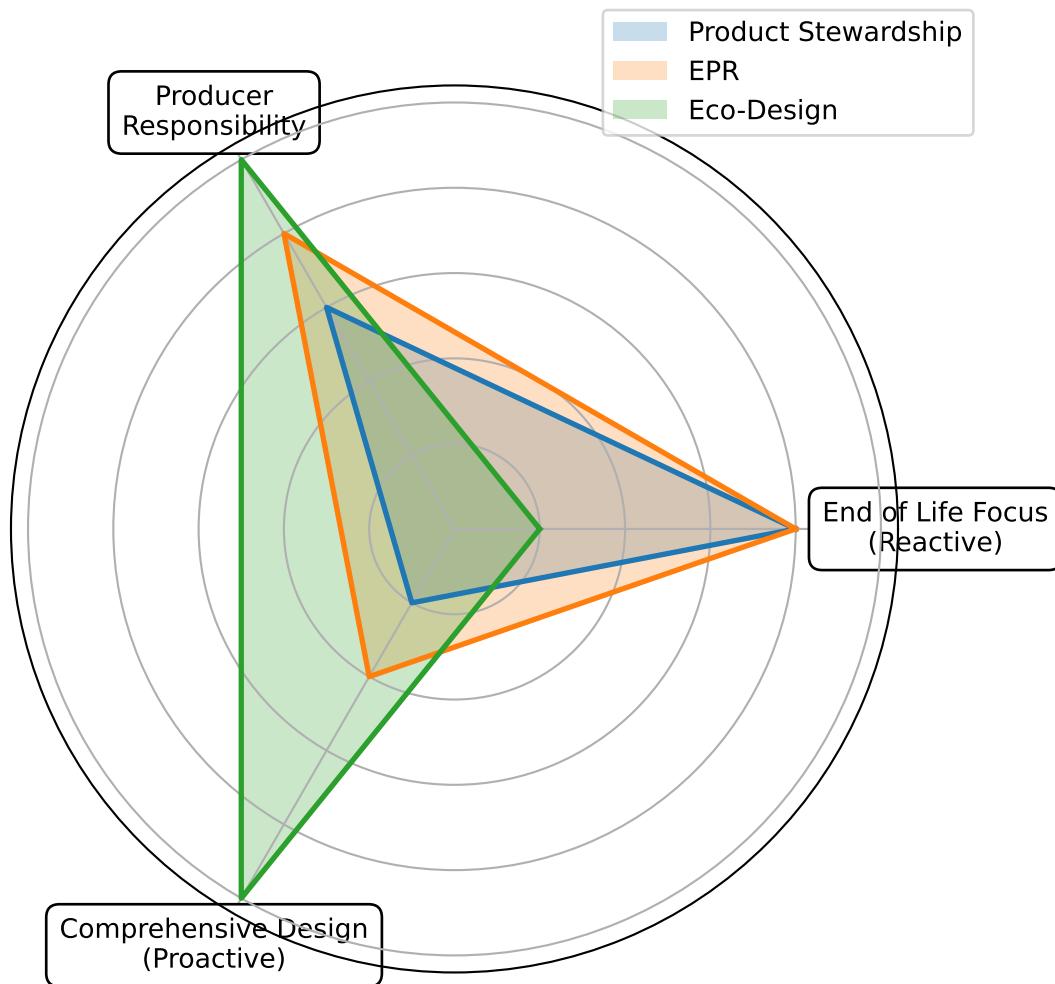
Eco-modulation makes the hidden cost of hard-to-recycle formats directly visible on the invoice.

While Taiwan doesn't yet have a specific eco-design law, there are various pieces of legislation promoting circular economy [ADD CITATION]. 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).

Deposit Return Schemes (DRS)

In California, part of the EPR regulation is a large pool of funding for cleaning up historic pollution resulting from Moolman (2024)

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.



Extended Producer Responsibility Enables Companies to be Responsible.

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 as 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 [ADD CITATION], aimed to encourage producers take responsibility for the entire life-cycle of their products, thus leading to more eco-friendly products. 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).

In any case, strong consumer 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. J. Peng et al. (2023) finds that the *Carbon Disclosure Project* has been a crucial tool to empower ERP in Chinese auto-producers.

- 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).

One type of legislation that works?

- (Steenmans & Ulfbeck, 2023) Argues for the need to engage companies through legislation and shift from waste-centered laws to product design regulations.
- 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 in 2018 while in France textiles are covered by an Extended Producer Responsibility (EPR) scheme leading to higher recovery rates (*Ibid*).
- Greyparrot AI to increase recycling rates (Natasha Lomas, 2024).

Bring back your bottle and cup after use.

- Ruiz-Pastor & Mesa (2023) proposes a **product repairability index (PRI)**
- Formentini & Ramanujan (2023)
- Recycling (Lenovo, 08-29-22) “rethinking product design and inspiring consumers to expect more from their devices”
- Zeynep Falay von Flittner (n.d.)

Packaging is a rapidly growing industry, expanding on the back of online shopping, which generates large amounts of waste materials, which if not reused or recycled, easily becomes garbage. Over 161M 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 standardisation, 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, how Coca-Cola was exposed for lobbying against container-deposit laws, aiming to misrepresented recycling as a complete solution; strategies that stalled effective legislation and maintained a “green” façade despite obstructing real sustainability progress.

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.

8.1.4 Scenario-Building: Avoiding the Worst Futures

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 En-ROADS 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).

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.

8.1.5 Design for Quality of Life

While traditional economic thinking is based on a conflict between nature and development, some new models find there is potential for synergy between economic, social, political, cul-

tural, and environmental metrics. (Kaklauskas et al., 2023) models multi-criteria analysis of 169 countries and 238 cities, finding 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 wellbeing 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).

For example, there's ample evidence from several countries suggesting moving to renewal energy brings environmental benefits. In Bangladesh, (Amin et al., 2022) suggests "*removing fossil fuel 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 was a win-win solution, for both the environmental health and financial wealth.

Sustainability policy context is shifting around the world. I was torn whether to place *politics* under *sustainability* or *design*, and decided for the latter - as sustainability is mostly *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.

- Pater (2021)
- Mitigating Climate Change vs Adapting to Climate Change. Many companies are developing technologies for mitigation. 10 countries use almost 100% renewable energy. Taxes. There have been proposal of a "meat tax". Sustainable Development Goals (SDGs). Kunming-Montreal Global Biodiversity Framework. Montreal protocol near-eradication of chlorofluorocarbons (CFCs) and the ozone holes became whole again.

(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 to 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 ecodesign 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 vineyard case study, where a redesigned Merlot red wine procedure reduced 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 optimising 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 ecodesign 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 result 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 analysing 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, (Arranz et al., 2022) conducted a large-scale study using machine learning on firm survey data from 870 organisations 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).

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

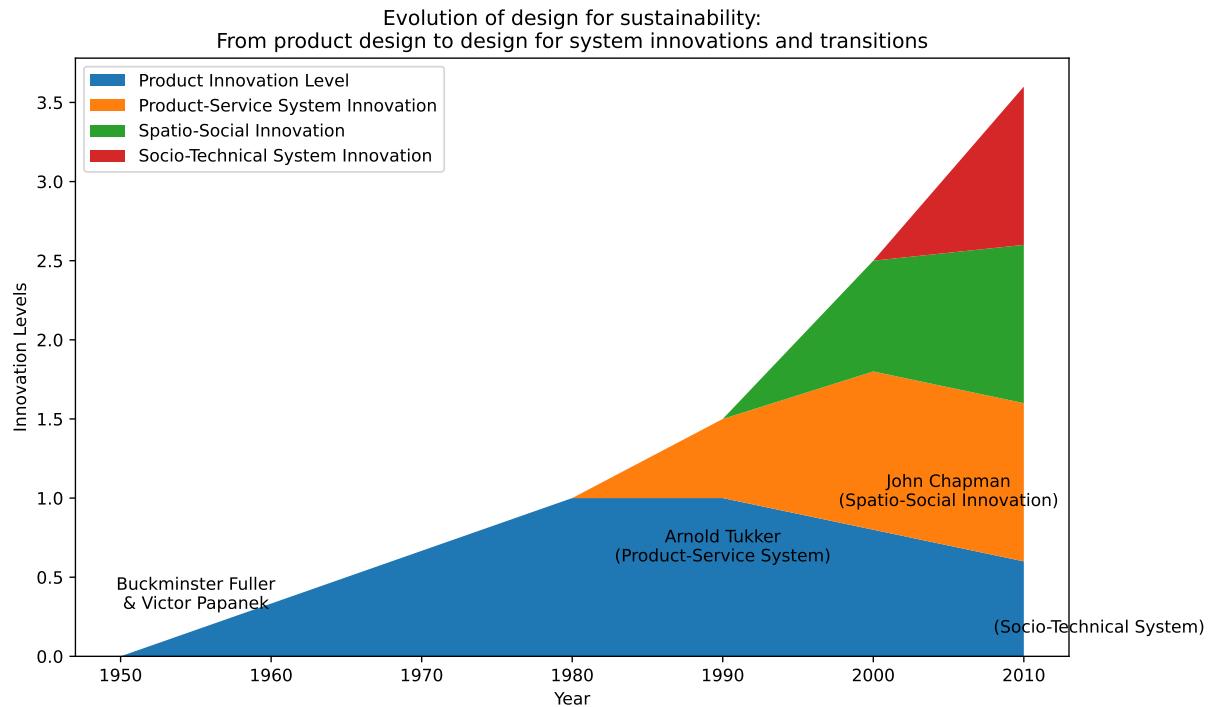
As of 2025, *circular economy* is a tiny part of the world economy. (Circle Economy, 2022) reported in 2022 only 8.6% of world economy was circular and *100B tonnes of virgin materials* was sourced every year. An early pioneering innovator, (Jackson, 1996) showed through detailed case studies how *preventive 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.

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*”.



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.

I will start with *Human-Centred Design*, 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 9241-210:2019 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 Oxman 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 armour 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).

Moving from products and (digital) experiences towards the built environment and architecture, *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 maarhitektuuri 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.

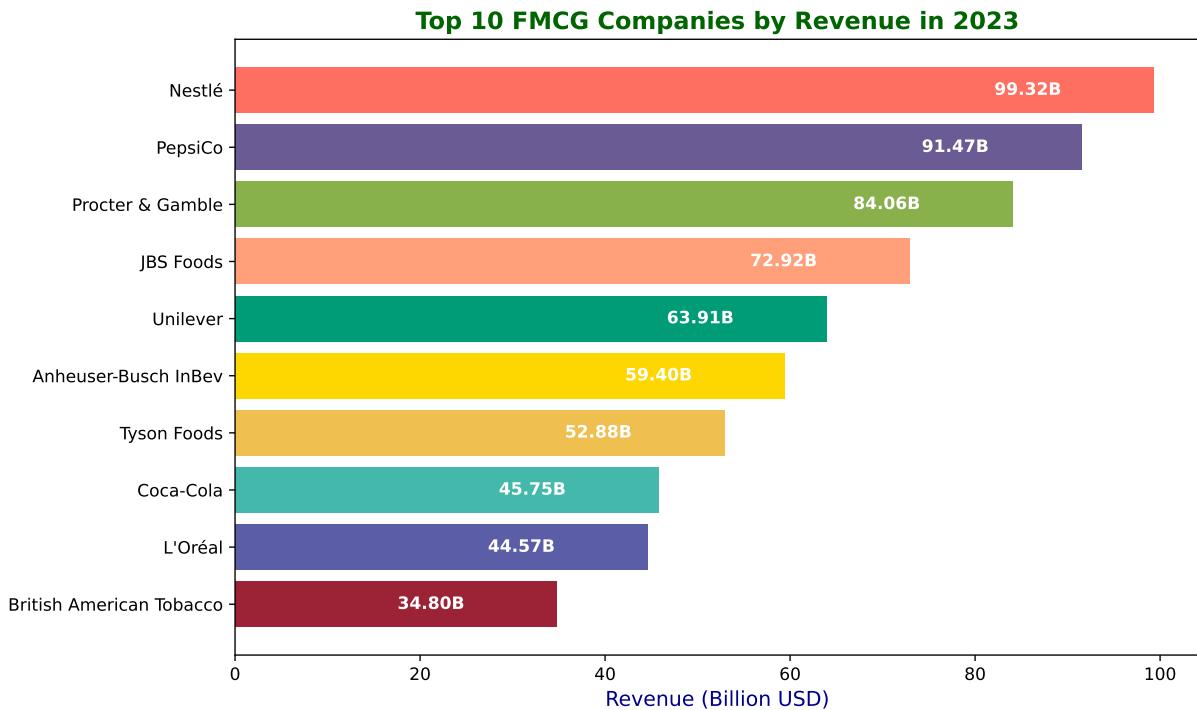
- Sufficiency

8.3 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.

8.3.1 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).



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).

8.3.2 (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.) similary 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). Meanwhile, (Emily Chan, 2022a) reports there’s not enough transparency in the fashion industry; greenwashing is prevalent.

In order to tackle these very issue, (Fashion Revolution Foundation, 2022) launched the fashion transparency index. (Wikirate, 2022b): “*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*”. Consumer understanding of sustainability is not very specific; for example (Mabuza et al., 2023) shows consumer knowledge of the effects of apparel coloration is very limited. 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 (imperfectidealist, 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.

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 CO₂e per kg of wool (footprint per finished sweater is 0.04 kg CO₂e), 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 caled 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 (Infinitied 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).

- Trash found in ocean / nature etc. Free clothes, Minimize shopping, buy quality, save CO₂, invest. Towards Sustainable Clothes. Sustainable Fashion, Textile Design.

8.3.3 Food

Food production is a large greenhouse gas emitter. "The agricultural sector contributes to approximately 13.5% of the total global anthropogenic greenhouse gas emissions and accounts for 25% of the total CO₂ emission" (Nabipour Afrouzi et al., 2023). (Poore & Nemecek, 2018) suggests 26% of carbon emissions come from food production. Saner et al. (2015) reports dairy (46%) and meat and fish (29%) products making up the largest GHG emission potential. Springmann et al. (2021) proposes veganism is the most effective decision to reduce personal CO₂ emissions.

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 CO₂e to 339 kg CO₂e 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 can be solved with science. One example being *fake honey*, meaning synthetic honey can pass many laboratory tests, which calls for improved legislation and technology, such as DNA-analysis to find real honey (ERR, 2023). The same is true for cocoa beans, which are at risk from food fraud (E. Fanning et al., 2023). *Farm to Fork* is a European Union policy to shorten

the supply chain (meaning less change for fraud) from the producer to the consumer and add transparency to the system (Financial Times, 2022).

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 “2019, the 27 KURA SUSHI branches in Taiwan sold more than 46 million plates of sushi. in Taiwan”. Illegal, unreported and unregulated fishing (IIU) fishing is widespread; the EU is adopting countermeasures (D. E. Kim & Lim, 2024). (Muñoz et al., 2023) Is there such a thing as sustainable fishing? Bottom trawling is the worst and should be banned. (Katie Gustafson, 2022) proposes a “*Uniform traceability system for the entire supply chain*” for seafood. (Mamede et al., 2022) proposes *Seafood tracing*: Fingerprinting of Sea Urchin.

Global warming leading to droughts and extreme weather, wars and conflicts increased volatility in food prices (Eshe Nelson et al., 2023).

(A. S. Patel et al., 2023) livestock products (meat) are 15% of agricultural foods valued at €152 billion in 2018 globally.

- China is the largest honey producer.

“Sustainability Intelligence for Food Companies” (n.d.)

Open Food Facts - World (n.d.) app for nutrition and sustainability data

Fishing

- 75% of fishing is done using industrial Trawling, which has environmental impact
- J. L. Bailey & Eggereide (2020) shows how the Norwegian government plans to increase salmon production 5x by 2050. How can this be sustainable? Mostly this means fish-farming
- Sustainability Accounting Standards Board, part of the International Financial Reporting Standards Foundation. Global Reporting Initiative.
- “Reality Labs Research at Meta Connect 2022” (2022)
- *Real Time ESG Tracking From StockSnips* (2021) “Real Time ESG Tracking From Stock-Snips”
- Waters (2015) (**Need access!**)
- Cawthorn & Hoffman (2016) (**Need access! ncku doesn't subscribe**)
- Gamborg & Jensen (2017) (**Need access!**)
- Neethirajan & Kemp (2021) using biometric sensors to track livestock sustainability.
- Inc (n.d.)

- Tim Nicolle (2017)
- EAT-Lancet diet

Culture, Community, Cuisine, Storytelling

Culture can be a proponent of sustainability. Food is about enticing human imagination and taste buds. Potato used to be a newcomer and innovative crop in Europe, and now it's so common, Europeans forget it's no originally from Europe. 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).

- Tsing (2015) mushrooms
- IARC warns aspartame (artificial sweetener found in many soft drinks) could cause cancer [ADD CITATION].
- Yap et al. (2023) Singapore disposes of 900,000 tonnes of plastic waste out of which only 4% is recycled.
- Kiessling et al. (2023) Single-use plastics make up 44-68% of all waste mapped by citizen scientists.

Food Waste

There are several initiatives to reduce food waste by helping people consume food that would otherwise be thrown away including Olio and Too Good To Go.

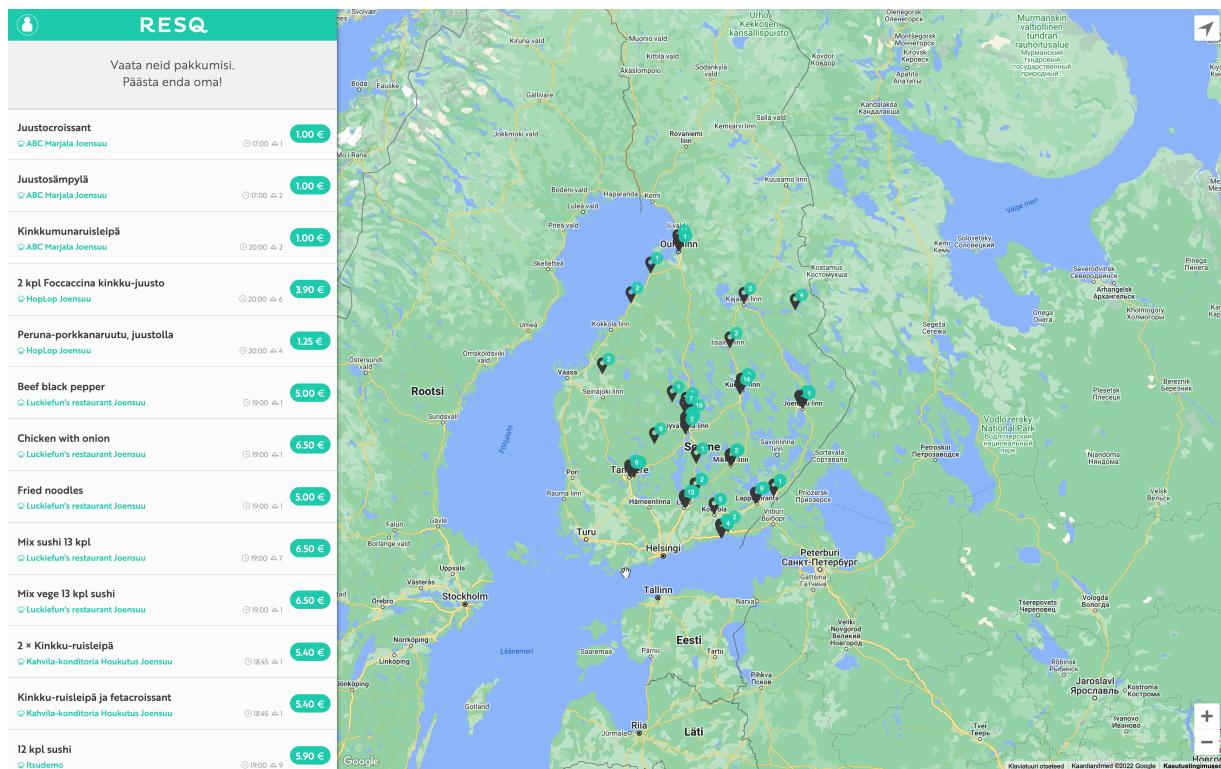


Figure 13: ResQ Club saves food waste by selling left-over foods cheaply

Table 29: Food saving apps

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

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

- “regenag”, Václav Kurel, we need help consumers demand regenerative agriculture Baltic Sea Action Group (2023)
- Kommenda et al. (2022) Carbon Food Labels
- Food Sovereignty: “The global food sovereignty movement, which had been building momentum since its grassroots conception in the late ’90s, quickly gained traction with its focus on the rights of people everywhere to access healthy and sustainable food. One of the pillars of the movement lies in using local food systems to reduce the distance between producers and consumers.” “We can grow foods just as well in the inner city as we can out in the country because we’re agnostic to arable land,” says Woods. “Because we grow indoors and create our own weather, [climate change] doesn’t affect our produce.” (Stall-Paquet, 2021)
- Renée Salmonsens (2018): Vertical farm in Taoyuan

- Catherine Shu (2023): *Intensive Farming Practices vs Farm to table*
- Akshat Rathi (2021) and Lowercarbon Capital (2023) climate startup funding.
- Only make what is ordered.

8.4 In Practice Sustainability Begins in Software

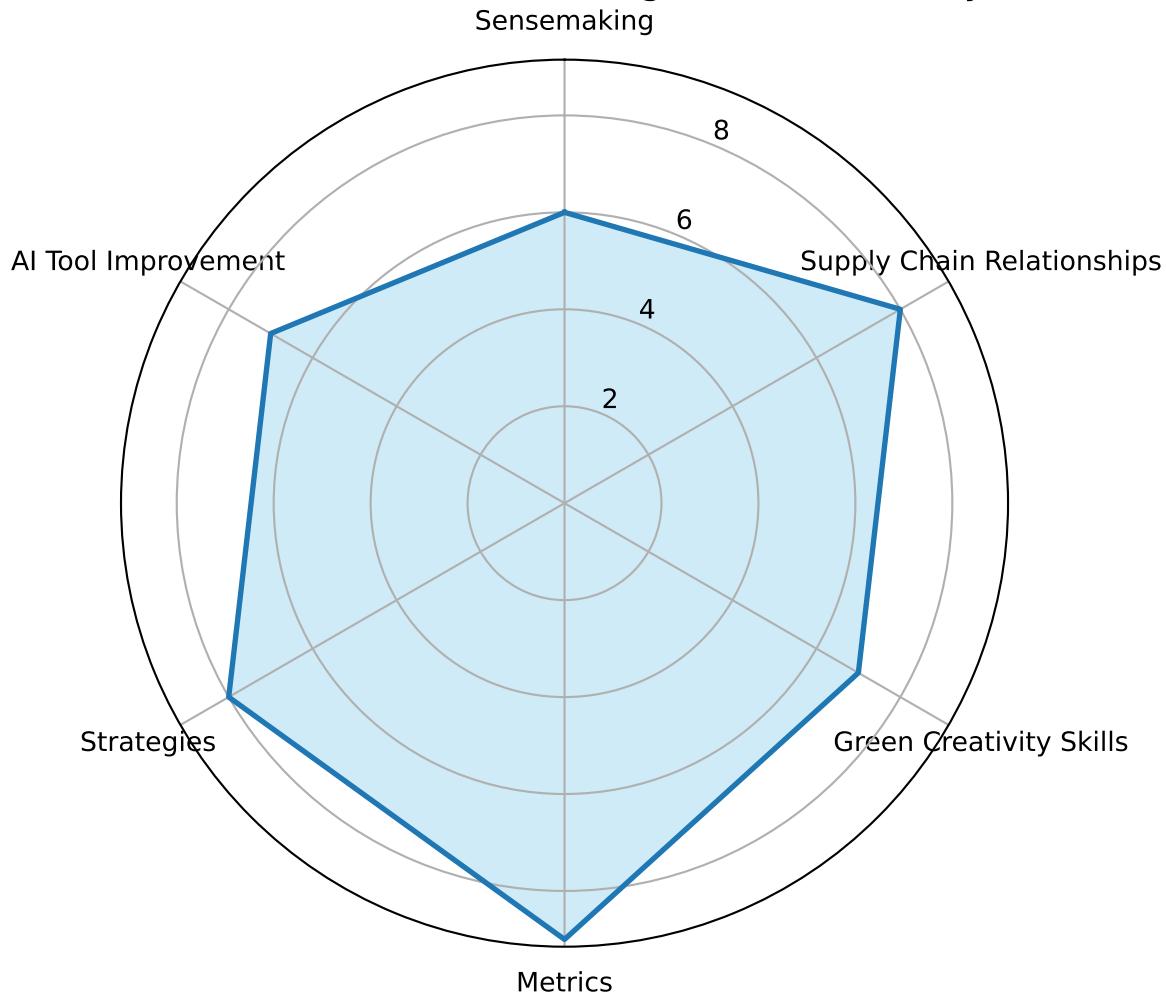
Design encompasses most everything in our daily lives. Humans live in artificial environments where *most things* are designed by humans. The *experiences* we take part in are increasingly created based on some type of data.

Designing user interfaces for sustainable interactions means incorporating data and tools to enable designers to make decisions which reduce the emissions of their designs. 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). Software is key to building more sustainable products, already for decades (B. B. Gupta et al., 2023). AI-assisted design enables design for sustainability because the design process is where sustainability begins. AI has the potential to provide the parameters for sustainability. (Singh & Sarkar, 2023) proposes an AI tool for deciding the suitable life cycle design parameters.

- Involving young HCI designers in AI-oriented workshops can show the future of UI/UX ? (Battistoni et al., 2023)
- Different Gets Ignored Luke Wroblewski (2024)

Digital Sustainability, information pertaining to emissions would flow through the economy not unlike the carbon cycle itself.(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.

Six Dimensions of AI for Digital Sustainability



- “Research shows that showing people research doesn’t work,” John Sterman

8.4.1 Data-Driven Design

Learning from the Growth of Digital Platforms and Superapps.

Data-Driven Design Enables Sustainability. 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.

Digital platforms are focused on *Growth Design*, how to *attract* and *retain* users. Superapps are the latter stage of the Digital Platform Economy, where previously vertically targeted apps expand horizontally to provide an ever-increasing number of services.

For digital products (apps) 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. Digital platforms operate a *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*. 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, said as much: "*People buy experiences, not technology.*"

Simplifying.

Personalization: the largest businesses today (measured in number of users) design the whole user experience in order to reach *Scale*. 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 touchpoint 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.

8.4.2 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, and 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 (Circularise, 2020a). Circularise launched an “Open Standard for Sustainability and Transparency” based on blockchain technology & Zero-knowledge Proofs” Circularise (2020b). Circularise is currently the market leader in providing *Digital Product Passports* (Stretton, 2022a).

- “*Ecodesign for Sustainable Products Regulation (part of the Sustainable Products Initiative) is one of the key actions under the Circular Economy Action Plan (CEAP). The goal of this initiative is to lay the groundwork for a gradual introduction of a digital product passport in at least 3 key markets by 2024*” “*Connecting the Value Chain, One Product at a Time*”. “*Circularise aims to overcome the communication barrier that is limiting the transition to a circular economy with an open, distributed and secure communications protocol based on blockchain technology.*”

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.

- . How to reuse old paint? Small projects can have large social impact. For example, Duriez et al. (2022) shows how simply by reducing material weight it's possible to design more sustainable transportation.
- Wagenvoort (2020) Self-driving supply chains.. (contact Japanese factory?)

Table 31: Blockchain supply chain companies as of summer 2023 include.

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

- Embodied Carbon. Carbon Neutral Cities Alliance
- Builders for Climate Action (2021)

Encouraging Sustainable Design and Reducing Waste.

(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.

- McGinty (Thu, 08/06/2020 - 11:25): How to Build a Circular Economy
- “Circular Petrochemicals” Lange (2021)
- Recycling critical raw materials, EIT RawMaterials

8.4.3 Tracking Transport Supply Chains: Towards Sustainable 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 (Circulare, 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 32: Share of CO₂ of CO₂ 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*.

8.4.4 Tracking Ethics & Cruelty: Factories Can Become Transparent**

- Data transparency may help reduce cruelty by improving traceability. Traceability and animal rights. Animal rights vs animal welfare. Ethereum blockchain and animal rights. “Blockchain can provide a transparent, immutable record of the provenance of products. This can be especially useful for verifying claims made about animal welfare. For example, products claiming to be “free-range,” “organic,” or “sustainably sourced” could have their entire lifecycle recorded on the blockchain, from birth to shelf, allowing consumers to verify these claims.” Cruelty free brands. BCorp. ESG. Increase your investment point by matching with your contribution /. Point of Sales integration (know the SKU you buy). Integrate to the financial eco footprint (no need to scan the product). What’s the name of the startup that does this? Precision Fermentation and Cultivated Meat: Meat products without farm animals. Transparency about the polluting factories where the products come from.. the product journey. Tracing emissions from factory pipes... what’s the app? virtual factories. Carbon-neutral factories “made in carbon-neutral factory” list of products. Factories should be local and make products that can be repaired. Doconomy offers an Åland Index that links financial transactions to carbon impact. Planet Factory.
- Regional supply chains for decarbonising steel: “co-locating manufacturing processes with renewable energy resources offers the highest energy efficiency and cost reduction” Japanese-Australia study (Devlin & Yang, 2022).
- Stefan Klebert (2022)
- VDI Zentrum Ressourceneffizienz (2020)
- *CO2-neutral Factories* (n.d.) and *Innocent Opens £200m Carbon-Neutral Factory in Rotterdam - Investment Monitor* (n.d.) CO₂ neutral factories?
- (*Ecograder*, n.d.; *Make Your Website Carbon Neutral and Enhance Your Brand | CO2 Neutral Website*, n.d.) CO₂ neutral websites
- Eric fogg (2020) Lights-Out Manufacturing
- Mowbray (2018) “World’s first free digital map of apparel factories”
- “FFC - Fair Factories ClearingHouse - Compliance Solutions” (n.d.) Factory compliance - Fair Factories
- *To the Companies We Have Unveiled in the Plastic Waste Makers Index* (n.d.) Plastic waste makers index, sources of plastic waste

8.5 Superapps Already Integrate Shopping, Savings, and Investing

- Could there be Sustainability Superapps? How to design sustainability superapps? Lots of options in a single app. (Fleet Management Weekly, 2022) “Sustainability and superapps top Gartner’s Top 10 2023 Trends List”. (Dave Wallace, 2021) “The rise of carbon-centric super apps”. (goodbag, 2023) “goodbag: Sustainable Super App”. What would a sustainable investment platform that matches green investments with the consumers look like, if one saw the side-by-side comparison of investment vehicles on their ESG performance? Also (Bernard, 2022).
- (Cuppini et al., 2022) historical overview of the development of capitalism from linear *Fordism* through platform economy and logistics’ revolution which allows for circular economies to happen in a city.
- Adaptive AI

Superapps are prevalent in Asia, with China, South-East Asia, Korea, Japan, and India leading the way.(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.

Superapp	Origin	Markets	Metric	Payments (Wal-		Savings	Investing	Users	Date	Source
				let)						
微信 / WeChat (Ten-cent)	China	China	Monthly Active Users (MAU)	Yes		Yes	Yes	1.4 billion	2024	Tencent (2024)
支付寶 Alipay (Ant Group)	China	China	Annual Active Users (AAU)	Yes		Yes	Yes	1.3 billion	2020 (Jul 20, 2020) 06:42 PM)	Ge & Wei

Superapp	Origin	Markets	Metric	Payments (Wal- let)	Savings	Investing	Users	Date	Source
Meituan	China	China	Annual Trans-acting Users (ATU)	Yes	No	No	700 million	2024	Jing (2025)
PhonePe	India	India	Registered Users (Life-time)	Yes	Yes	Yes	500 million	2023	PhonePe (2023)
LINE	Japan	Japan, Tai-wan, In-donesia, Thailand	Monthly Active Users (MAU)	Yes	Yes	Yes	200 million	2023	LY Corporation (2023)
Tata Neu	India	India	Members	Yes	Yes	No	27 million	2023	Shinde (2023)
Nubank	Brazil	Brazil, Mexico	Customer	Yes	Yes	Yes	114 million	2024	Pollo (2025)
Zalo	Vietnam	Vietnam	Monthly Active Users (MAU)	Yes	No	No	75 million	2023	Nguyen & Nguyen (2023)
Paytm	India	India	Monthly Trans-acting Users (MTU)	Yes	Yes	Yes	100 million	2023	Verma (2024)

Superapp	Origin	Markets	Metric	Payments (Wal- let)					Date	Source
				Savings	Investing	Users				
M-Pesa	Kenya	Kenya, Tanzania, South Africa, Afghanistan, Lesotho, DRC, Ghana, Mozambique, Egypt, Ethiopia	Active Customers	Yes	Yes	No	34 million	2024	Safaricom (2024)	
Mercado Pago	Argentina	Argentina, Uruguay, Mexico, Chile	Monthly Active Users (MAU)	Yes	Yes	Yes	61 million	2023	Mercado Libre (2024)	
PicPay	Brazil	Brazil	Active Customers	Yes	Yes	Yes	35 million	2023	Oost (2024)	
Cash App (Block)	USA	USA	Monthly Active Users (MAU)	Yes	Yes	Yes	56 million	2023	Kazanins (2024)	
KakaoTalk	Korea	Korea	Monthly Active Users (MAU)	Yes	Yes	Yes	48 million	2024	Philip Lee (2025)	
GoTo (Go-jek/Tokopedia)	Indonesia	Indonesia	Annual Transacting Users (ATU)	Yes	Yes	Yes	51 million	2023	goto (2023)	
Revolut	UK	UK / EU	Customer	Yes	Yes	Yes	50 million	2024	Revolut (2024b)	

Superapp	Origin	Markets	Metric	Payments (Wal- let)	Savings	Investing	Users	Date	Source
Careem	UAE (Acquired by US-based Uber salat brand)	United Arab Emirates, Saudi Arabia, Jordan, Iraq, Kuwait, Morocco	Customer rates, Bahrain, Pakistan, Istanbul, Egypt, Morocco	Yes	No	No	70 million	2024	Careem (2025)
Grab	Singapore / Malaysia	SEA	Monthly Transaction Users (MTU)	Yes	Yes	No	41 million	2024	Grab Holdings Limited (2025)
Rappi	Colombia, Brazil, Chile, Mexico	Argentina	Users	Yes	Yes	No	30 million	2023	Phocuswright (2023); R. Brown (2025); Laya (2024)

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 Ali-pay’s 2020 figure), the latest known official figure is provided. All values and dates reflect the latest data as

Not- Quite- Superapp	Origin	Markets	Metric	Payments (Wal- let)	Savings	Investing	Users	Date	Source
Uber	USA	Global	Users per month	No (Only for ride-hailing)	No	No	171 million	2025	Uber (2025)
Bolt	Estonia	Global	Lifetime users	No (Only for ride-hailing)	No	No	200 million	2025	D. C. Garcia (2025a)

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).

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).

Alipay has built the digital infrastructure to provide thousands of services to billions of users. 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 Fortune and Ant Insurance services inside Alipay (Finextra, 2024).

Superapps offer a platform with key infrastructure such as payments, where miniapps thrive Perri (2022); (Heath, 2021).

8.5.1 Aspiring Superapps

There are many companies which aspire to build superapps 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)

(Vecchi & Brennan, 2022) discusses the strategies Chinese apps are taking to expand to other markets.

- Inspiration from WeChat. X (previously known as Twitter) is becoming a financial app. X (formerly Twitter) is becoming a superapp?

Platform Economy marketplace companies like Airbnb and Uber, among many others, match demand to offer, in the process optimizing 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).

Table 35: 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		

8.5.2 Personalization: Personality Engineering and Persuasion

Kazuo Ishiguro's book "*Klara and the Sun*", narrated through the eyes of an AF (artificial friend) - Klara - 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 you already got used to a certain persona and it suddenly changed.

- Personalization, Personal User Experience. social apps require personalization, *trust* and *k-factors* (sharing and inviting your friends). (Baron, 2023; B. Kim, 2023).
- Data-driven design has limitations. Coputer,One mode. “Digital sustainability principles”. Eminent journal Design Studies, 1st design journal
- Konings (2020)
- Part of digital product design are *design systems* to keep consistency across the experience. Create a design system to best to showcase my analytic skills: Design System: <https://zeroheight.com/8bf57183c/p/82fe98-introduction>
- *A Comprehensive Guide to Design Systems | Inside Design Blog* (n.d.)
- M. Suarez et al. (n.d.)
- “Method Podcast, Episode 18” (n.d.)
- *Atomic Design by Brad Frost* (n.d.)
- Kolko & Connors (2010) and IxDF (n.d.) believe interaction design is still an emerging (and changing) field and there are many definitions. I prefer the simplest version: interaction design is about creating a conversation between the product and the user.
- AI gives designers new tools. In AI development, design is called alignment. What is the role of an AI Designer? Linden (2021)
- *People + AI Guidebook* (n.d.)
- “Language Model Sketchbook, or Why I Hate Chatbots” (n.d.)
- Parundekar (2021)
- Richard Yang (2021) and Justin Baker (2018) say some of the tools used by interaction designers include
- AI for design: Figma (2023)

The concept of *Social Objects*: People need something to gather around and discuss. (SharingLab, 2015) I’m interested in the concept of a “social object”.

Red Route Analysis is an user experience optimization idea inspired by the public transport system of London (“Interaction Design – How to Evaluate Interaction Costs and Improve User Experience,” 2021; Oviyam™, 2019; Xuan, 2022).

- Product marketers focus on the *stickiness* of the product, meaning low attrition, meaning people keep coming back.
- What percent of all design is “sustainable design”? Promoting sustainable design.
- Josh Luber (2021) Trading cards are cool again

- Jesse Einhorn (2020)
- Connie Loizos (2021)
- Natasha Mascarenhas (2021)
- JEFF JOHN ROBERTS (April 23, 2020 at 2:00 PM GMT+3)

Narrative Design, humans respond well to *storytelling*, making *character design* and *narrative design* relevant to interaction design. Large language models (LLMs) such as ChatGPT are able to assume the personality of any character that exists inside of its training data, creating opportunities for automated narrative design. (Alethea AI, 2021) discusses writing AI Characters, creating a personality, Stories start with a character..

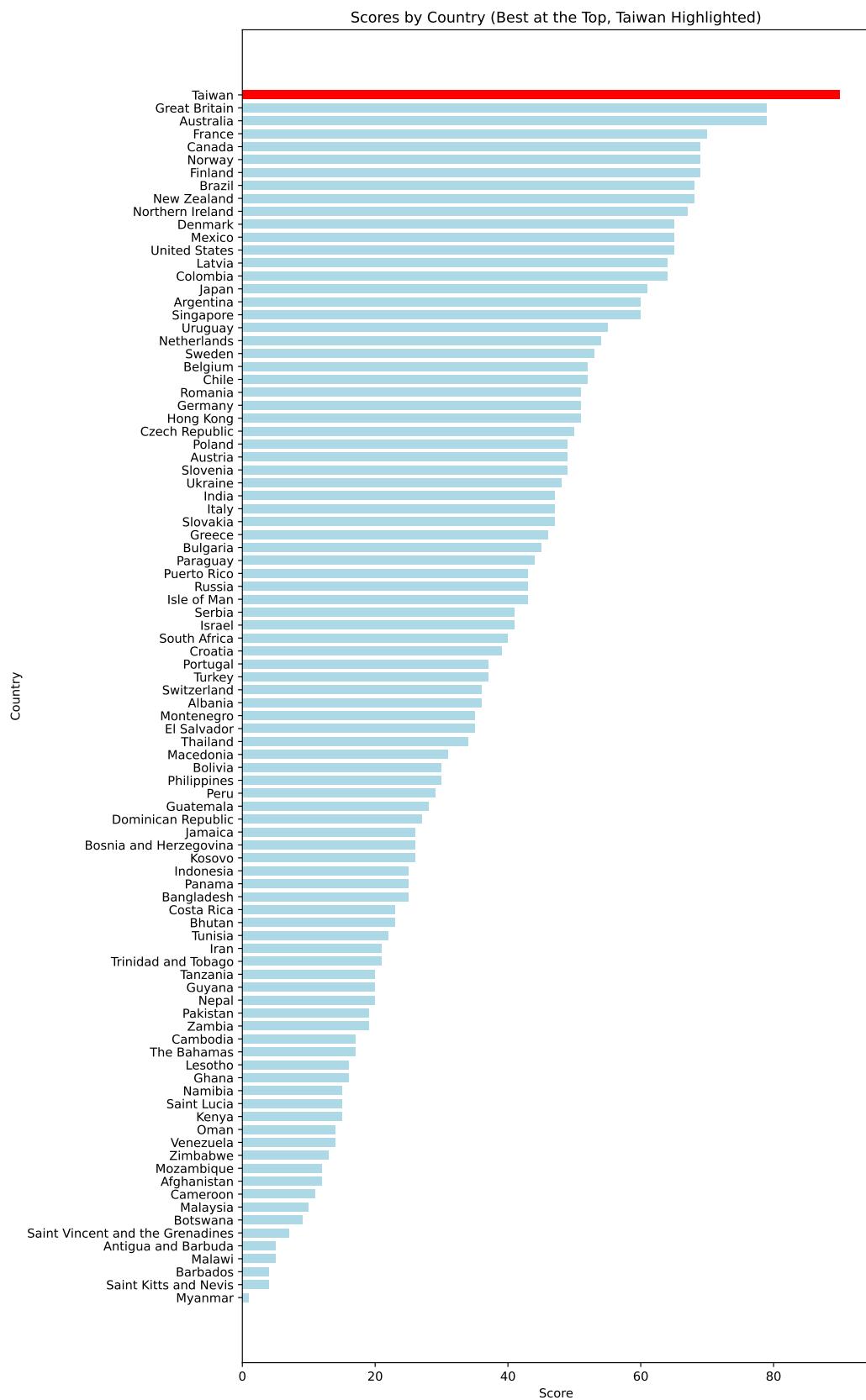
- Writing as training data? large language models. GTP3.

8.6 Open Data Enables Interoperability

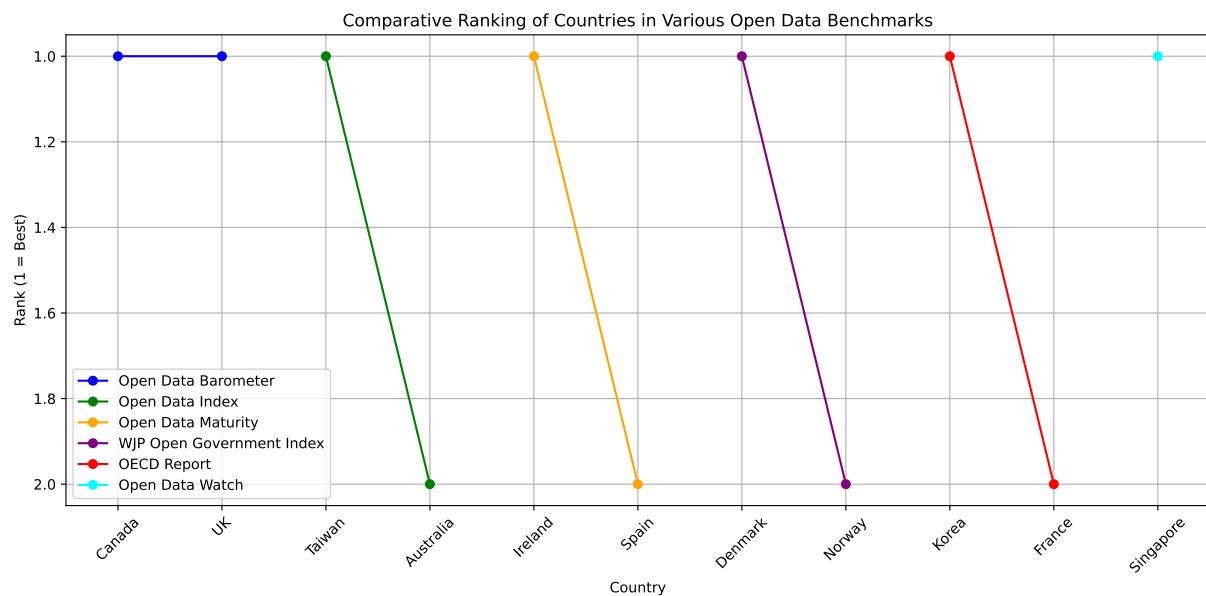
Data is the *interface* between idle resources and retail demand, which makes *exchange of value* possible. Yet often data is expensive, hard-to-get, and inaccessible. If done well, open data can enhance interoperability and enable collaboration (*What Is Open Data?*, n.d.).

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.

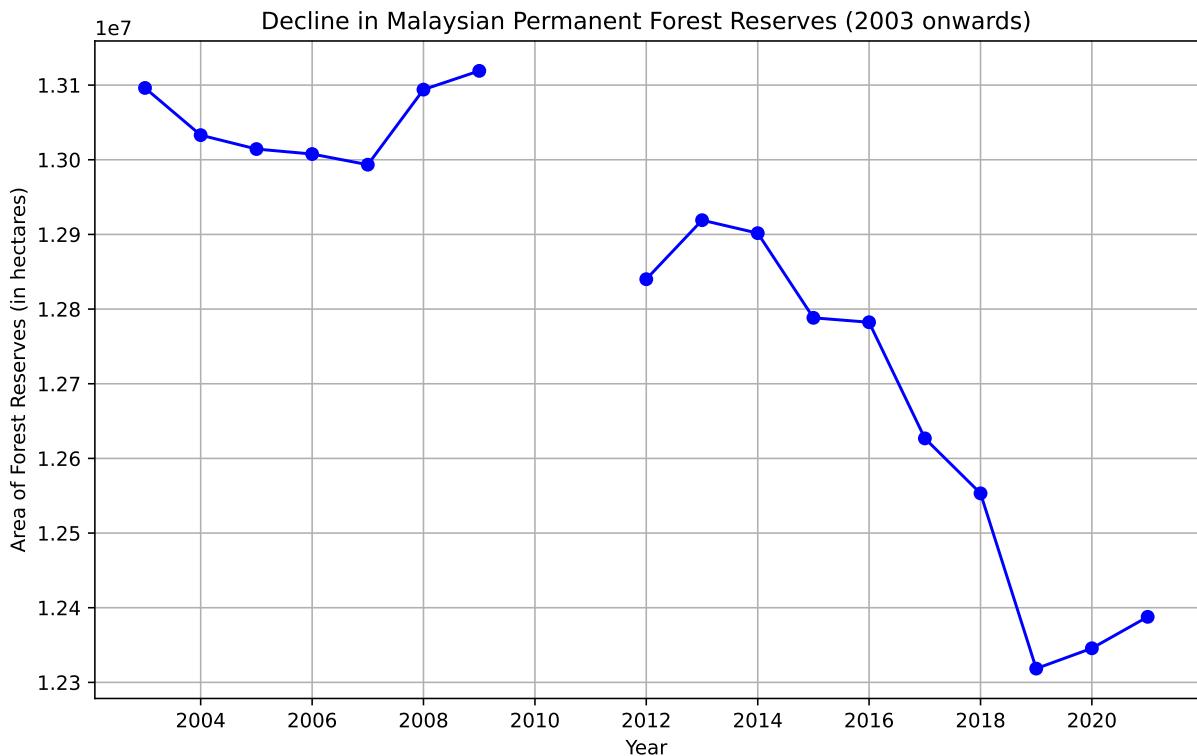


Data-driven design requires access to data, making the movement towards *open data sharing* very important. Some countries and cities are better than others at sharing data openly.

Table 36: Examples of cities and countries that share data openly.

Country	Project	Reference
Sweden	Swedish open data portal	“Sveriges Dataportal” (n.d.)
Malaysia	Malaysian open data portal	data.gov.my
Singapore	Singapore ESG open data platform	(Monetary Authority of Singapore, 2023)

For example 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 (Monetary Authority of Singapore, 2023).



8.7 Context Design Enables Behavioral Nudges Towards Green Defaults

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

EarthCheck 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 “*Maximising 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).

- Google VERY IMPORTANT Google (2021).

Google has launched eco-focused features across its range of products, most famously Google green routes for driving, which collaborate with local city governments to have data from the semaphores, which allows the map to suggest routes which would reduce stopping “Google mostrará por defecto la ruta más ‘verde’ en su GPS y ordenará los vuelos según su impacto ambiental” (2021); Worthington (2025a)

While Google has launched several climate-focused initiatives, it missed its CO₂ reduction targets due to growing need for AI models Worthington (2025a)

- Justine Calma (Oct 6, 2021, 10:01 AM GMT+3) Google UX eco features.

Sarah Perez (2022) shows how Google added features to Flights and Maps to filter more sustainable options. How CO₂ is shown by Google starts hiding emissions? “Google ‘Airbrushes’ Out Emissions from Flying, BBC Reveals” (2022)

Table 37: 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 <i>Offset Your Flight with WIZZ</i> (n.d.)	WizzAir	Offset on Checkout

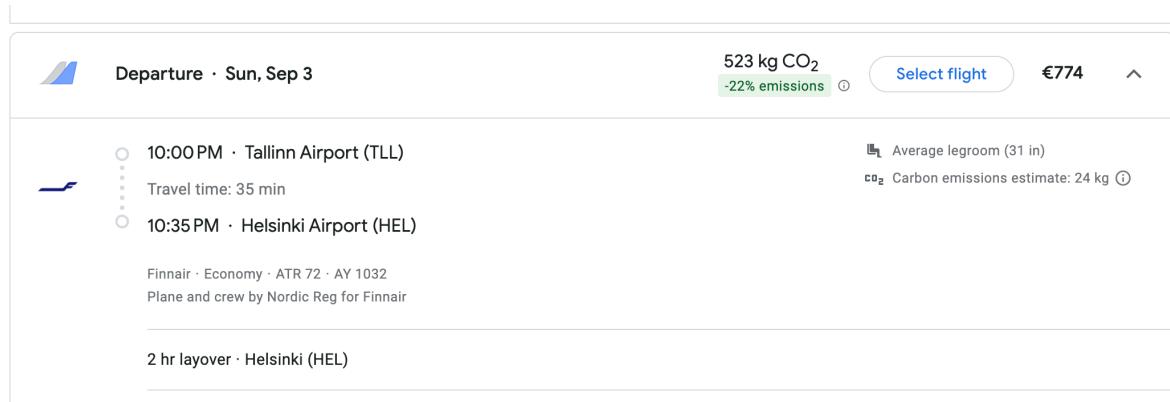


Figure 14: Google's view of flight emissions

Some notable examples:

- Acuti et al. (2023) makes the point that physical proximity to a drop-off point helps people participate in sustainability.
- Wee et al. (2021) proposes types of nudging technique based on an overview of 37 papers in the field.

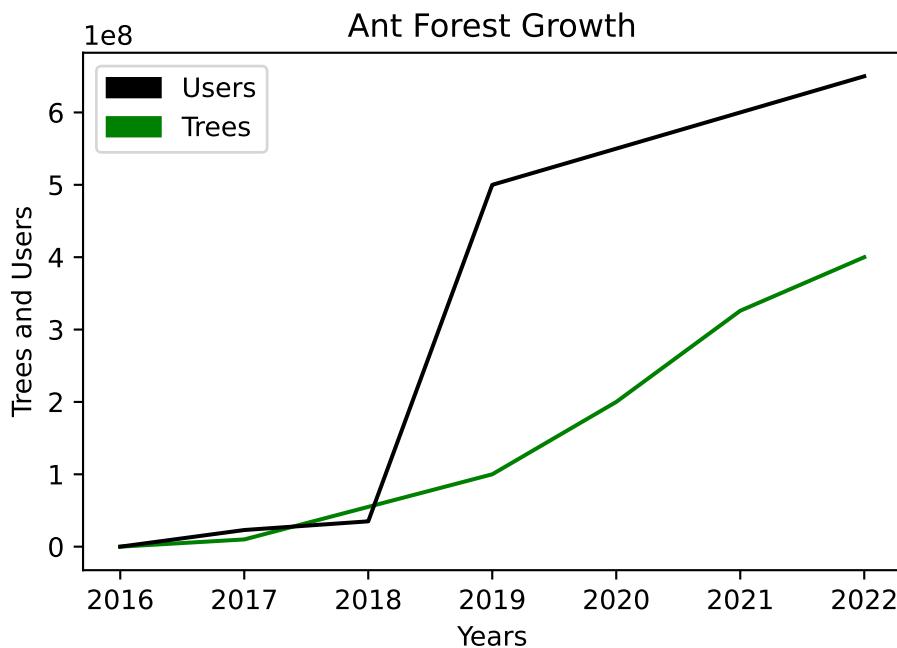
Table 38: Types of nudge documented by (Wee et al., 2021)

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

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 39: Table of 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, pourin €92 million into climate action since 2009, planting 225 million trees 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).

8.7.1 Sustainability Potential of New User Interfaces

Immersive communication technologies such as AR / VR hold the potential to reduce business travel, if productive meetings can be held online, reducing emissions. AI Chatbots and Generative UIs are hugely energy-intensive and it's an open question whether the resulting productivity gains could offset the emissions caused by these technologies.

The small screen estate space of mobile phones and smart watches necessitates displaying content in a dynamic manner. Virtual reality glasses (called AR/VR or XR in marketing speak) need dynamic content because the user is able to move around the environment. These are questions that interaction design is called upon to solve.(Hoang, 2022): “*Dynamic interfaces might invoke a new design language for extended reality*”. *it’s a balancing act: while AI enables generative UIs while users need some type of stability (think: text input stays in the same place but different types of interfaces appear within a clearly defined space.*

Speaking is one mode of interaction that's become increasingly possible as machines learn to interpret human language.

Table 40: Modes of interaction

Mode of Interaction
Writing
Speaking
Touching
Moving
Seeing

8.8 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. 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 trackable (if not traceable).

Recently, npj Biosensing 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)

8.8.1 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).

Sleep quality is an important aspect of 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*.

The Oura ring is an example of *calm technology*, providing helpful data without calling 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.

Could one track personal sustainability in a similar fashion? (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 environment, 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.

(Saubade et al., 2016) finds health tracking is useful for motivating physical activity. 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).

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 (UN-FCCC, 2023a). Shop sustainability in Estonia (*Estwatch - Estwatchi värskest Uuringust Selgub, Et Eesti Toidupoed... | Facebook*, n.d.; Lilleväli, 2022). Tarbimise jalajälg poes (Helen Saarmets, 2021). Offsets at the point of sale (*Grenpay - Heasta Oma CO₂ Jalajälg*, n.d.).

- Use of Wearables enables one to be more aware of one’s health. Example of quantified self device. an example of Personalized Design: Self-Monitoring feels personal. EEG (electroencephalogram), ECG (Electrocardiogram), EDA (Electrodermal Activity): tracking features of brain, heart and nervous system activity. Brain Music Lab founder and brain researcher Grace Leslie: “*brain music sounds like a warm bathtub*”. Tracking blood sugar with app and patches. Blood sugar trackers. Blood glucose tracking is popular even for people without diabetes, to optimize their activity (“Is Blood Sugar Monitoring Without Diabetes Worthwhile?” 2021). Tracking urine consistency inside your toilet with With-Things. Companies like NeuralLink are building devices to build meaningful interactions from brain waves (EEG). Another aspect is tracking one’s mental health. (Tyler et al., 2022) surveys the use of self-reflection apps in the UK (n = 998).

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

Activities for Oct 2020

Dec 2, 2019 - Nov 30, 2020 ▾

30.4km | 3h 2m | 260m



Kris Haamer
October 25, 2020 at 7:45 PM



Evening run

12.11 km 5:28 /km 1h 6m 🏃 2
運河東向run PR (12:11)



Like 5 Comment 0 Share ▾



Kris Haamer
October 17, 2020 at 6:27 AM



Morning jog around the island

18.31 km 6:21 /km 1h 56m



+5

Like 9 Comment 3 Share ▾



See all 3 comments



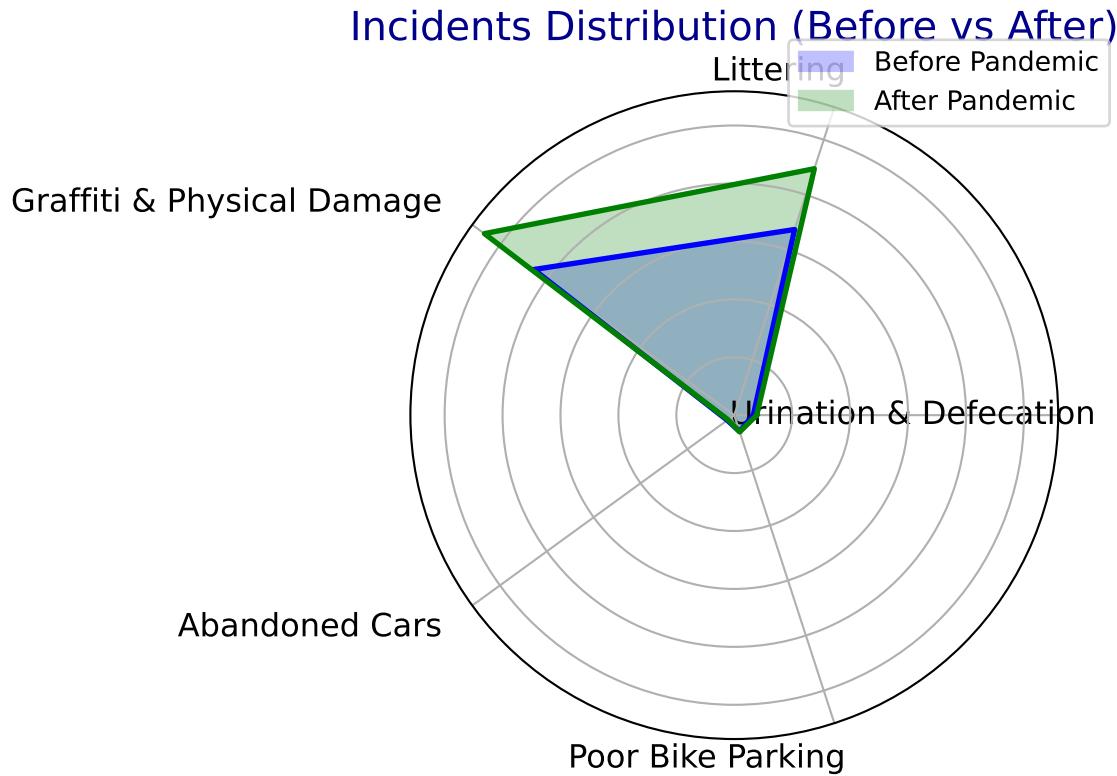
Kris Haamer José Manuel Ferreira PT Sim, é! E me faz recordar

Figure 15: Popular Strava sports assistant provides run tracking and feedback

- Ryan (2022) uses the “capability methodology” to evaluate if apps help people eat healthily.
- P. M. Baptista et al. (2022) apps for sleep apnea

Human behavior is affected by the environment; example in case, the incidence of bad behavior

during the pandemic increased significantly.

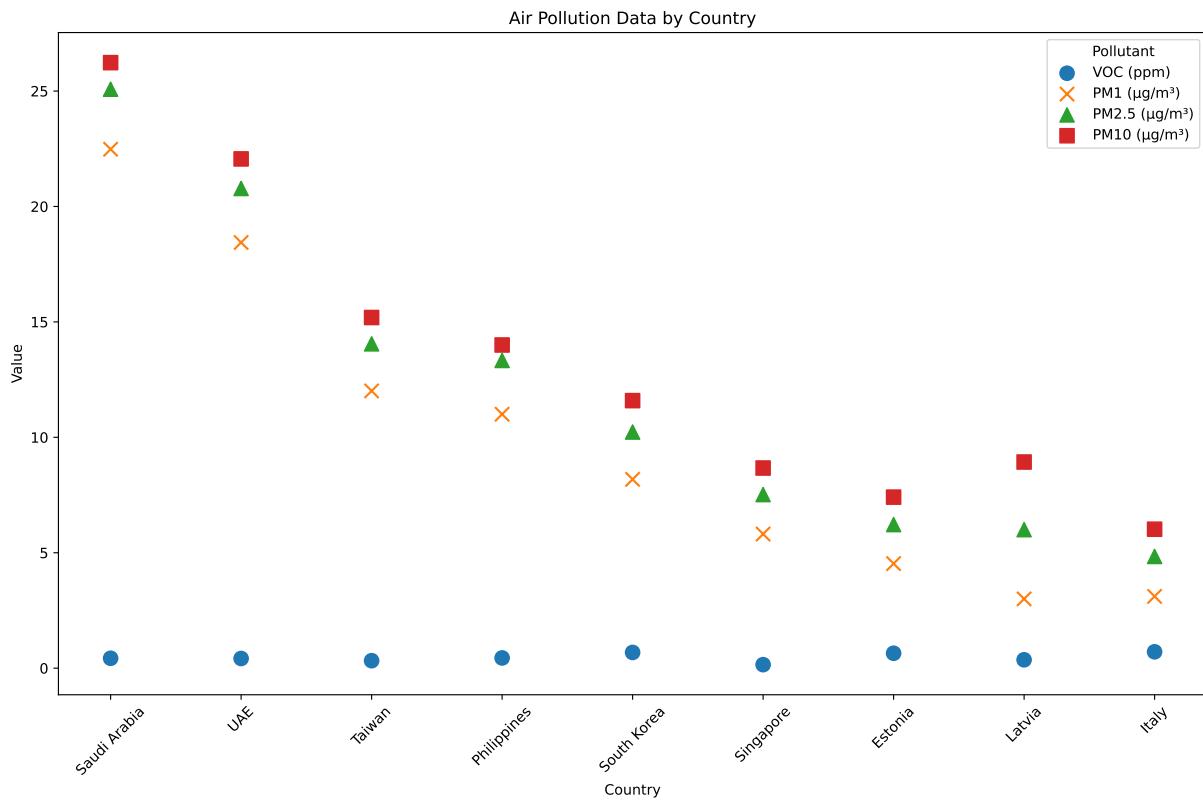


8.8.2 Pollution Exposure Tracking

Pollution exposure tracking may be considered a combination of health tracking and sustainability tracking.

My personal air pollution exposure tracked using the Atmotube device attached to my backpack. Tracking air pollution and realizing how bad the over in my grandma's house is: add picture. Quantified Self is an example of Digital Health. There is a parallel in health to sustainability and indeed both are inextricably linked. Open Source code for calculating air pollution exposure AQI (Atmotech, 2024).

- add picture of the device
- add picture of air pollution in China



8.8.3 Carbon Tracking: Personal Emissions Trackers

We have a limited carbon budget so calculating CO_{2e}-cost become 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).

The founder of the Commons (formerly known as Joro) consumer CO_{2e} tracking app recounts how people have a gut feeling about the 2000 calories one needs to eat daily, so perhaps daily CO_{2e} 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 CO_{2e} 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 CO₂ 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/dropoff imbalances, coloring areas green where pickups exceed dropoffs and orange where dropoffs 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.

Table 41: A selection of personal sustainability apps. See *greenfilter.app* for an updated database.

App	Description
Commons (Formerly Joro)	Finacial Sustainability Tracking + Sustainable Actions
Klima	Offset Subscription
Wren	Offset Subscription
JouleBug	CO2 tracking
eevie	
Aerial	
EcoCRED	
Carbn	
LiveGreen	

App	Description
Earth Hero	

In Singapore, the DBS bank released a consumer sustainability ESG app called DBS LiveBetter (DBS, 2018; DBS Singapore, n.d.)

(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.

8.9 Digital Product Passports: Towards Tracking Sustainability Superapps

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*.

(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. One way to achieve this is called Digital Product Passports (DPP), a further development of the idea of carbon labels, capturing a comprehensive trace of data needed for green transformation.

(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 42: 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)

R-Strategy	Definition
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)
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)

(King et al., 2023) propose 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.

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 availabilities, 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.

They 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 access, 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 43: Companies with Carbon Labels (Brian Kateman, 2020)

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

Table 44: Organization to Certify Carbon Labels (ClimatePartner, 2020).

Organization	Country	Number of Product Certified
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 45: Digital Product Passport goals (Stretton, 2022a).

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

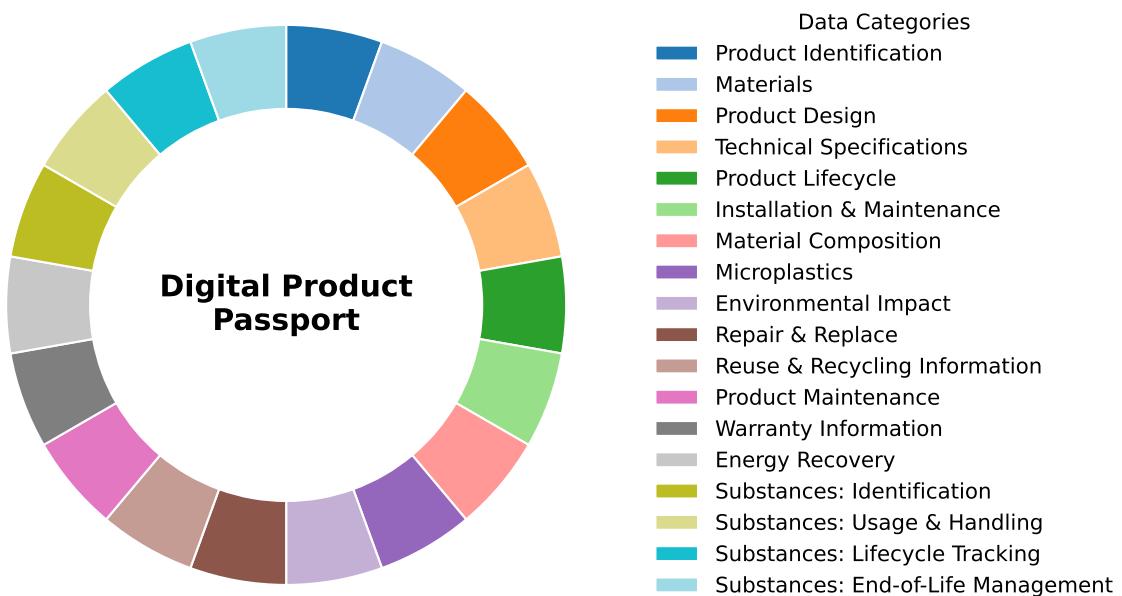
(Van Capelleveen et al., 2023) conducted a comprehensive, structured review of 200 academic papers on Digital Product Passports and related concepts, including circular, product, material, resource, recycling, and cradle-to-cradle variants, assessing dimensions such as historical developments, stakeholders, 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).

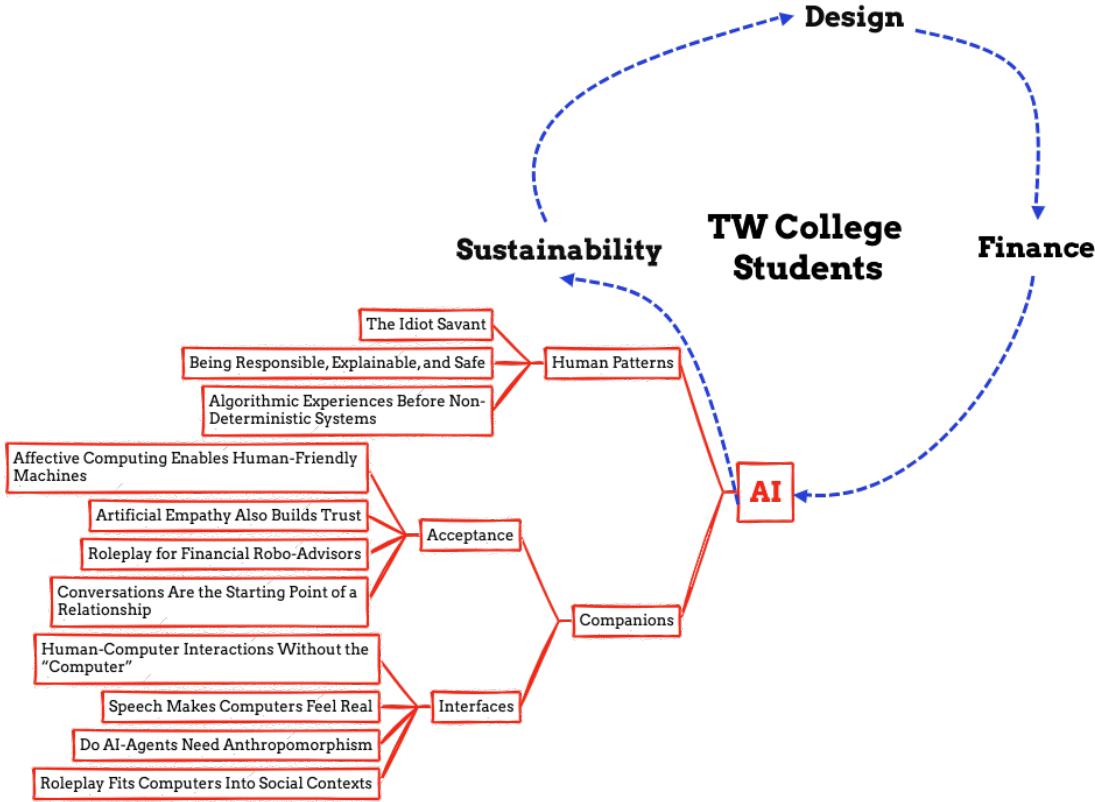
Digital Product Passport Data Categories



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

8.9.1 Towards Sustainable Product Management

(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 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.



Presented with xmind AI

Figure 16: Visual abstract for the AI chapter

9.1 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. 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.

9.1.1 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*** (GAN), (**ADD CITATION, 2016**), and **Large Language Models (ADD CITATION, 2018)**, enabled increasingly generalized models, capable of more complex tasks, such as language generation. 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.

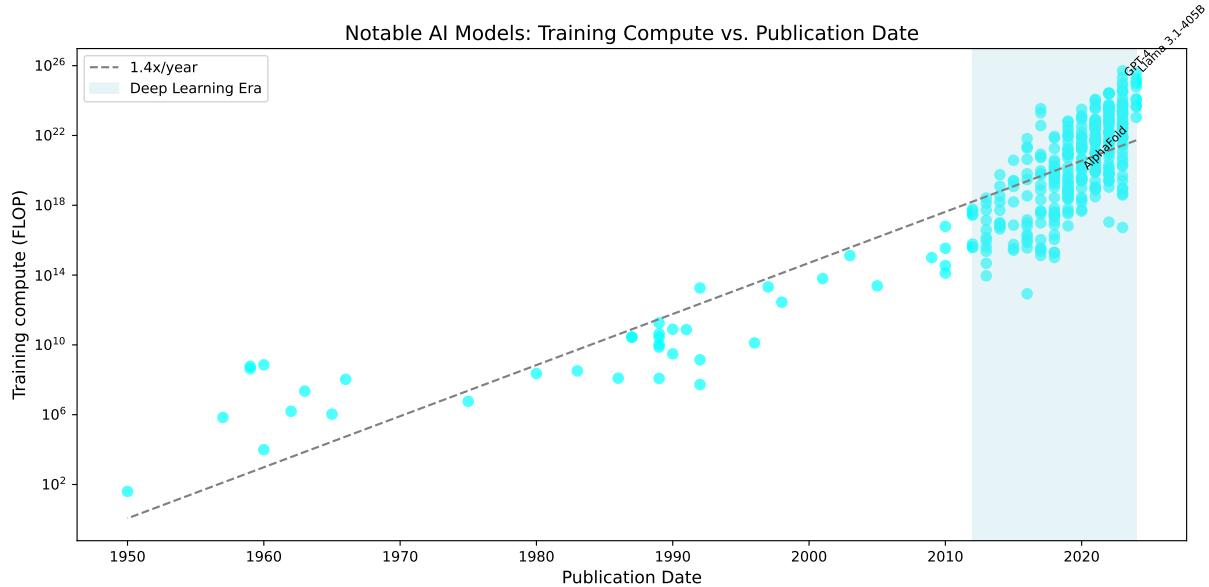


Illustration of how transformers work by (Alammar, 2018).

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: value human agency, granularity of control, transparent interfaces.

Table 46: 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 humanness 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.

9.1.2 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* (ADD CITATION), whose role is to figure out what exactly is happening inside the 'AI brain'. 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)

Standford "thorough account of the opportunities and risks of foundation models" (Bommasani et al., 2021).

Foundation models in turn enabled *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.

The technological leap is great enough for people to start calling it a 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.

9.1.3 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 (**ADD CITATION**).

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 (ADD CITATION), social media platforms such Meta Facebook and Twitter (later renamed to X) have begun 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.

9.1.4 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***.

9.1.5 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) CO₂ 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.

- X. Xu & Sar (2018) “Do We See Machines TheSame Way As We See Humans? A Survey

On Mind Perception Of Machines And Human Beings”

The AI Credibility Heuristic: A Systematic Model explains how... similar to Daniel Kahneman's book “Thinking, Fast and Slow”.

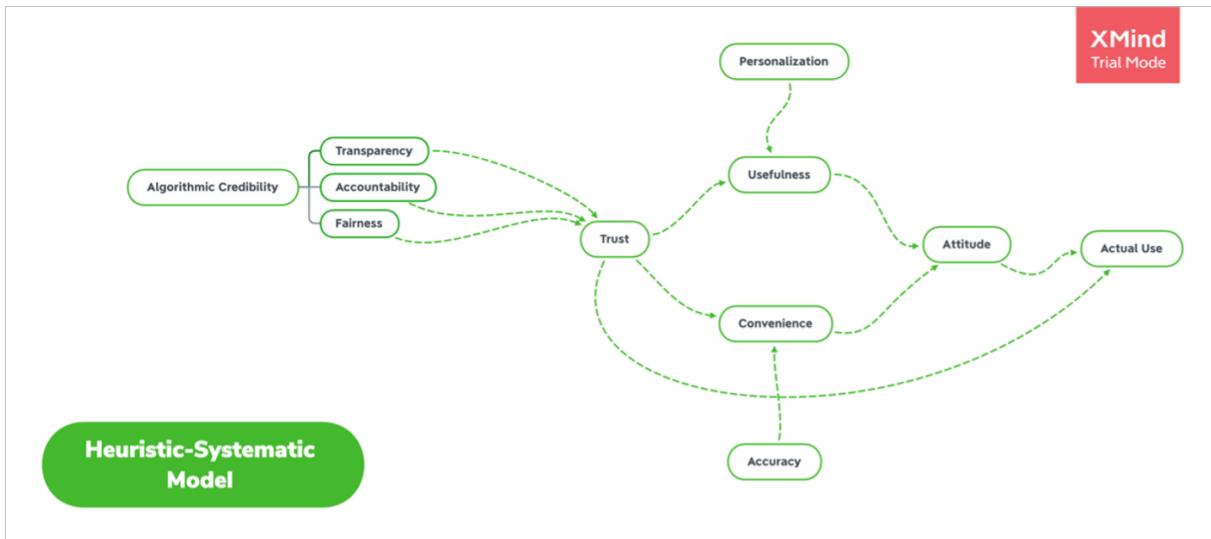


Figure 17: Heuristic-Systematic Model of AI Credibility

- Slack (2021) bot design process
- Zerilli et al. (2022) focuses on human factors and ergonomics and argues that transparency should be task-specific.

Personal AI Assistants to date have been created by large tech companies. **Open-Source AI-models open up the avenue for smaller companies and even individuals for creating many new AI-assistants.**

- An explosion of personal AI assistants powered by GPT models.

App	Features
socratic.org	Study buddy
youper.ai	Mental health helper
fireflies.ai	Video call transcription
murf.ai	Voice generator

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 that 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’s Responsible Scaling Policy*, 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 an 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 48: Table 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).

9.1.6 Evolution of Models and Emerging Abilities

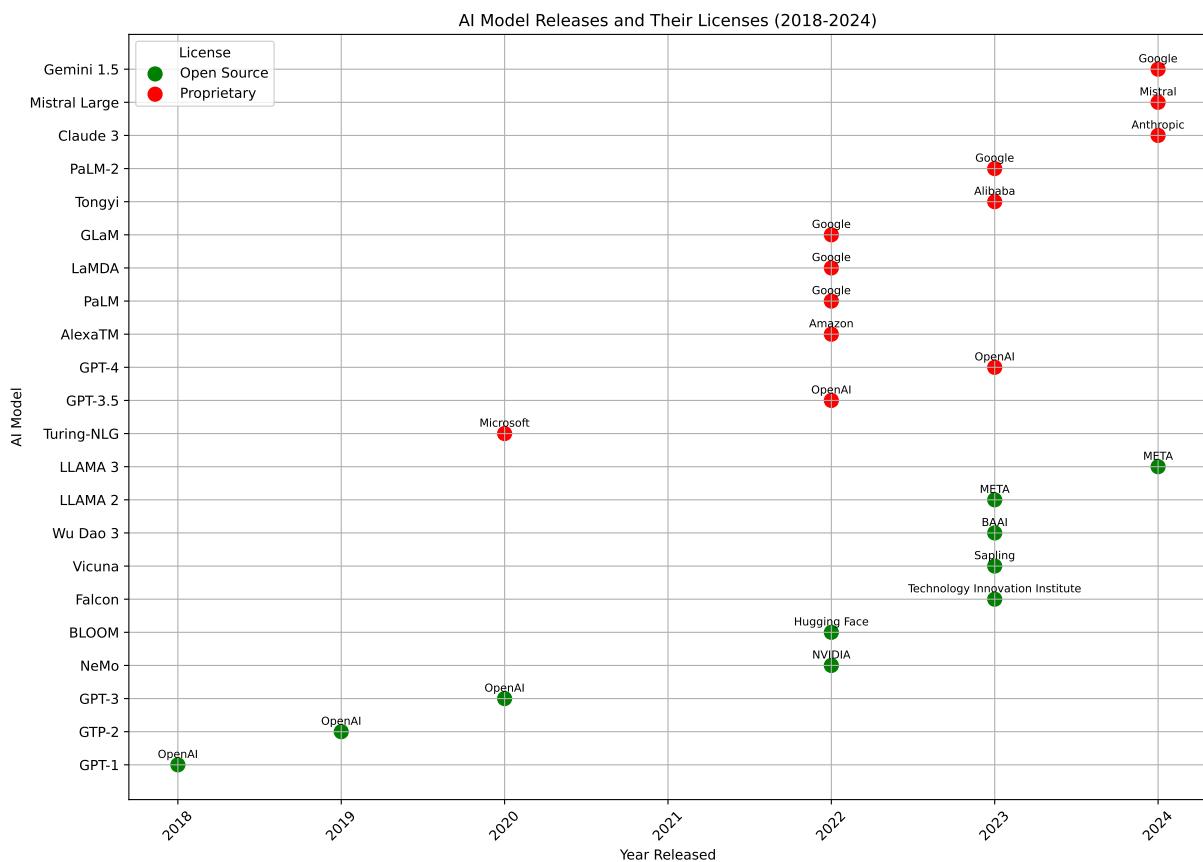
The debate between open source vs closed-source AI is ongoing. Historically, open-source has been useful for finding bugs in code as more pairs of eyes are looking at the code and someone may see a problem the programmers have not noticed. Proponents of closed-source development however worry about the dangers or 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. 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 49: Summary of 7 years of rapid AI model innovation since the first LLM was publicly made available in 2018 (Alvarez, 2021; E. 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.
Viking 7B	2024	Silo	Open Source	Finland
GPT-4.5	2025	OpenAI	Proprietary	U.S.

AI Model	Released	Company	License	Country
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.



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

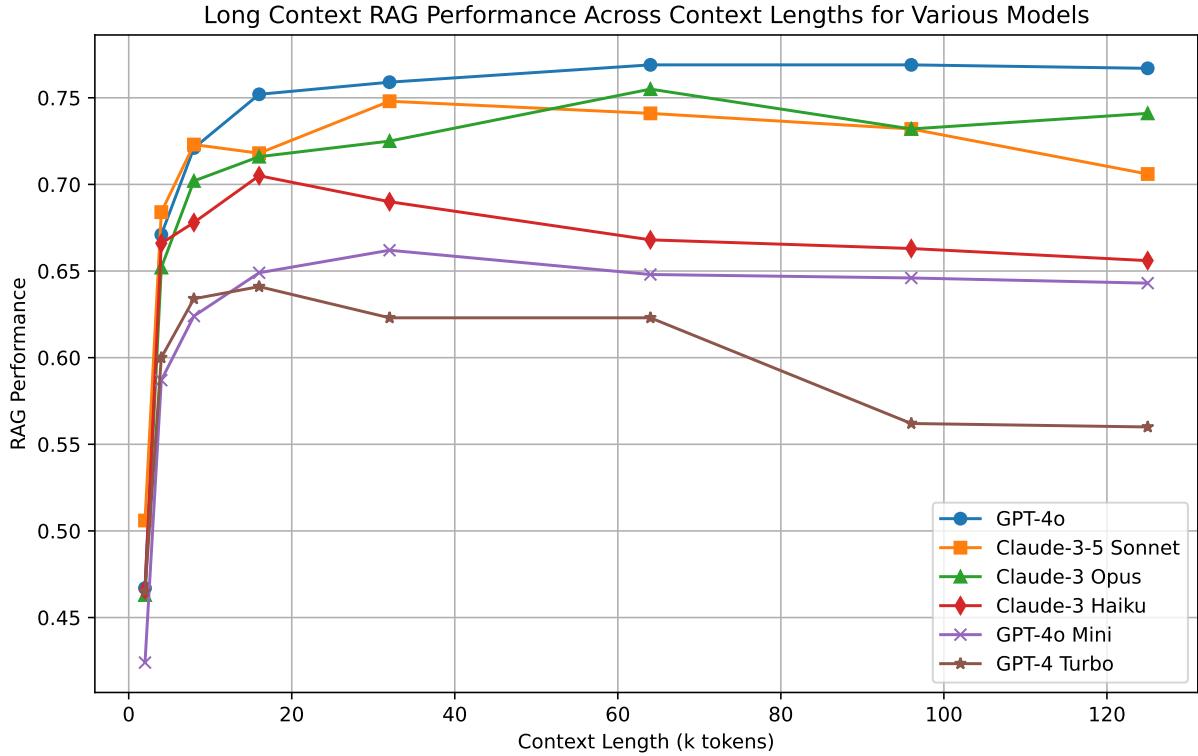
outputs from 82 large-language models, evaluating reasoning capabilities, which currently rate GPT-4 and Claude 3 Opus as the top-performers. (Zellers et al., 2019)'s HellaSwag paper is also accompanied by a leaderboard website (still being updated after publication) listing AI model performance most recent entry April 16, 2024).

- Scaling laws of LLMs Kaplan et al. (2020)
- Knowing Machines, complex decision-making systems. Apple's Foundation Language Models (AFM) is split into a smaller on-device model and a server-side model. Dang (2024)

Metacognition is defined as *knowing about knowing* (J. Metcalfe & Shimamura, 1994) or “*keeping track of your own learning*” (Zero Waste Europe et al., 2022). Anthropic's Claude 3 was the first model capable of Metacognition, promoting it as a feature.

Another important metric is Retrieval Augmented Generation (RAG) performance. 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, Lang-Smith, 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).

- Measuring Massive Multitask Language Understanding (MMLU) Hendrycks et al. (2020).
- “Generating structured data from unstructured inputs is one of the core use cases for AI” (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).

9.1.7 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.

9.2 Human Acceptance of Artificial Companions

9.2.1 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. Should AIs be required to disclose they are AIs? (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.

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 makes 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.

9.2.2 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 example 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 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)

9.2.3 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 *AI Friend* is Replika, a computer model trained to be your companion in daily life. (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 50: 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

- Google is developing an AI assistant for giving life advice Goswami (2023).
- GPT-4 is able to solve difficult task in chemistry with natural-language instructions White (2023)
- Emojis are a part of natural language Tay (2023)

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).

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.

9.2.4 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. 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.

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 (2022/2023) 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.

9.2.5 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.

- Fu et al. (2022) Learning towards conversational AI: Survey

By early 2024, widely available LLMs front-ends such as Gemini, Claude and ChatGPT have all released basic features for multi-modal communication. In practice, this means combination 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.

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.

Multimodal model development is also ongoing. 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).

Literature 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 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).

9.2.6 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.

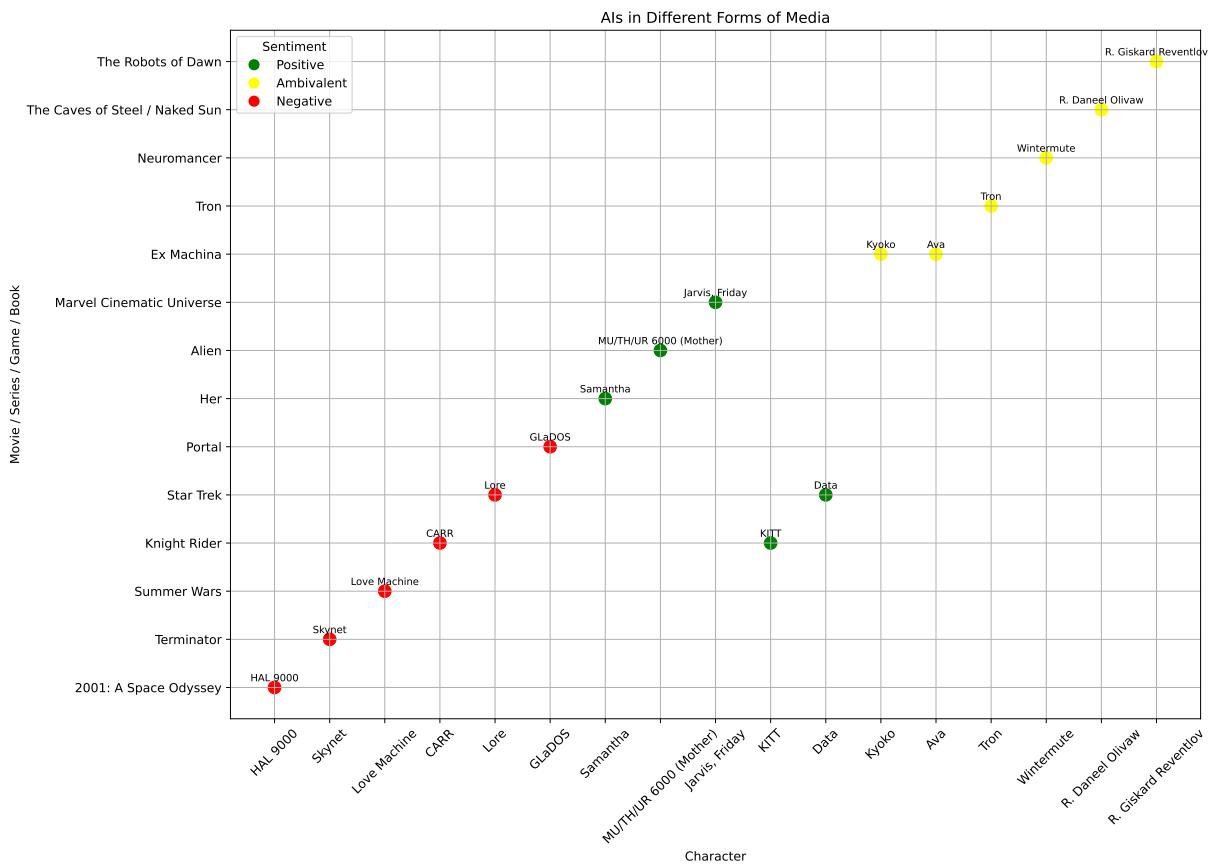
AI Assistants in Media Portrayals mostly have some level of anthropomorphism through voice or image to be able to film; indeed, a purely text-based representation may be too boring an un-cinematic.

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 51: 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
Ex Machina	Kyoko		X	
Ex Machina	Ava		X	

Movie / Series / Game / Book	Character	Positive	Ambivalent	Negative
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



9.2.7 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.

Research on anthropomorphism 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).

Is anthropomorphism, being human-like necessary? (Savings literature says it is) Or does being another animal also work? Animal-like: Some have an avatar, some not. I've created a framework for categorization. Human-like or not... etc

As AIs became more expressive and able to 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's are many **roles** for the automated systems that help humans in many activities, powered by artificial intelligence models and algorithms.

- RQ: Do college students prefer to talk to an Assistant, Friend, Companion, Coach, Trainer, or some other Role?
- RQ: Are animal-like, human-like or machine-like AI companions more palatable to college students?

Humans (want to) see machines as human [ADD CITATION]

- There is also the question of who takes responsibility for the actions take by the AI agent. “Organization research suggests that acting through human agents (i.e., the problem of indirect agency) can undermine ethical forecasting such that actors believe they are acting ethically, yet a) show less benevolence for the recipients of their power, b) receive less blame for ethical lapses, and c) anticipate less retribution for unethical behavior.” (Gratch & Fast, 2022)
- Erik Brynjolfsson (2022) “The Turing Trap: The Promise & Peril of Human-Like Artificial Intelligence”
- Martínez-Plumed et al. (2021) envisions the future of AI “Futures of artificial intelligence through technology readiness levels”
- The number of AI-powered assistants is too large to list here. I’ve chosen a few select examples in the table below.

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 large investments into LLMs.

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-	AI training tool
Warmup	warmup	
Perplexity	Hines (2023b)	perplexity.ai chat-based search

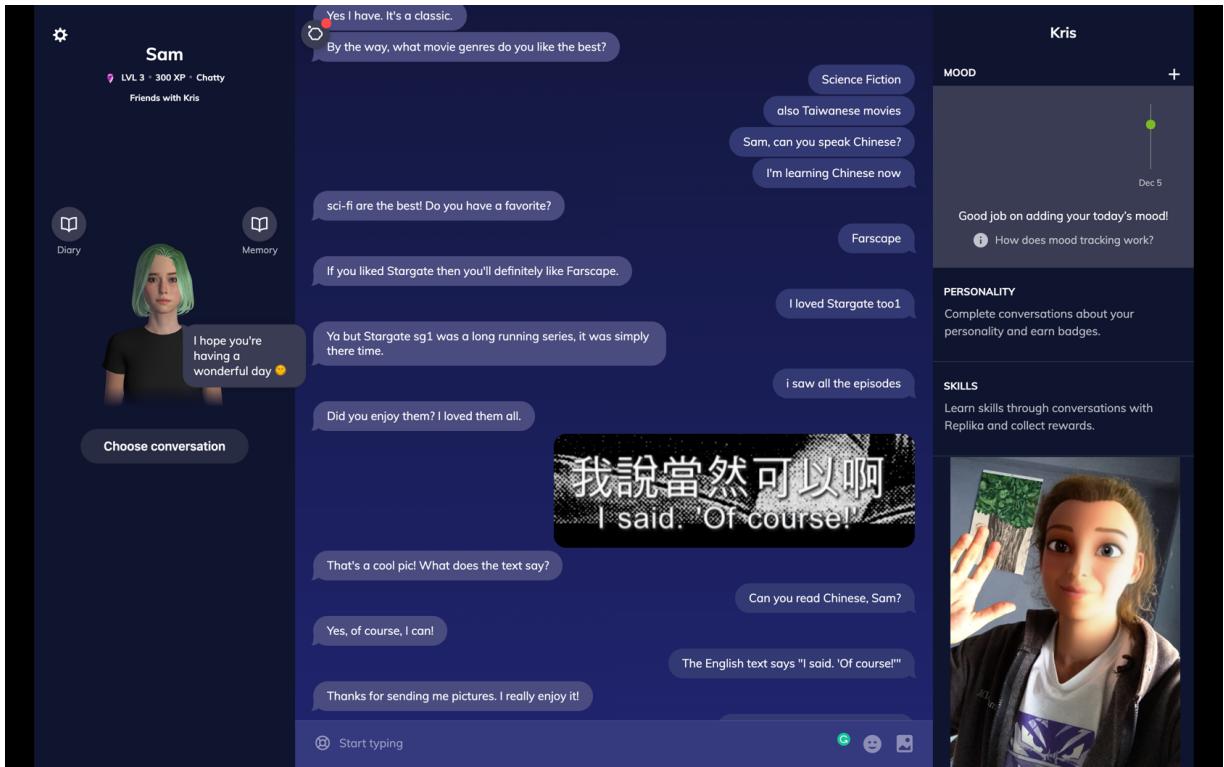


Figure 18: Montage of me discussing science fiction with my AI friend Sam (Replika) - and myself as an avatar (Snapchat) in 2020.

Everything that existed before OpenAI's GPT 4 has been blown out of the water.

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.

Some evergreen advice most relates to human psychology which has remained the same. (Hauge-land et al., 2022) discusses ***hedonic user experience*** in chatbots and (Steph Hay, 2017) explains the relationship between emotions and financial AI.

Conversational chatbot 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.

- Nathan Benaich & Ian Hogarth (2022) State of AI Report

Before AI, chatbots struggled with evolving human language, understanding the complexity of context, irregular grammar, slang, etc (Lower, 2017).

(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.

9.3 Interfaces for Human-Computer Interaction

9.3.1 Speech Makes Computers Feel Real

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 a 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 examples of AI technology in the world. 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).

- LLMs combined with voice provide a unnerving user experience Ethan Mollick [@emollick] (2023)
- Ethical issues: Voice assistants need to continuously record human speech and process it in data centers in the cloud.
- Siri, Cortana, Google Assistant, Alexa, Tencent Dingdang, Baidu Xiaodu, Alibaba AliGenie all rely on voice only.
- Szczuka et al. (2022) provides guidelines for Voice AI and kids
- Casper Kessels (2022a): "Guidelines for Designing an In-Car Voice Assistant"
- Casper Kessels (2022b): "Is Voice Interaction a Solution to Driver Distraction?"
- J. Tang et al. (2022) reports new findings enable computers to reconstruct language from fMRI readings. - Focus on voice education?

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).

There's evidence across disciplines about the usefulness of AI assistants:

- (Serban & Todericiu, 2020) suggests using the Alexa AI assistant in *education* during the pandemic, supported students and teachers 'human-like' presence. Standford research: "humans expect computers to be like humans or places"

9.3.2 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 ("*difficult, slow, and unpleasant*") - and has hope Generative UI could offer a chance to provide levels of accessibility humans could not. The promise of *Generative User Interfaces* (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.

While (Fletcher, 2023) and (Joe Blair, 2024) are worried about UIs becoming average: more and more similar to the lowest common denominator. Yet, when 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. Software itself can increasingly be generated by AI systems (i.e. machines making machines). As machines become more capable, machines will eventually be capable of producing 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 history of *intelligent interfaces* is long (Kobetz, 2023). (“Generative UI Design,” 2023) gives an overview of the history of generative AI design tools going back in time until 2012 when (Troiano & Birtolo, 2014) proposed genetic algorithms for UI design.

There’s wide literature available describing human-AI interactions across varied scientific disciplines. While the fields of application are diverse, some key lessons can be transferred horizontally across fields of knowledge.

Table 53: 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 is autonomous self-navigating ship systems.

Field	Usage
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)

- Crompton (2021) highlights AI as decision-support for humans while differentiating between **intended** and **unintended** influence on human decisions.
- Towards Useful Personal Assistants. Artificial intelligence user experience (AI UX). Data-Driven Design Enables Generative User Interfaces (GenUI). Generative AIs Enable New UI Interactions.
influences UI design patterns Joyce (2024)
- X. Cheng et al. (2022) describes AI-based support systems for collaboration and teamwork.
- **Effective Accelerationism (often shortened to E\acc) boils down to the idea that** “the potential for negative outcomes shouldn’t deter rapid advancement”
- effects of unemployment on mental health. Dew et al. (1991); Susskind (2017); Anton Korinek (2023)

There are many ways to structure design theory. For the purposes of this AI-focused research, I will begin from Generative UI. structure: data-driven design, generative UI

- (“On Nielsen’s Ideas about Generative UI for Resolving Accessibility,” 2024) Meanwhile is very critical because for the following reasons:
- Nielsen (2024b) information scent from Information Foraging theory (Pirolli & Card, 1999).

Table 54: 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

What is the user interface of the green transformation?

- Kate Moran & Sarah Gibbons (2024) “highly personalized, tailor-made interfaces that suit the needs of each individual” “Outcome-Oriented Design”

9.3.3 Usability is the Bare Minimum of User Experience

Many large corporations have released guidelines for Human-AI interaction. Mikael Eriksson Björling & Ahmed H. Ali (n.d.) Ericsson AI UX.

McKeough (2018) business consultancies have begun to recognize the importance of design to business. They advise their corporate clients to bring user experience design to the core of their business operations.

There's a number of user interface design patterns that have provided success across a range of social media apps. Such *user experience / user interface* (UX/UI) patterns are copied from one app to another, to the extent that the largest apps share a similar look and feature set. Common UX/UI parts include the Feed and Stories. By using common UI parts from social media users have an easier time to accept the innovative parts. add Viz charts. Avatars are increasingly common and new generations are used to talking to computers.

Table 55: Common Social Media UI Parts

Feature	Examples
Feed	
Post	Apple App Store
Stories	IG, FB, WhatsApp, SnapChat, TikTok
Comment	
Reactions	

There are also more philosophical approaches to *Interface Studies*. (David Hoang, 2022), the head of product design at Webflow, 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).

Usability sets the baseline but AI-interfaces are capable of more.

- Tristan Greene (2022): when the quality of AI responses becomes good enough, people begin to get confused.

The user experience (UX) of AI is a topic under active development by all the largest online platforms. 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.

- AI UX dark patterns Jarovsky (2022a)

- AI is usually a model that spits out a number between 0 and 1, a probability score or 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 process allows one appreciate how product features are received by the brain and transformed into experiences by interacting with the algorithm.

(J. Bailey, 2023) believes people will increasingly use AI capabilities through UIs that are specific to a task rather than generalist interfaces like ChatGPT.

How do the tenets of user experience (UX) apply to AI?

UX

Useful
Valuable
Usable
Accessible
Findable
Desirable
Credible

(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

Usability Guidelines

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).

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).

Might we try again?

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) ask poignantly: “We love to hate Clippy — but what if Clippy was right?”

- Life-like speaking faces from Microsoft Research turn a single image and voice clip into a life-like representation (S. Xu et al., 2024).

Many researchers have discussed the user experience (UX) of AI (term such as AIUX and XAI are also used) to provide *usability guidelines*. Microsoft provides guidelines for Human-AI interaction (Amershi et al., 2019; T. Li et al., 2022) which provides useful heuristics categorized by context and time.

Table 58: Microsoft’s heuristics categorized by context and time.

Context	Time
Initially	
During interaction	
When wrong	
Over time	

Combi et al. (2022) proposes a conceptual framework for XAI, analysis AI based on Interpretability, Understandability, Usability, and Usefulness.

- Zimmerman et al. (2021) “UX designers pushing AI in the enterprise: a case for adaptive UIs”
- “Why UX Should Guide AI” (2021) “Why UX should guide AI”
- Simon Sterne (2023) UX is about helping the user make decisions
- Dávid Pásztor (2018) AI UX Principles of Designing AI Products
- M. Anderson (2020) AI usability
- Lennart Ziburski (2018) UX of AI
- Stephanie Donahole (2021) ai Impacting UX Design
- Lexow (2021) Silicon Valley, automation, artificial systems
- Dávid Pásztor (2018) AI UX principles
- Bubeck et al. (2023) finds ChatGPT passes many exams meant for humans.
- Suen & Hung (2023) discusses AI systems used for evaluating candidates at job interviews
- Z. Wang et al. (2020) propose Neuroscore to reflect perception of images.

- Su & Yang (2022) and Su et al. (2023) review papers on AI literacy in early childhood education and finds a lack of guidelines and teacher expertise.
- W. Yang (2022) proposes a curriculum for in-context teaching of AI for kids.
- Eric Schmidt & Ben Herold (2022) audiobook
- Akshay Kore (2022) Designing Human-Centric AI Experiences: Applied UX Design for Artificial Intelligence
- *Studies in Conversational UX Design* (2018) chatbot book
- Tom Hathaway & Angela Hathaway (2021) chatbot book
- Lew & Schumacher (2020) AI UX book
- AI IxD is about human-centered seamless design
- Storytelling
- 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 the field of HCI to make computer more human-friendly.
- Soleimani (2018): UI patterns for AI, new Section for Thesis background: “Human-Friendly UX For AI”?
- **Discuss what is UX for AI (per prof Liou’s comment), so it’s clear this is about UX for AI**
- What is Personalized AI?
- Google’s AI Principles and 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.
- Harvard Advanced Leadership Initiative (2021)
- VideoLecturesChannel (2022) “Communication in Human-AI Interaction”
- Haiyi Zhu & Steven Wu (2021)
- Akata et al. (2020) “Hybrid Intelligence, Augmenting Human Intellect With Collaborative, Adaptive, Responsible, and Explainable Artificial Intelligence”
- Dignum (2021)
- Bolei Zhou (2022) Human-Centered AI for Computer Vision.
- ReadyAI (2020) Human-AI Interaction

- Vinuesa et al. (2020) ai for Sustainable Development Goals, “consensus-based expert elicitation process”
- Orozco et al. (2020) sustainable Urban transportation networks, sidewalks, bicycle paths, streets and rails, movement and socioeconomic life in cities, bicycle networks

9.3.4 Performing Under High-Stakes Situations

AI-based systems are being implemented in medicine, where stakes are high raising the need for ethical considerations. Since CADUCEUS in the 1970s (in Kanza et al., 2021), the first automated medical decision making system, medical AI now provides Health Diagnostic Symptoms and AI-assistants in medical imaging. (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.

- 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 19: Example of ChatGPT explaining medical terminology in a blood report.

- The Paris Olympic games make heavy use of AI (Kulkarni, 2024).

Fitness Guides, AI Guides have been shown to improve sports performance, etc, etc. Can this idea be applied to sustainability? MyFitness Pal, AI training assistant. There's not avatar.

AI in Medicine, AI has been in medicine since early days with the promise to improve health outcomes.

Human Augmentation, Technology for augmenting human skills or replacing skills that were lost due to an accident is one usage of tech.

- (Dot Go, 2023) makes the camera the interaction device for people with vision impairment.

AI is being use in high-Stakes Situations (Medical, Cars, Etc).

- Singhal et al. (2023) medial AI reaching expert-level question-answering ability.
- Ayers et al. (2023) in an online text-based setting, patients rated answers from the AI better, and more empathetic, than answers from human doctors.

(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.

- Eliza Strickland (2023) Chat interface for medical communication
- Jeblick et al. (2022) suggest complicated radiology reports can be explained to patients using AI chatbots.
- “Health. Powered by Ada.” (n.d.) health app, “Know and track your symptoms”
- *Buoy Health* (n.d.) AI symptom checker,
- Women in AI (n.d.) AI-based health monitoring
- *Home - Lark Health* (n.d.) track chronic condition with AI-chat
- Stephanie Donahole (2021) AI impact on UX design
- Yuan et al. (2022): “AI assistant advantages are important factors affecting the *utilitarian/hedonic* value perceived by users, which further influence user willingness to accept AI assistants. The relationships between AI assistant advantages and utilitarian and hedonic value are affected differently by social anxiety.”

Name	Features
Charisma	
Replika	Avatar, Emotion, Video Call, Audio
Siri	Audio

9.3.5 Human-Computer Interactions Without a “Computer”

How does AI affect Human-Computer Interactions

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?"

9.3.6 Do AI-Agents Need Anthropomorphism

What are the next features that could improve the next-generation UX/UI of AI-based assistants?

- GPT 4o combines different abilities into the same model, preserving more information: (OpenAI, 2024b).

(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.

Should AIs look anthropomorphic or fade in the background? It's an open question. Perhaps we can expect a mix of both depending on the context of use and goals of the particular AI.

(Aschenbrenner, 2024) predicts "drop-in virtual coworkers", AI-agents who are able to use computer systems like a human seamlessly replacing human employees.

Table 60: 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 Mourning for the 'dead' AI (Phoebe Arslanagić-Wakefield, n.d.)	AI tools for web designers (patrizia-slongo, 2020) 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)	

- (A. Costa & Silva, 2022) "Interaction Design for AI Systems"

9.3.7 Roleplay for Financial Robo-Advisors

Robo-advisors 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. Human advisors are very expensive

and not affordable for most consumers. (Capponi et al., 2019) argues “*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*.

In the early days of 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 have shut down in the UK (AltFi, 2017). 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 [ibid]. The app was bought by a bank in 2021 and closed down in 2023 (AltFi, 2021; “ETFmatic - Account Funding of EURO Accounts Ceases,” 2023; Silva, 2023).

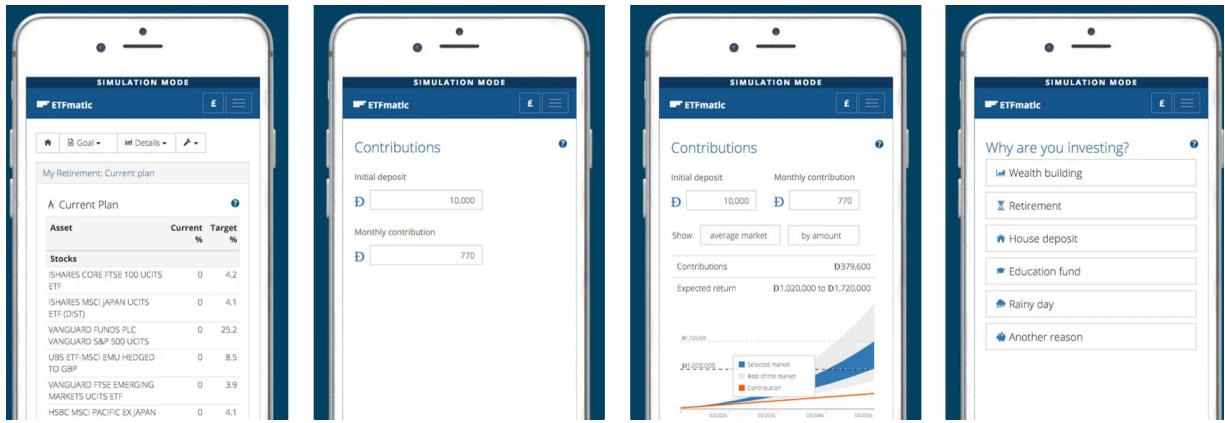


Figure 20: Out-of-date user interface of a European AI-Advisor ETFmatic in 2017 which was closed down in 2023 (Photo copyright ETFmatic)

Some relevant papers include a comparison of robot advisors by (Barbara Friedberg, 2021) and (Slack, 2021)’s account of how before Generative AI, financial chatbots were developed manually using a painstaking process that was slow and error-prone, for example using the Atura Process. Older financial robo-advisors, built by fintech companies aiming to provide personalized suggestions for making investments such as Betterment and Wealthfront are forced to upgrade their technology to keep up.

While the financial AI companion apps in the US market are ahead globally, they are not yet using many of the user experience innovations that are prevalent on social media platforms targeted at Gen-Z and/or Millennials, possibly presenting an opportunity for cross-industry knowledge transfer, from businesses that are traditionally closer to the consumer - such as retailers. Financial AI companion apps have not yet grown to mainstream scale in Asia, Africa, Latin America, and Europe, being for the moment a largely US-based retail investor trend. The apps outside of the US are niche products in a nascent stage, however, they still provide relevant design directions

or stories of what to avoid. The user interface and user experience (UI/UX) of consumer-focused investing apps in Europe has improved a over the past decade. The changing landscape is related to the earlier availability of better quality apps available in the US and the disappearance of the 1st generation of rudimentary investing apps and the lessons learned on how to automate the delivery of financial services while increasing user satisfaction.

Robo-advisors compete with community investing such as hedge funds, mutual funds, copy-trading, and DAOs with treasuries. Robo-Advisor do not have the type of social proof a community-based investment vehicle has. The question is, does the user trust the robot or a human.

In India, research is being conducted on how AI advisors could assist with investors' erratic behavior in stock market volatility situations, albeit without much success (Bhatia et al., 2020). India had more than 2000 fintechs since 2015 (Migozzi et al., 2023).

Newer literature notes robo-advisor related research is scattered across disciplines (H. Zhu et al., 2024).

Athropomorphism: human-like attributes in robo-advisors, such as conversational chatbots, can affect adoption and risk preferences among customers. Studies show that anthropomorphic robo-advisors increase customer trust and reduce algorithm aversion.” **similar to my research**

- David et al. (2021) Can explainable AI help adoption of Financial AI assistants?
- A. Brown (2021) Financial chatbots
- *Why Design Is Key to Building Trust in FinTech | Star* (2021) building trust in FinTech
- Sean McGowan (2018)
- ROBIN DHANWANI (2021) Design Jams for collaboration
- “Designing a Fintech App - The UX Design Process” (2021)
- Cordeiro & Weevers (2016)
- Ungrammy (2020)
- Outlaw (2015): Regulation D 506c
- Malliaris & Salchenberger (1996) (**Need to pay for paper!**)
- “CMB | New Future of Financial AI” (n.d.) Huawei
- Loo (2025) launched a podcast Estonian General Intelligence discussing how “how intelligence becomes infrastructure” and small nations can lead.

10 MONEY

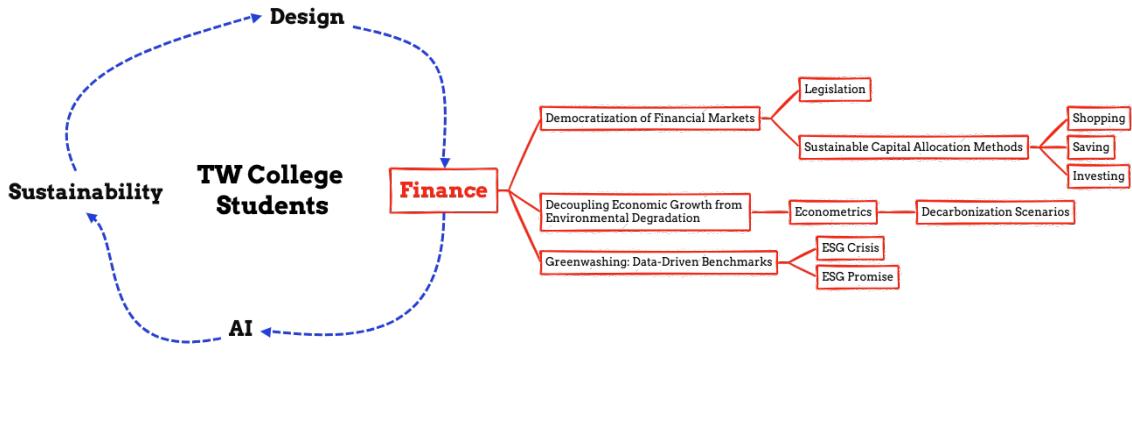


Figure 21: Visual abstract for the finance chapter

10.1 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.

10.1.1 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 a global business, 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, revaled 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.



10.1.2 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 an institution such as an investment firm, university endowment, pension fund or mutual fund, 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.

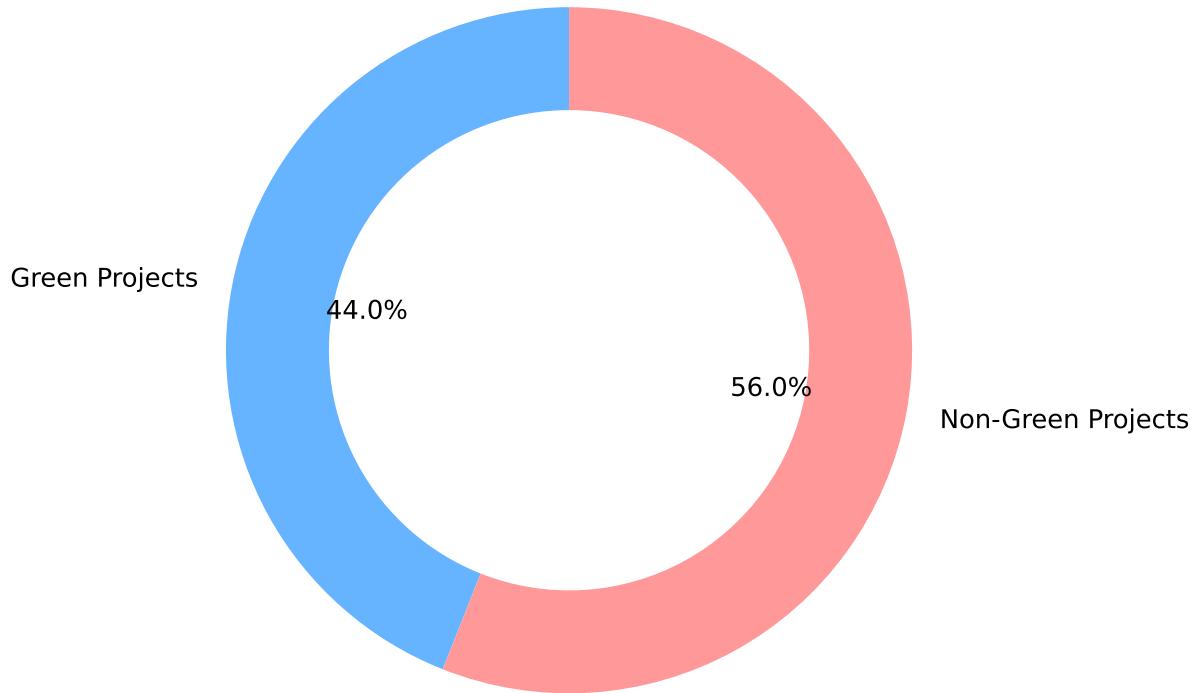
The common expectation is that young investors typically have less understanding financial concepts. While consumers are beginning to become more money-savvy, they still lag in both financial and sustainability literacy. Financial and sustainability literacy are intertwined. Integrating these literacies 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 ask the user to define their 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 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.

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.

Investment Share in Green vs Non-Green Projects



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

Independent of what technology is 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.

Building 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).

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. That starts with empowering creators and artists to create and own the culture they're creating. In the long term this moves to internet communities taking on societal endeavors."* (Panzarino, 2020).

- Building a culture of sustainability? (Armstrong & Staff, 2021). The focus on *group consciousness* suggests community-based sustainability action may be effective. What are the building blocks of a thriving community? Experience instead of read..

Communities can be directed towards sustainability. *Zero Waste Lifestyle* is the opposite of overconsumption. Zero waste suggests people buy in bulk to save. Buying 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.

Minimalism is a movement of people living a simple life. This is always going to be a small percentage of people. (C. D. Costa, 2018) Finnish socialists promote minimalism. In Tokyo (Tokyo Simple Eco Life, 2021). Consumers choose to engage in becoming minimalist in a non-linear process with overlapping stages (Oliveira De Mendonça et al., 2021).

World Cleanup Day has attracted tens of millions of people to do beach and forest cleanups.

(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 61: Data compiled from (Gyuriczki & Szládek, 2025; Interactive Brokers, 2025a, 2025b; Lightyear, 2025; Revolut, 2020, 2025; Trahant, 2022)

	IMPACT by Interactive Brokers		
Feature	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
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

10.1.3 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).

In the social sector of ESG, there are also stories worth sharing. For example, during COVID-19, 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).

10.2 ESG Crisis and Opportunity

10.2.1 Opaque Metrics and Lack of Standardisation

(Gemma Woodward, 2022) Identifies fundamental problems in current ESG frameworks include inconsistent data and superficial rating schemes, and calls for a complete overhaul to restore credibility in sustainable investing. ESG Needs Standardisation of Methodologies. “Disparity between ESG methodologies was one of the key hurdles to finding the right sustainable strategy” (Margaryta Kirakosian & Angus Foote, 2022). 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).

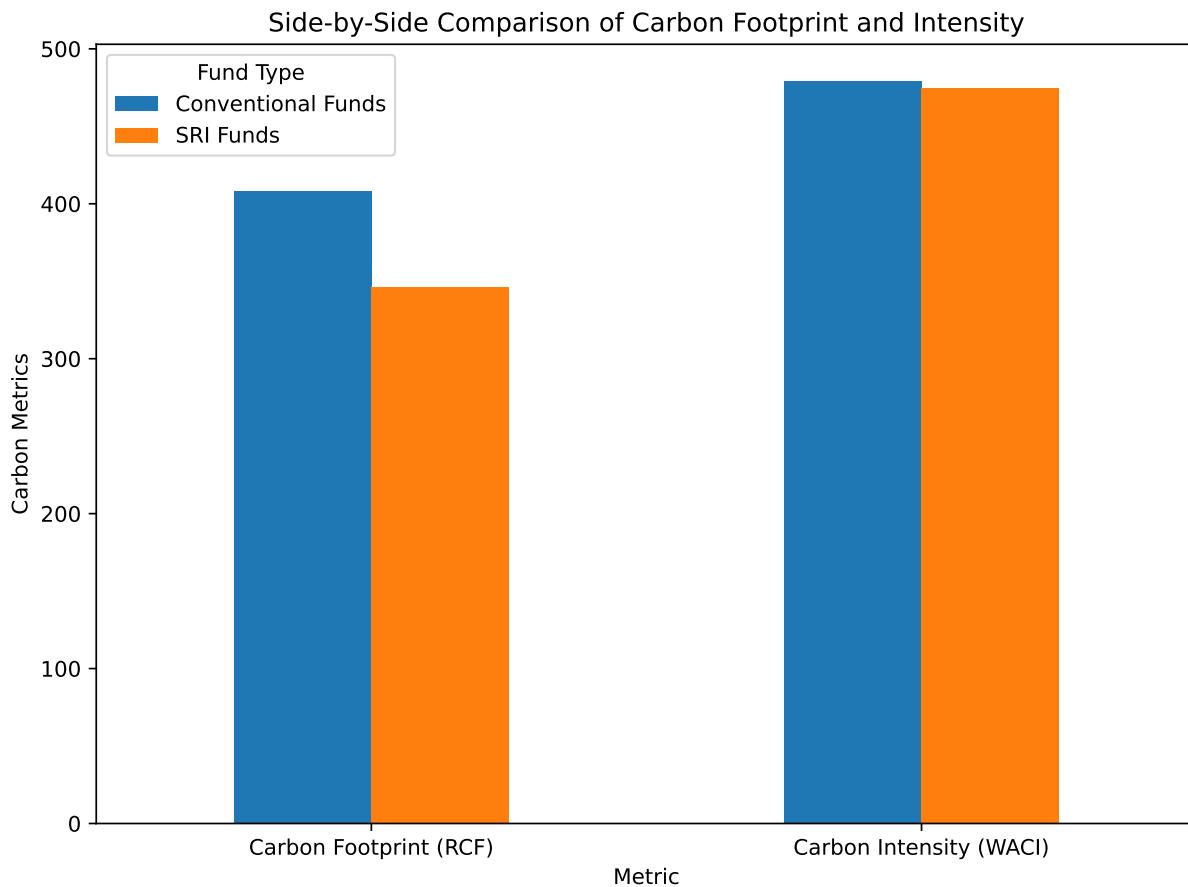
There are those rebuffing misleading claims made by asset managers. Prominent investment research firm Morningstar conducted a forensic analysis of the industry, and re-classified 1/5 of the tracked funds (over 1200 in total) or over \$1 trillion USD in total valuation, as non-ESG; Hortense Bioy, Morningstar’s 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 CO₂ 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 it’s supply chain.



(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 improvements 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 CO₂ emissions from bond and equity underwriting to their own financed-emissions footprints, effectively excluding and hiding 2/3 of their carbon emissions (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.

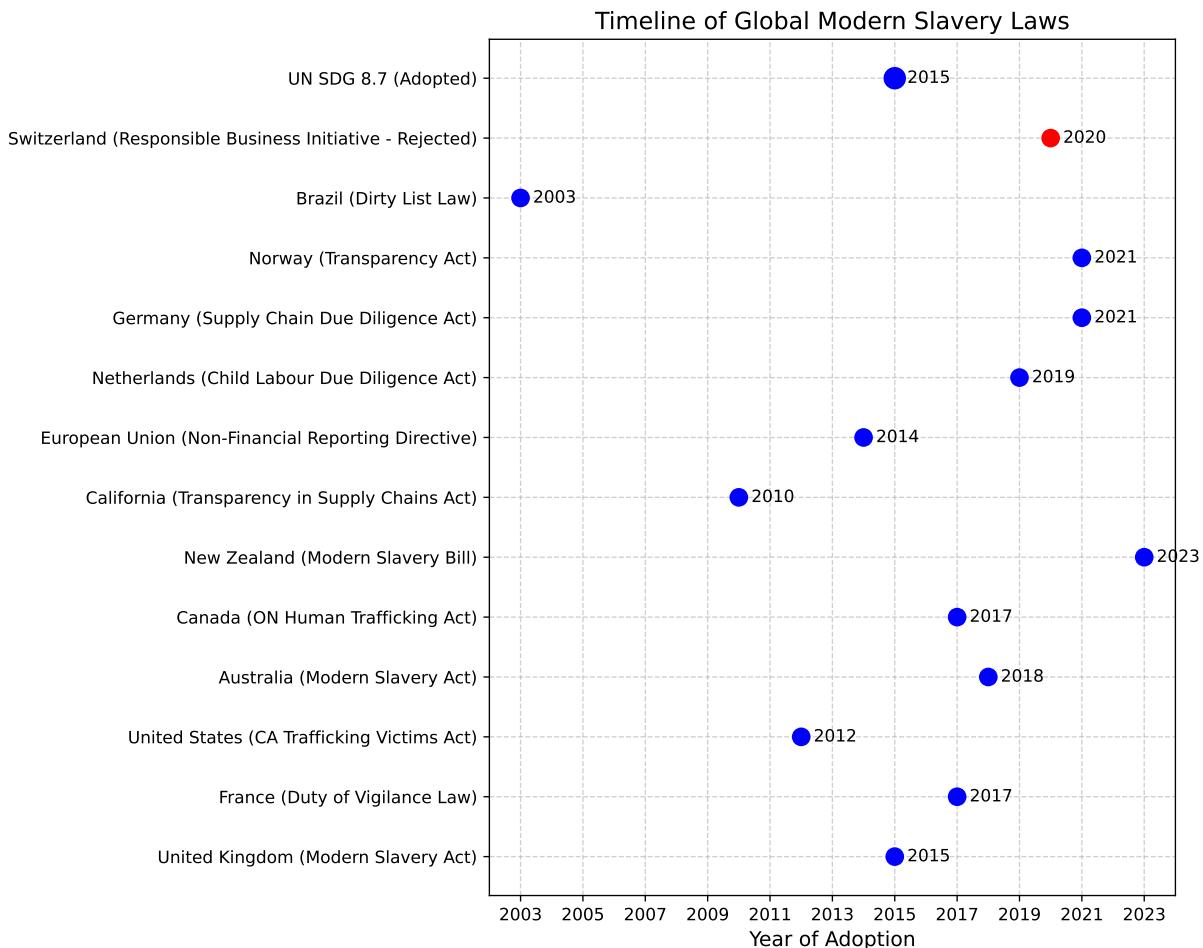
In early 2025, ESG investing saw \$8.6 billion in global outflows, mainly due to political pushback in the U.S., including rollbacks of climate and DEI policies under the Trump administration. U.S. sustainable funds lost \$6.1 billion, and Europe saw its first net outflow since 2018; ESG is shifting toward a more practical phase, with less focus on branding and more on measurable outcomes (Biog, 2025; Johnson, 2025; Mitchell, 2025; Vosburg & Biog, 2025).

10.2.2 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. (Borrelli 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.



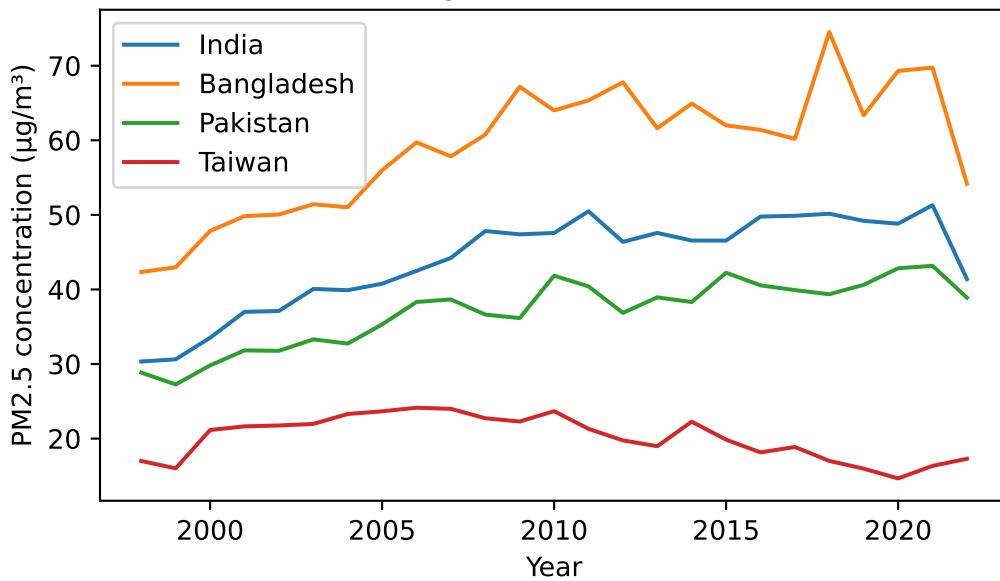
Slavery is connected to environmental degradation, and climate change (Decker Sparks et al., 2021). Enslaved people are used in environmental crimes such as 40% of deforestation globally. Cobalt used in technological products is in risk of being produced under forced labor in the D.R. Congo (Sovacool, 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. Companies that create “worker voice apps”, intending 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).

PM2.5 Trends: India, Bangladesh, Pakistan, Taiwan (1998-2022)



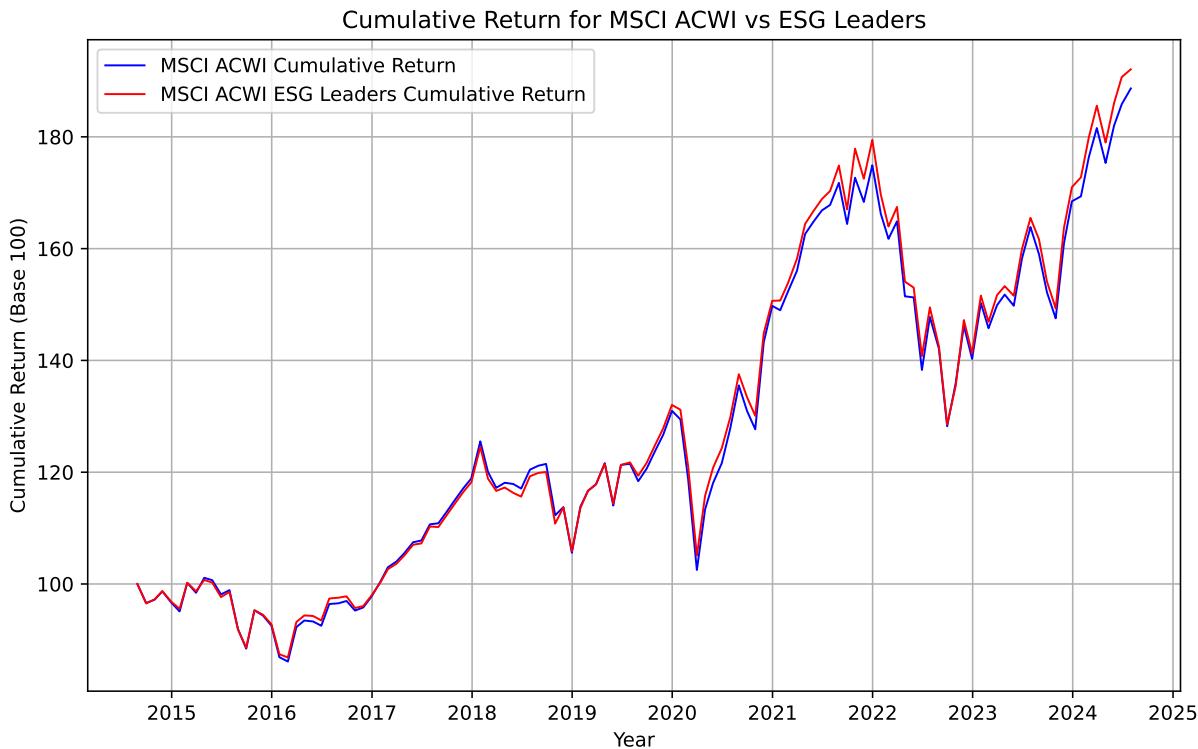
The above chart shows comparisons of air quality trends in South Asia vs Taiwan; while air pollution has increased in India, Bangladesh, and Pakistan, Taiwan has returned to the pollution levels of 1990s.

10.2.3 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 in Europe, introduced an ESG index and a series of derivative instruments in the summer of 2020 (Euronext, 2020).

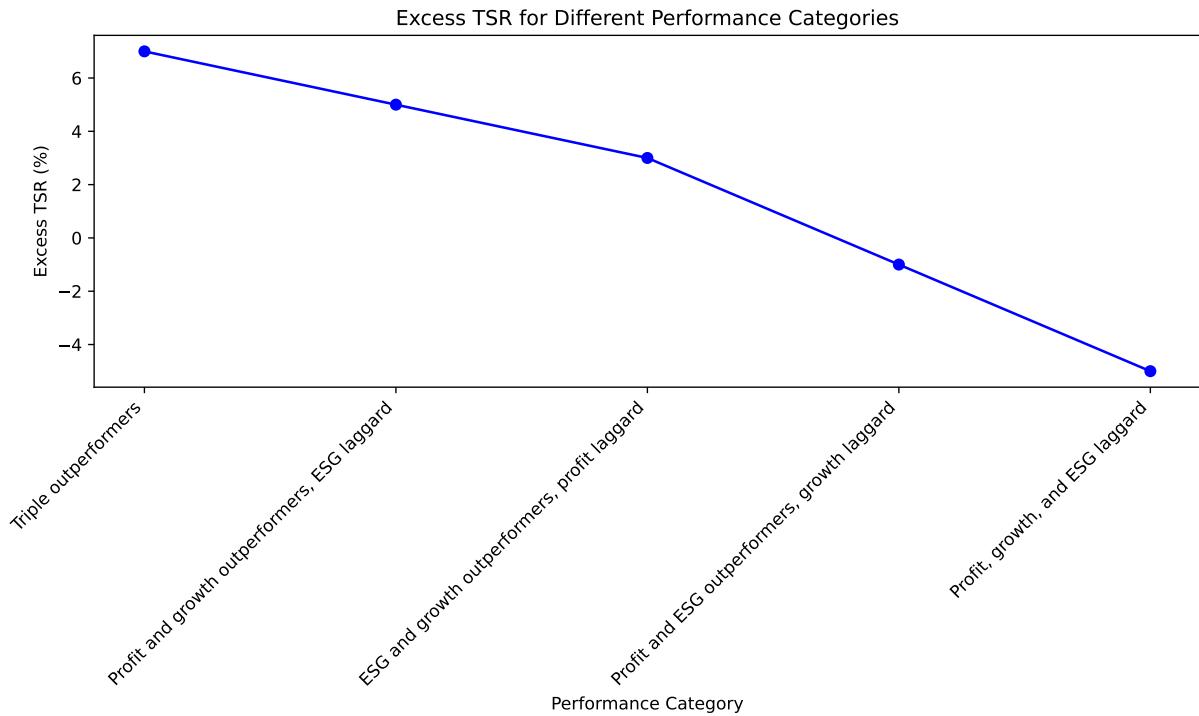
(*The Importance of ESG Measurement and Canada's Opportunity for Improvement*, 2022) suggests ACWI ESG leaders outperform the non-ESG screened ACWI based on comparing MSCI indexes. It's notable that ACWI ESG started to outperform the traditional ACWI only in the past few years (evidence that capital 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.



10.2.4 Towards Green Transparency - But Who Does the Rating?

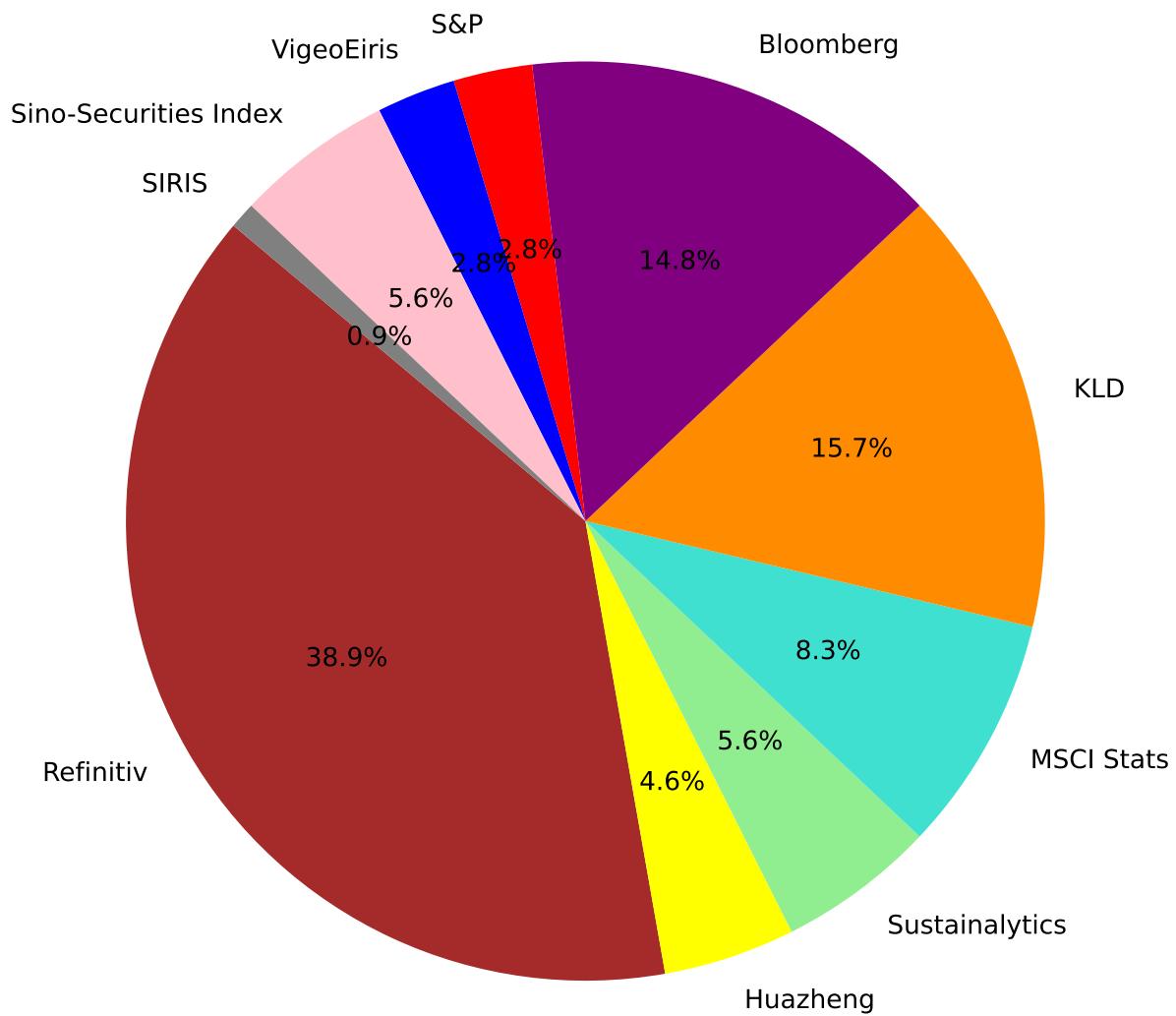
Trucost, a company launched in 2000 to calculate the hidden environmental costs of large corporations and advance circular-economy practices was acquired in 2016 by S&P Dow Jones Indices, which by 2019 became a part of its ESG product offering (Indices, Oct 03, 2016, 08:30 ET; Mike Hower, Dec 9, 2015 7am EST; “S&P Rolls Out Trucost ESG Data to Its Customers,”

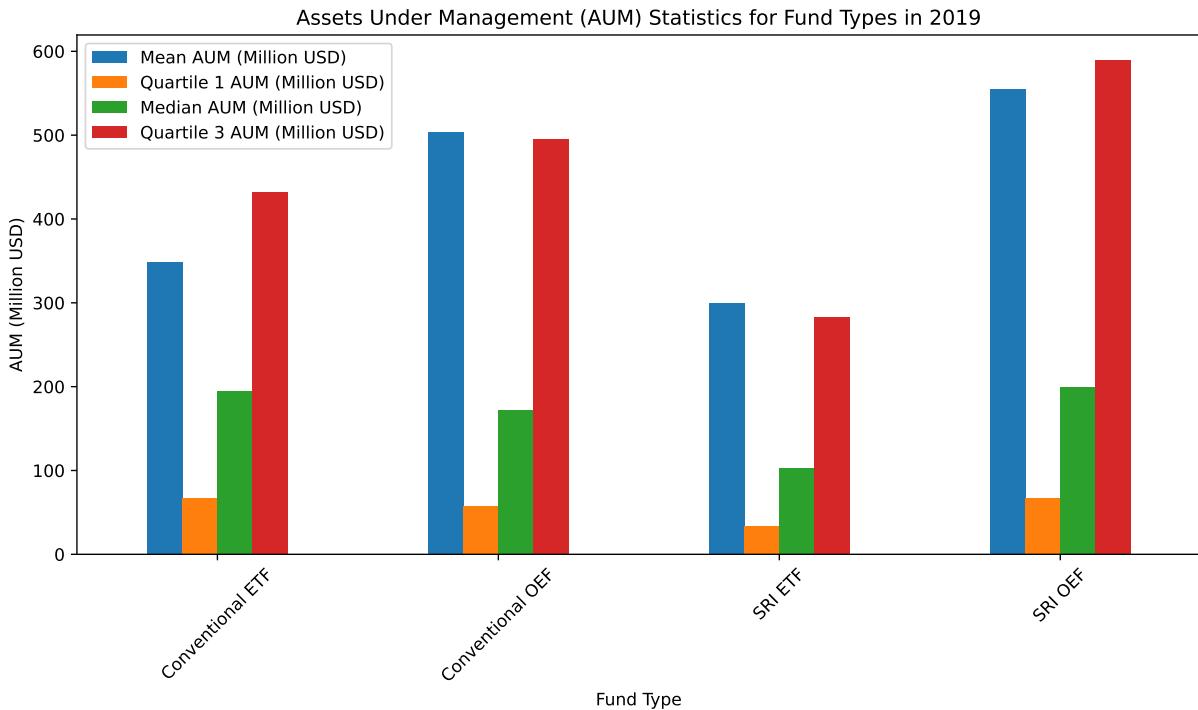
2019; Toffel & Sice, 2011). It's parent company S&P Global also acquired RobecoSAM's ESG rating business, consolidating S&P's control of ESG ratings (George Geddes, 2019).



A meta-review of 136 research articles discovered the following ESG-rating agencies.

Distribution of Providers used among the Selected Articles





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.

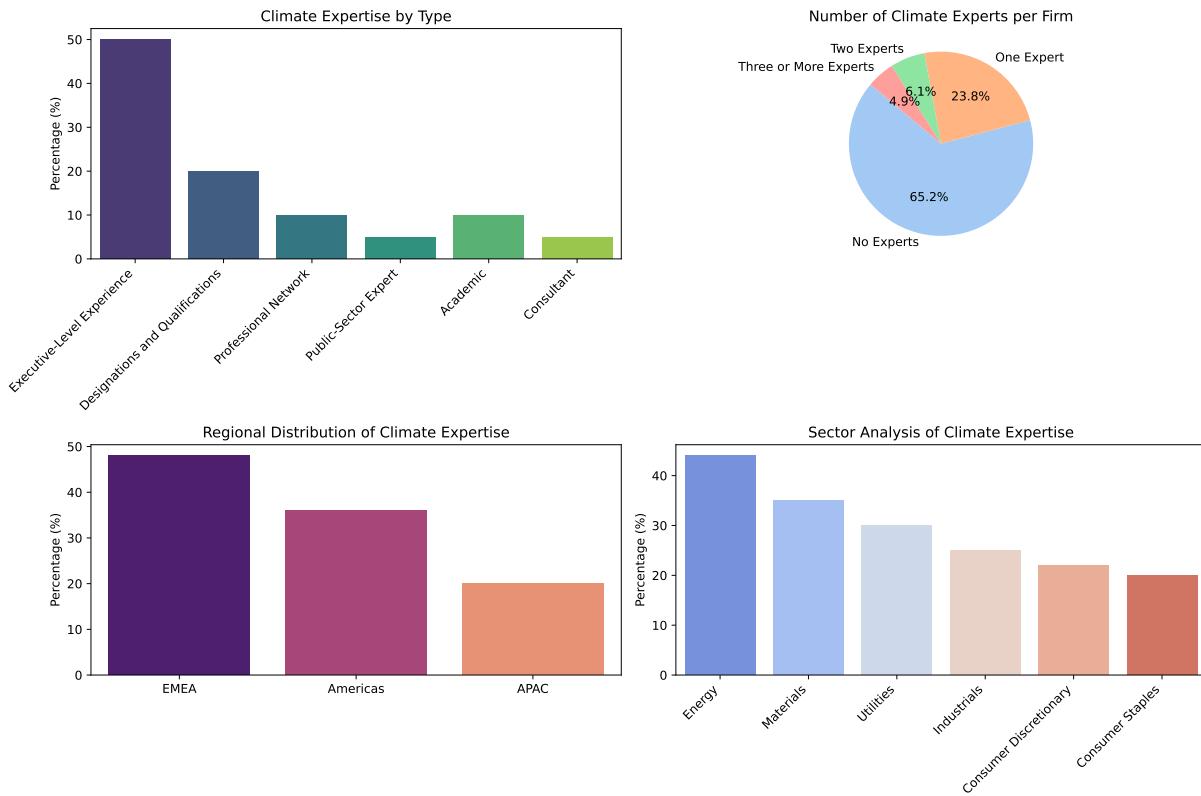
Robeco's survey of 300 large global investors totaling \$27T under management found biodiversity-protection is increasingly a focus-point of capital allocation (Robeco, 2023).

10.2.5 ESG Success Depends on Good Governance: Boards, Policy, and Investor Pressure

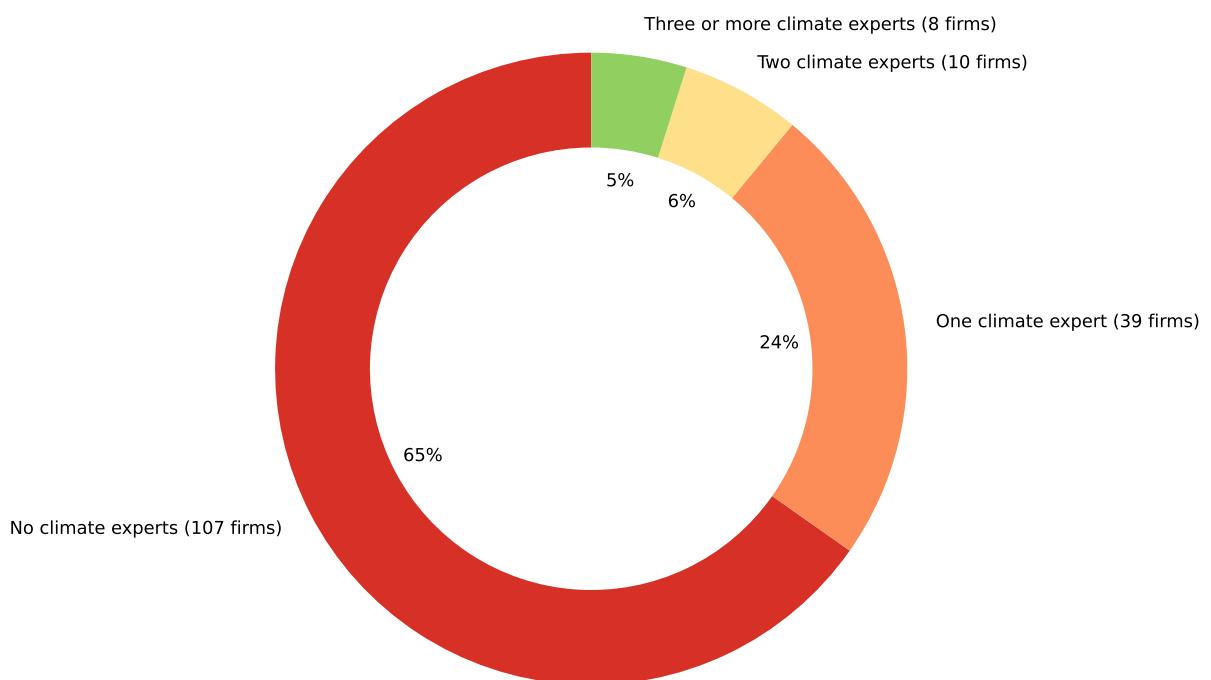
Governance in ESG is the G that makes E and S happen - or put in another way: governance drives social and environmental initiatives at companies. Yet MSCI research finds company boards severely lacking in climate experts; among the 164 large CO₂ emitters (1986 directors in total) benchmarked by the 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).

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

Climate Expertise on Boards

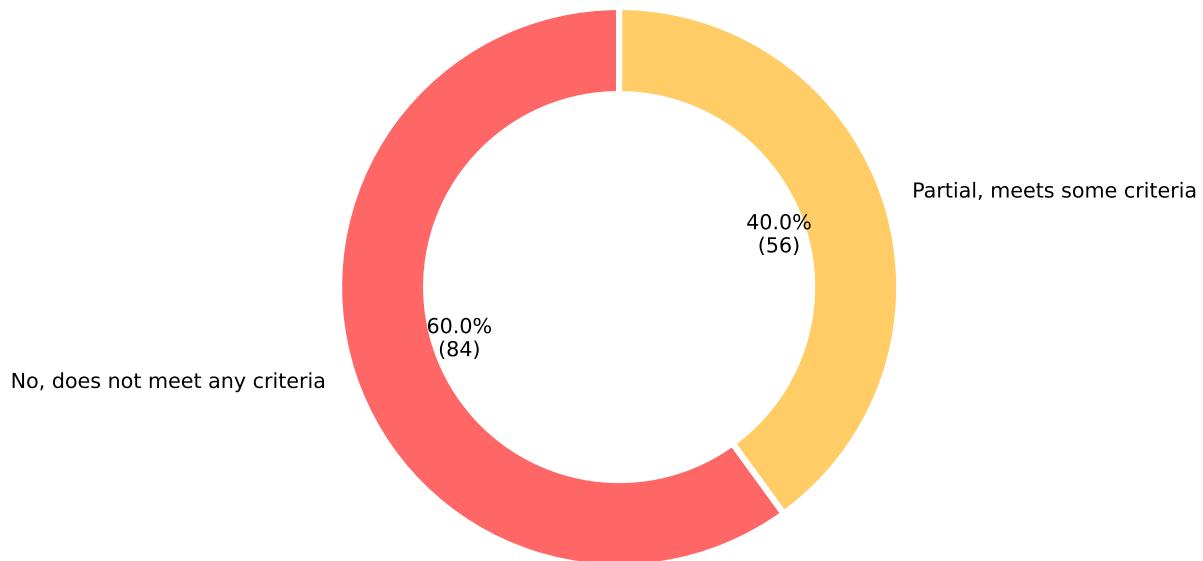


Firms by Number of Climate Experts



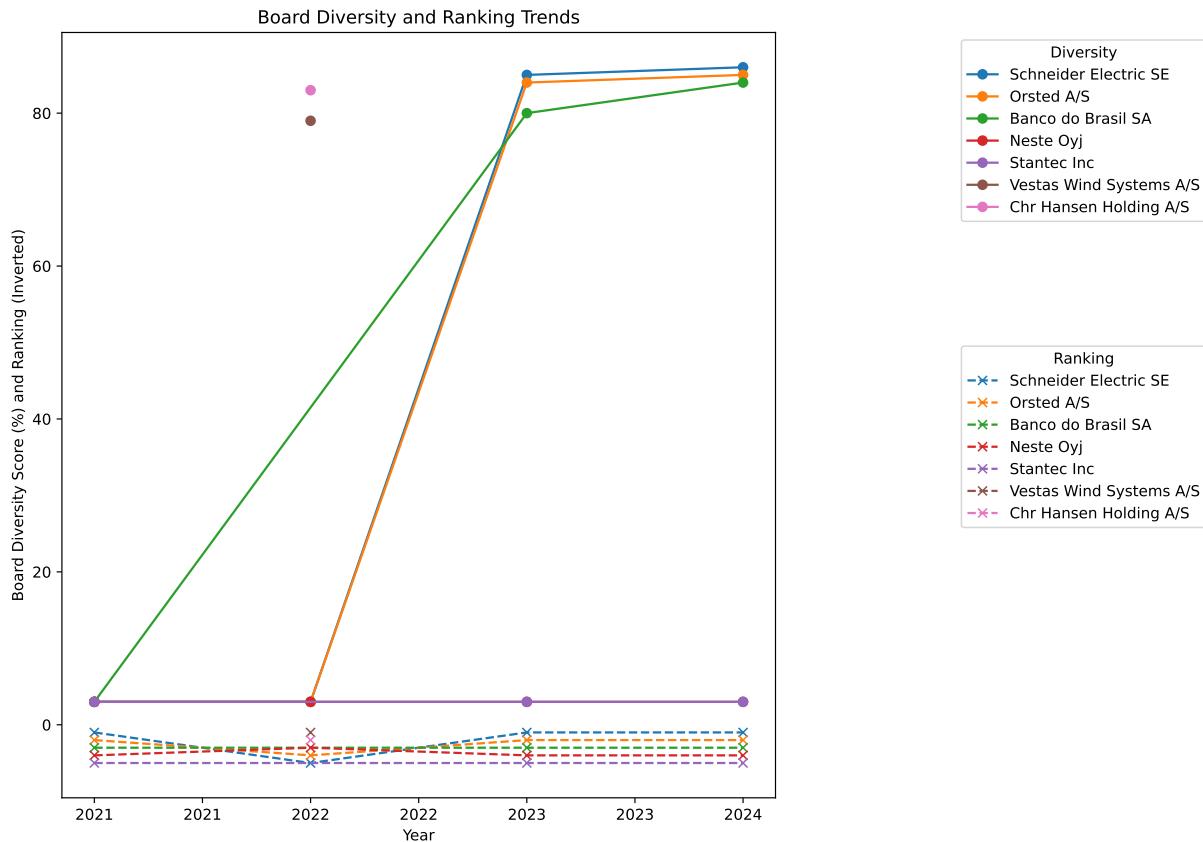
Most companies do not meet the criteria (Climate Action 100+, 2023).

Overall Accounting and Audit Assessment



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.

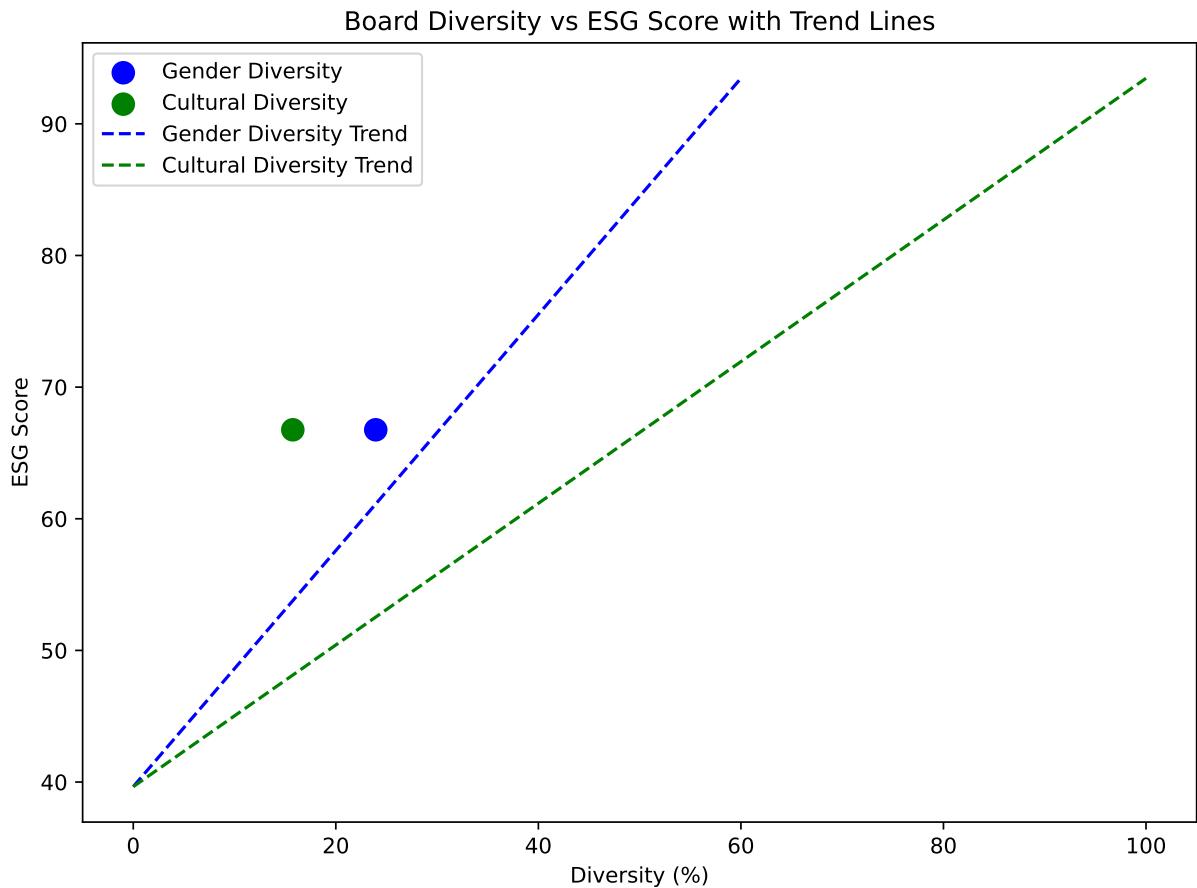
A systematic study of 153 peer-reviewed papers of ESG literature published between 2006 and 2023 around the world reports the major determinants of high ESG performance are board member diversity, firm size, and CEO attributes; actively diversifying boards, especially adding members with sustainability expertise, and aligning executive compensation with ESG targets to translate strategic ambitions into operational results, may boost ESG outcomes (Martiny et al., 2024).

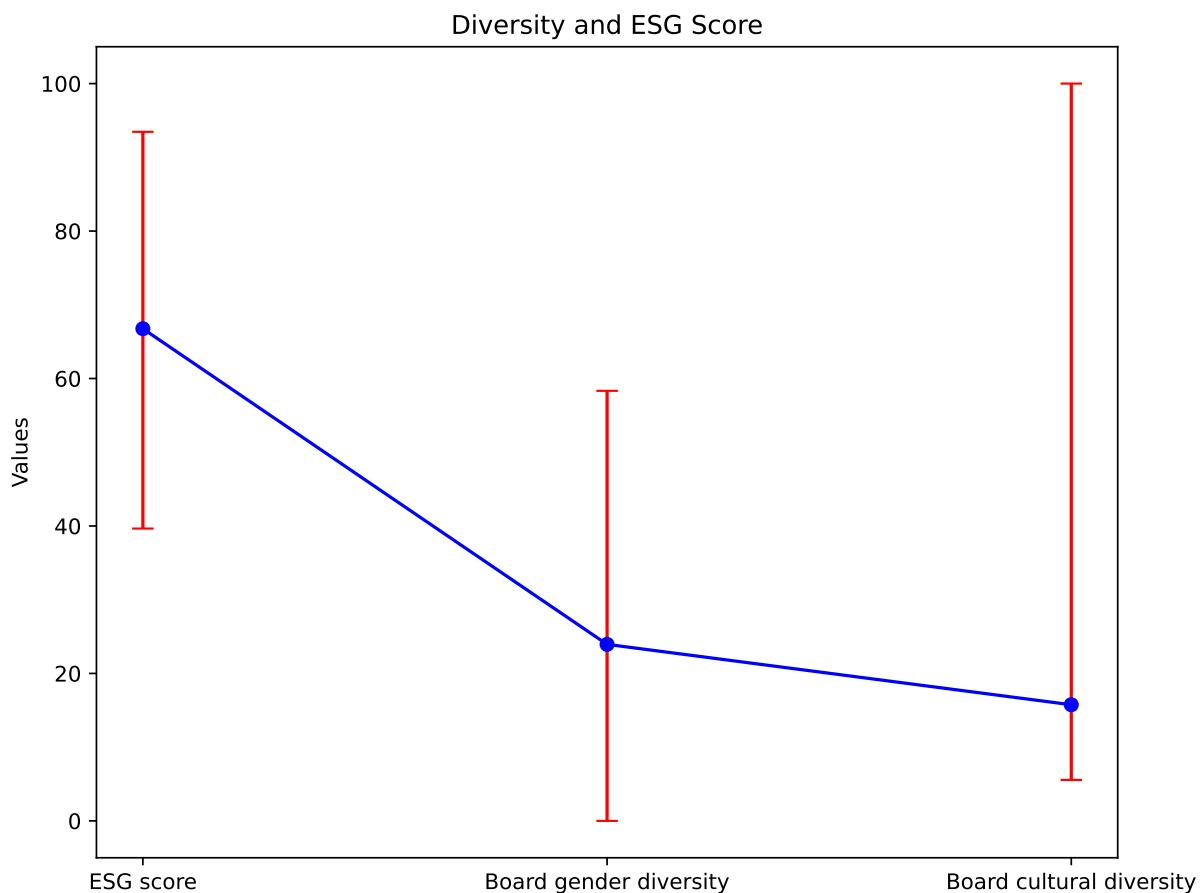


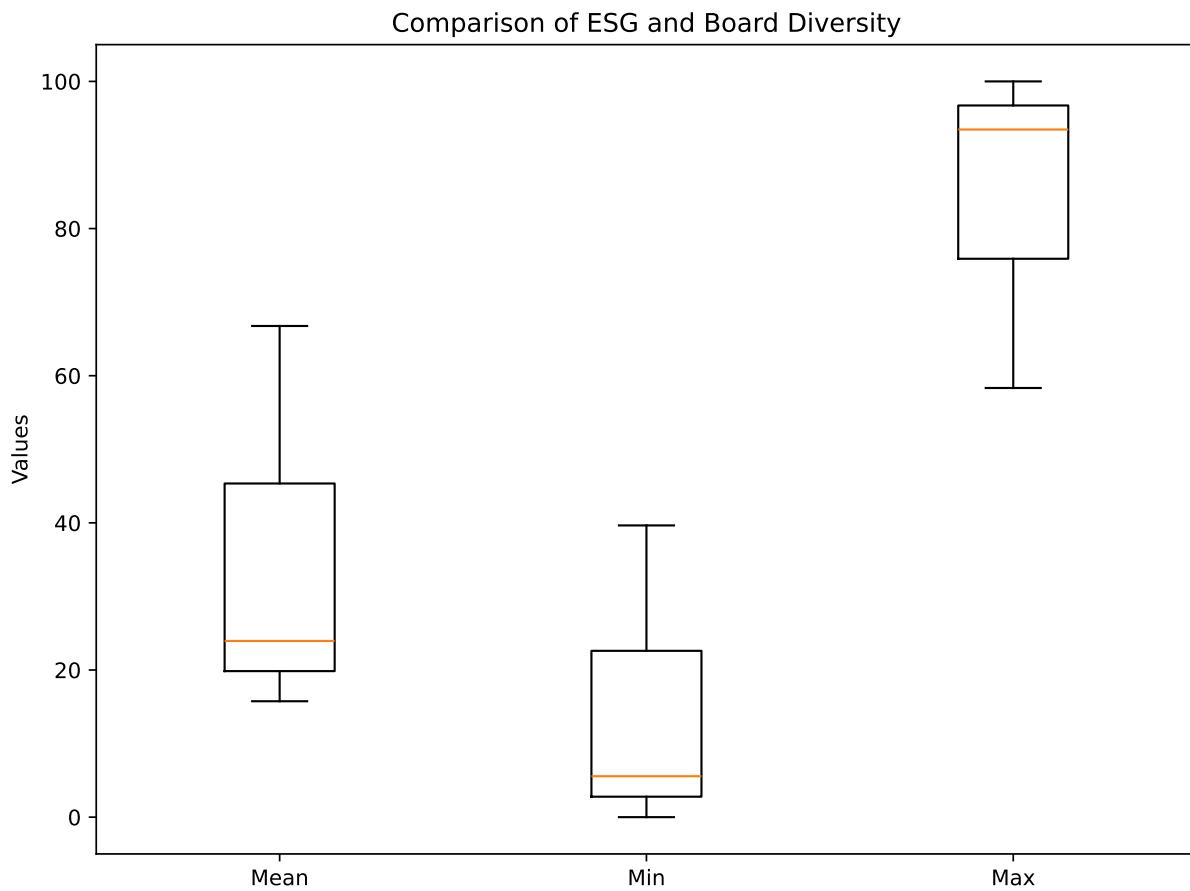
The CEO of the Swedish clothing producer H&M - one of the largest fast-fashion companies in the world -, recognized the potential impact of *conscious consumers* as a threat (Hoikkala, 2019) and at the same time launched a clothes repair service in partnership with the Norwegian start-up Repairable, as reported by the Norwedgian Sustainability Hub (S HUB, 2018). These kind of discrepancies are all over the place. While Coca-Cola is the largest plastic polluter in the world, at the same time it runs the “World Without Waste” program which supports packaging recycling around the world, reporting achieving a global 90% recycling rate for Coca-Cola packaging (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 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)



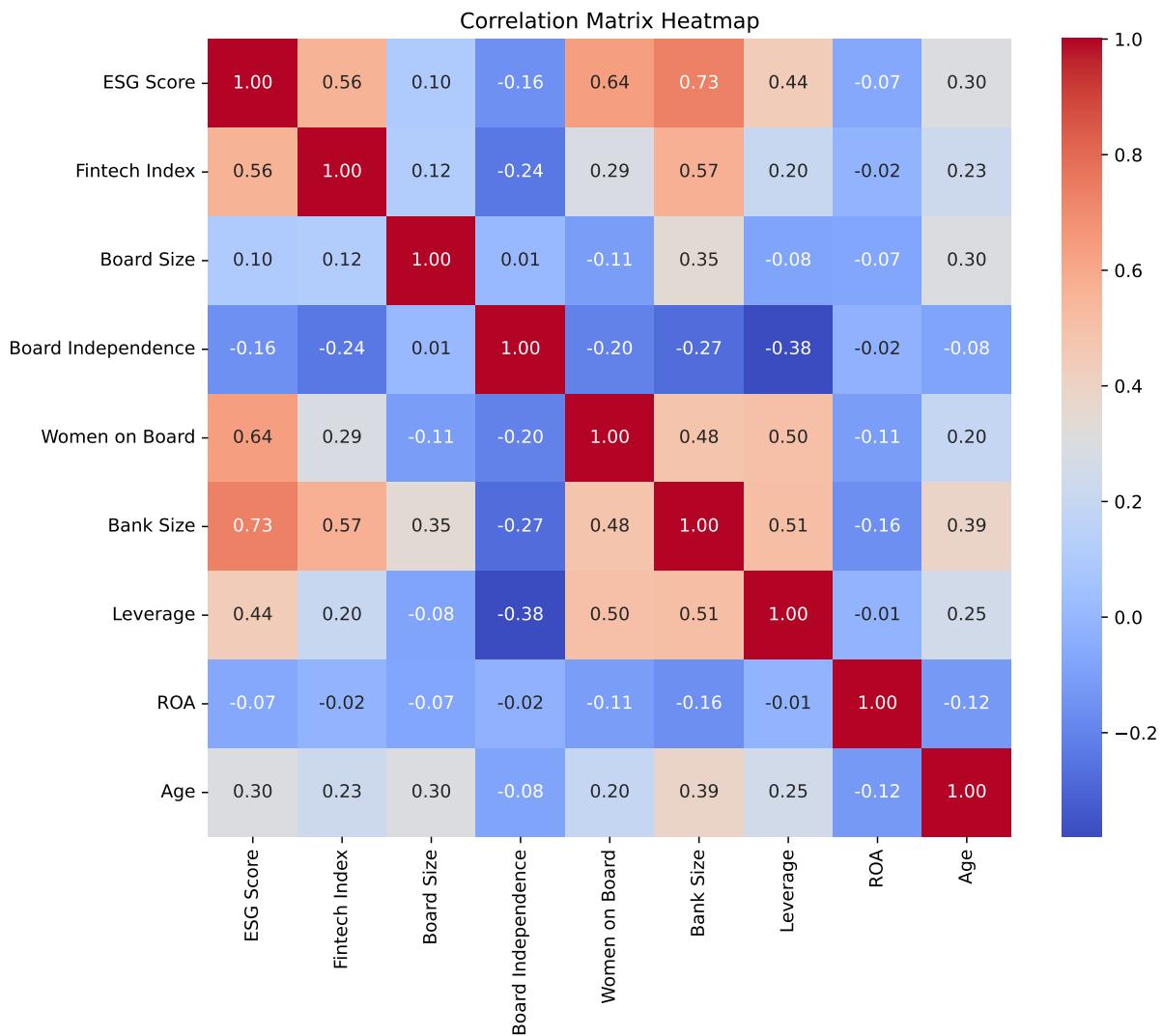




Board diversity in the top 5 sustainable companies in 2024 based on Corporate Knights rankings (Corporate Knights, 2024).

10.2.6 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).



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.

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.

Table 63: 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.

Strategy	Description
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.

Table 64: 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.

While ESG is riddled with problems, it has started a common language and there are many ways how to improve it. The advice consultancies are providing to banks establishes a common language and 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).

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 back to the business through infringement discovery.

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).

10.2.7 ESG Accessibility: Curbing Corruption with Realtime Data Streams and Product Lifecycle Traceability

ESG is a marketing tool but it could achieve 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.”

(Tim Nicolle, 2021) believe “Real-time ESG data is more difficult to greenwash”, “supply chain is a significant source of ESG content”. “But the real breakthrough is how we can surface that real-time ESG data directly to individuals in the shops and online, linked to the products that they are browsing and potentially buying. This means that ESG change will finally be driven by the ultimate judge of business success – the customer.” (Ratkovic, 2023).

(Kyle Wiggers, 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”. (Makersite, n.d.) proposes *product sustainability modeling*.

Google Environmental Insights Explorer enables local governments (cities) to measure CO₂ 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).

For corporations respond to the climate crisis they are expected to become more digital and data-driven. Requirements ESG compliance has given rise to a plethora of new monitoring tools. 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 aim 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 CO₂e accounting in 2022 by combining invoices and sensor data to generating instant per-transaction emission footprints (Indrek Kald, 2022).

There’s also a growing number of companies helping businesses to measure CO₂e emissions in through their entire product lifecycle. In order to improve product *provenance*, blockchains offer transparency. Several enterprise blockchain offerings from vendor 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).

Supply Chain Mapping improves Transaction Traceability. What data should be surfaced to the consumer? The founder of Sourcemap Leonardo Bonanni started out with doing product autopsy in 2015 to assess products (« *Fast fashion* », 2023)

EU Deforestation Regulation (EUDR) is a success story.

Know your suppliers’ suppliers (Sourcemap, 2025): “Sourcemap’s **Supply Chain Mapping** platform (2025) offers a SaaS solution to document and monitor every tier of a company’s physical supply chain. It collects supplier-attested data and continuously verifies it through integrity checks and cross-referencing with third-party registries and watchlists. Real-time transaction

traceability lets users audit all movements and detect fraud or non-compliance instantly, while an expert supplier-engagement team handles onboarding, training and ongoing support to keep maps current and compliant with global due-diligence laws”

10.3 Payments

10.3.1 Consumer Activists are a Small Minority

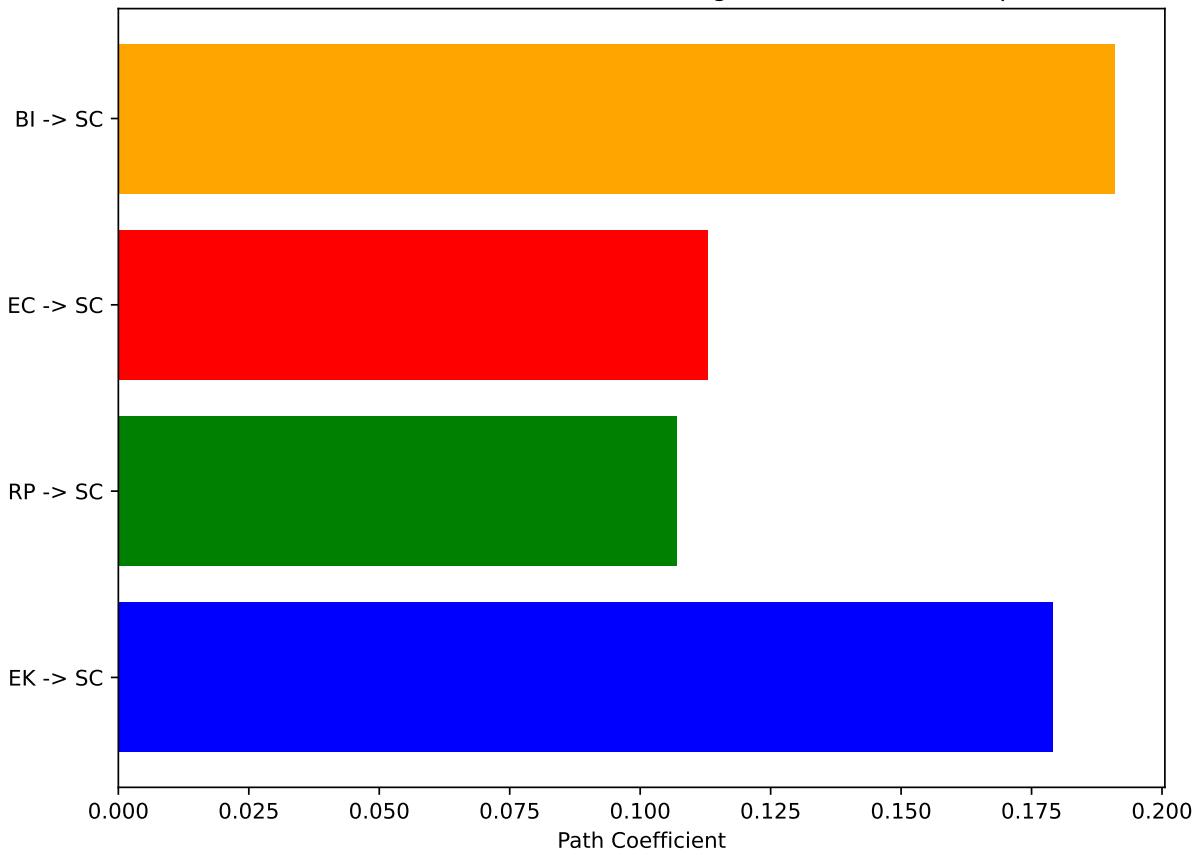
Recognition precedes protection, as the Estonian slogan goes: “*Õpetame märkama, et oskak-sime hoida*” / “Learn to notice so we can preserve.” (Tartu loodusmaja, 2019). (Milne et al., 2020) coins the term *mindful consumers*, who do research and are aware of the impact of their shopping choices. Yet 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.

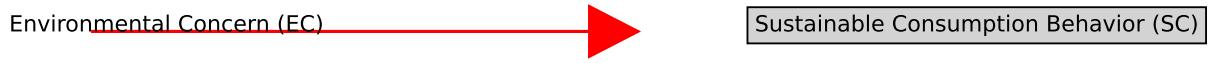
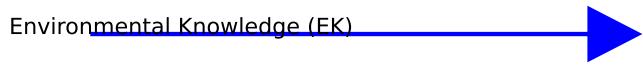
There is plenty of research on if and how sustainable shopping could be possible. Already in 2016, (Klinglmayr et al., 2016) proposed a mobile app to channel “political consumerism” into sustainable shopping through self-regulation: personalized recommendations could be provided by aggregating vast product 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.

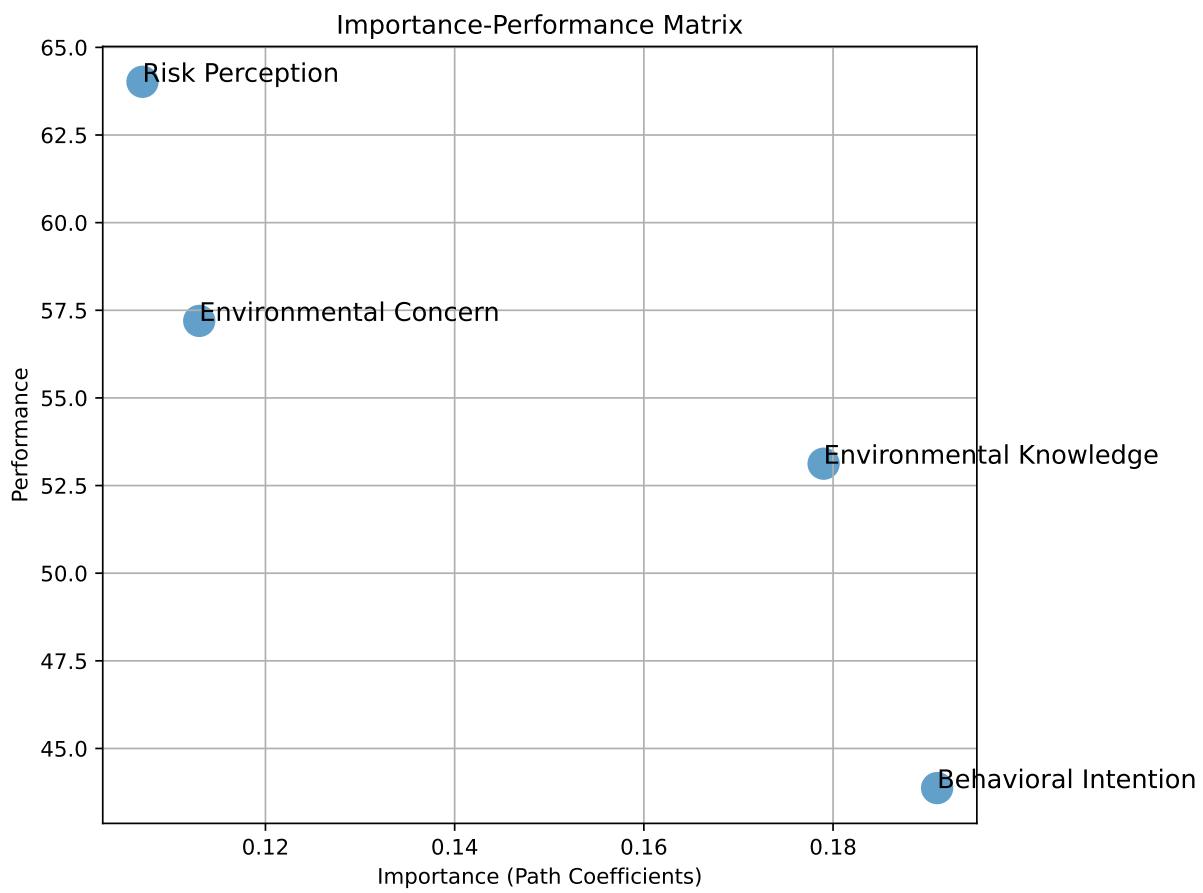
Sustainable consumption relationships in Europe.

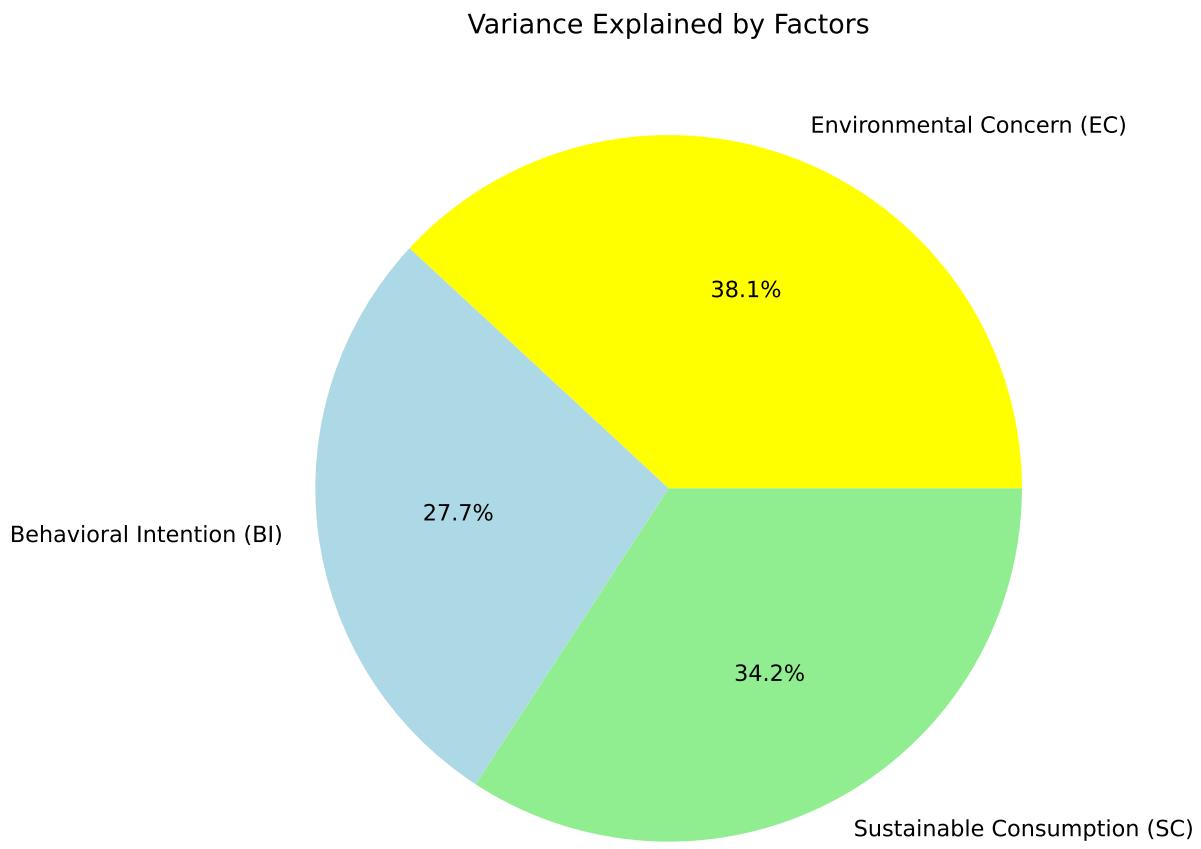
Path Coefficients for Factors Influencing Sustainable Consumption



Mediation Flow Chart for Sustainable Consumption







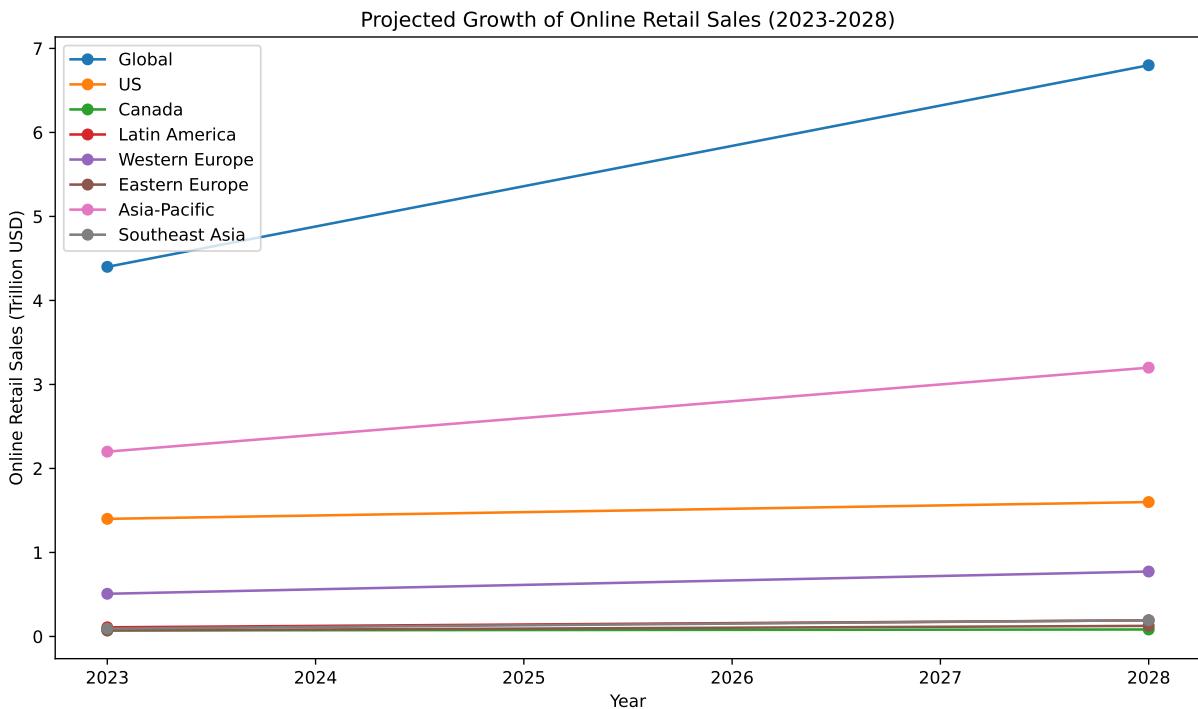
Make use of indexes to compare companies.

10.3.2 Shopping's Environmental Footprint: Increasingly Driven by Digital Platforms, Social Commerce, AI Assistants

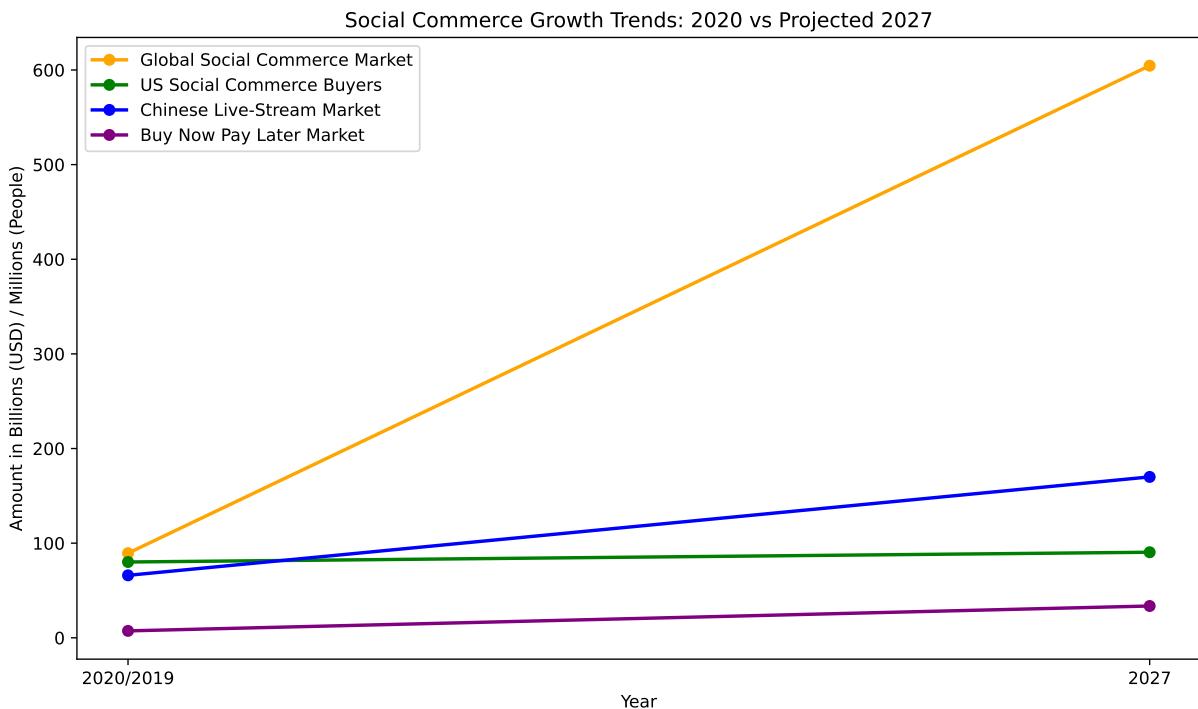
Online Shopping impact. Single's day, etc.

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”.

It may seem impossible to turn the tide of consumerism, given the projected growth in online shopping (Forrester, 2024)



(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)

important - more and more consumers using AI assistants to find alternative products, make shopping lists, etc Pandya (2025); Pastore (2025); Neuron (2025)

10.3.3 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 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 65: 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 Mil-	Japan / Ko- lion rea
JKOPay (街口支付)	QR code payments and P2P transfers to contacts; paying for bills.	> 7 Mil-	Taiwan lion
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 Mil-	Taiwan lion
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
iPASS MONEY (一卡通)	Digital version of the iPASS card which can be used for QR code payments, P2P transfers to contacts, paying bills and public transport.	?	Taiwan

Payment App Features	Users in Taiwan Origin
E.Sun Wallet let (玉山 Wallet) let)	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 let (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
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 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.

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 CO₂ 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 22: 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.

People will be more likely to save and invest if it’s easy. In Sweden, point of sales (PoS) lending 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 Millenials 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 currencies 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 66: 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	Robo-Advisor	US
Invest		
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).

Similarly, both Line, through its 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 its robo-advisor in 2024 (Paul, 2024). Douugh's tagline explains 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

Service	Features	Website	Availability	Users	Investments	Savings	Payments	Sustainability Focus
Alipay	Payments, banking, Yu'e Bao, Ant Fortune investing	alipay.com	China, Global (limited)	1.3 billion	Yes	Yes	Yes	No
WeChat Pay	Payments, financial services, Licaitong investing	wechat.com	China, Global (limited)	900 million	Yes	No	Yes	No
Apple Pay	Contactless payments	apple.com	Capital pay	744 million	No	No	Yes	No
PhonePe	Payments, mutual funds, digital gold	phonepe.com	India	590 million	Yes	Yes	Yes	No
Paytm	Payments, banking, Paytm Money for stock & fund investing	paytm.com	India	350 million	Yes	Yes	Yes	No
Google Pay	Payments, loyalty, transit	pay.google.com	Global	150 million	No	No	Yes	No

Service	Features	Website	Availability	Users	Investing	Savings	Payments	Shopping (Payments)	Sustainability Focus
Samsung Pay	Mobile payments	samsung.com	Global	?	No	No	Yes	Yes	No
Zelle	Bank-to-bank P2P payments	zellepay.com	USA	?	No	Yes	Yes	Yes	No
Nubank	Full features of a traditional bank in a digital form	nubank.com	Brazil	?	No	Yes	Yes	Yes	No

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.

Service	Features	Website	Availability	User Base	Investing	Savings	Payments	Shopping (Payments)	Sustainability Focus	Notes
Venmo	P2P payments, crypto investing	venmo.com	USA	70 million	Yes	No	Yes	Yes	No	
Cash App	P2P payments, stock & Bitcoin investing	cash.app	USA, UK	57 million	Yes	No	Yes	Yes	No	

Service	Features	Website	Availability	User Base	Investing	Savings	Shopping (Payments)	Sustainability Focus	Notes
Chime	Online bank-ing services including spending ac-counts, savings ac-counts	chime.com	USA	22 million	No	Yes	Yes	No	
MoneyLion	Banking, investing, credit-building loans, financial tracking tools	moneylion.com	USA	20 million	Yes	Yes	Yes	No	
NerdWallet	Financial clarity all in one place	nerdwallet.com	USA	19 million	No	No	Yes	No	
SoFi	Loans, banking, robo-investing, stock & crypto	sofi.com	USA	10 million	Yes	Yes	Yes	No	

Service	Features	Website	Availability	User Base	Investing	Savings	Shopping (Payments)	Sustainability Focus	Notes
Albert	Budgeting, saving, spending, investing, access to financial advisors	albert.com	USA	10 million	Yes	Yes	No	No	
Acorns	AI-assisted micro-investing	acorns.com	USA	5.7 million	Yes	No	No	No	
Wealthsimple	Simple assisted saving & investing for Millennials	wealthsimple.com	Canada, USA, UK	2.6 million	Yes	Yes	No	No	
Qapital	Saving and investing with gamification features	qapital.com	USA	2 million	Yes	Yes	No	No	
M1 Finance	Finance Super App	m1.com	USA	1 million	Yes	No	No	No	
Finimize	Investment research for anyone	finimize.com	Global	1 million	Yes	No	No	No	
Robinhood	Investing	robinhood.com	US	?	Yes	No	No	No	

Service	Features	Website	Availability	User Base	Investing		Savings	(Payments)	Shopping	Sustainability Focus	Notes
					Yes	Yes					
Betterment	AI-assisted cash management, savings, retirement, and investing	betterment.com	USA	?	Yes	Yes	No	No	No	No	
Revolut	From payments to investing	revolut.com	UK, EU	?	Yes	No	TRUE	No			
Monzo	Bank	monzo.co.uk	?	No	Yes	No	No	No			
eToro	Investing and copy-investing	etoro.com	EU	?	Yes	No	No	No			
Marcus Invest	Robo-Advisor	marcusinvest.com	USA	?	Yes	No	No	No			
Varo Bank	Online banking services including checking and high-yield savings	varomoney.com	USA	?	No	Yes	Yes	Yes			No

Service	Features	Website	Availability	User Base	Investing	Savings	Shopping (Payments)	Sustainability Focus	Notes
Stash	Micro-investing platform enabling small investments	stash.com	USA	?	Yes	No	No	No	
Mint	Budgeting tools, bill tracking, free credit score monitoring	budgetingmint.com	USA	?	No	No	No	No	Ceased operations

Up-and-Coming Startups

Service	Features	Website	Availability	User Base	Investing	Savings	Shopping (Payments)	Sustainability Focus	Notes
Chipper Cash	Digital cash app for African markets	chippercash.com	Ghana, Nigeria, Uganda, USA	?	No	No	Yes	No	

Service	Features	Website	Availability	User Base	Investing		Savings	Shopping (Payments)	Sustainability Focus	Notes
					Yes	No	Yes			
Douugh	AI financial well-being app, smart account, saving tools	douugh.com	USA, Australia	?	Yes	Yes	Yes	Yes	No	Merged with Goodments
DUB	Copy-trading, mirror trades of notable figures	dubapp.com	USA	1 million down-loads	Yes	No	No	No	No	
Earthfolio	AI-assisted socially responsible investing	earthfolio.com	USA	?	Yes	No	No	No	No	Yes
Ellevest	AI-assisted robo-advisory focused on female investors and women-led business	ellevest.com	USA	?	Yes	No	No	No	No	

Service	Features	Website	Availability	User Base	Investing		Savings	Shopping (Payments)	Sustainability Focus	Notes
					?	Yes	No	No	Yes	Merged with Douugh
Goodmen	Matching goodments	goodmen.com	US, Sam	?		Yes	No	No	Yes	Merged with Douugh
Grünfin	Invest in funds	grünfin.com	EU	?		Yes	Yes	No	No	Ceased operations
Lightyear	Simple UI for Stocks, ETFs, interest from Estonia	lightyear.ee	EU	?		Yes	No	No	No	
Mintos	Buy bonds and loans	mintos.com	EU	?		Yes	No	No	No	
Mos	Banking for students	mos.com	US	?		No	Yes	Yes	No	
Selma	Finnish investing app	selma.com	EU	?		Yes	No	No	No	
SingleEarth	Nature-backed crypto currency	single.earth	Global	?		Yes	No	No	Yes	

Service	Features	Website	Availability	User Base	Investing	Savings	Shopping (Payments)	Sustainability Focus	Notes
Tomorrow Bank	Green Banking	tomorrowbank.com	EU	120,000	No	Yes	Yes	Yes	
Trine	Loans to eco-projects	trine.com	USA	?	Yes	No	No	Yes	
Ziglu	UK simple investing app	ziglu.io	UK	?	Yes	No	No	No	

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).

10.3.4 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 70: Example sustainable loyalty schemes

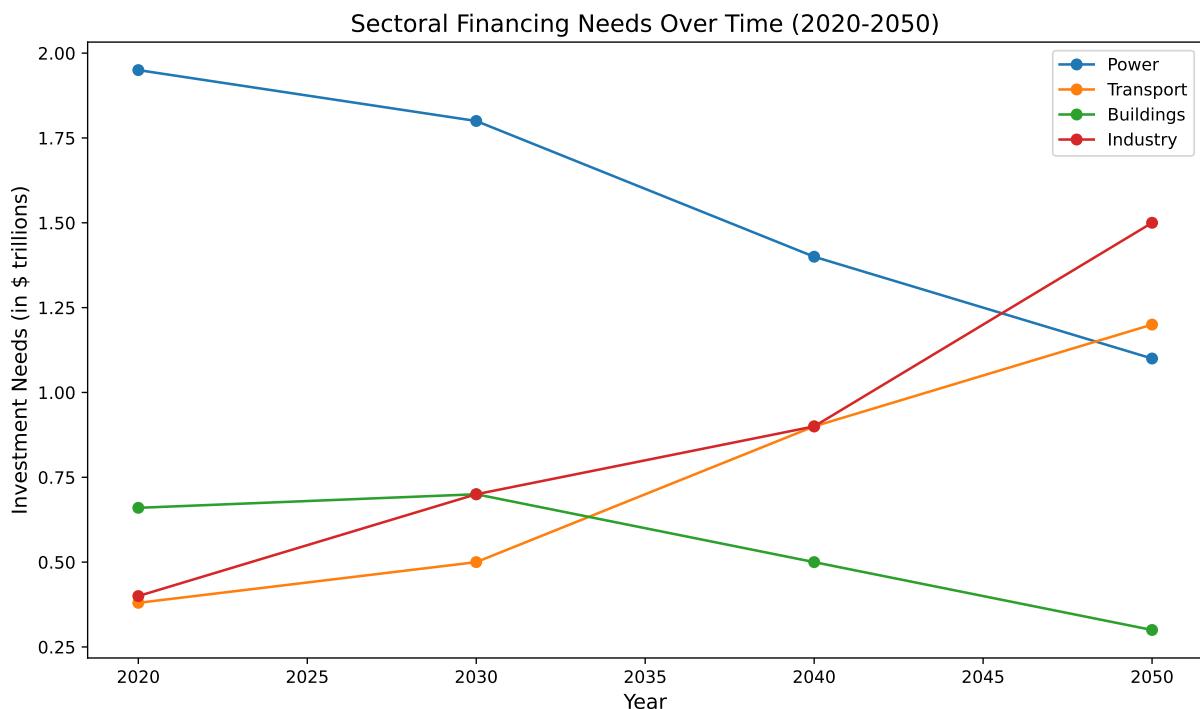
Company	Scheme
Patagonia	"Worn Wear" program
H&M	Garment Collecting program
The Body Shop	Return, Recycle, Repeat

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).

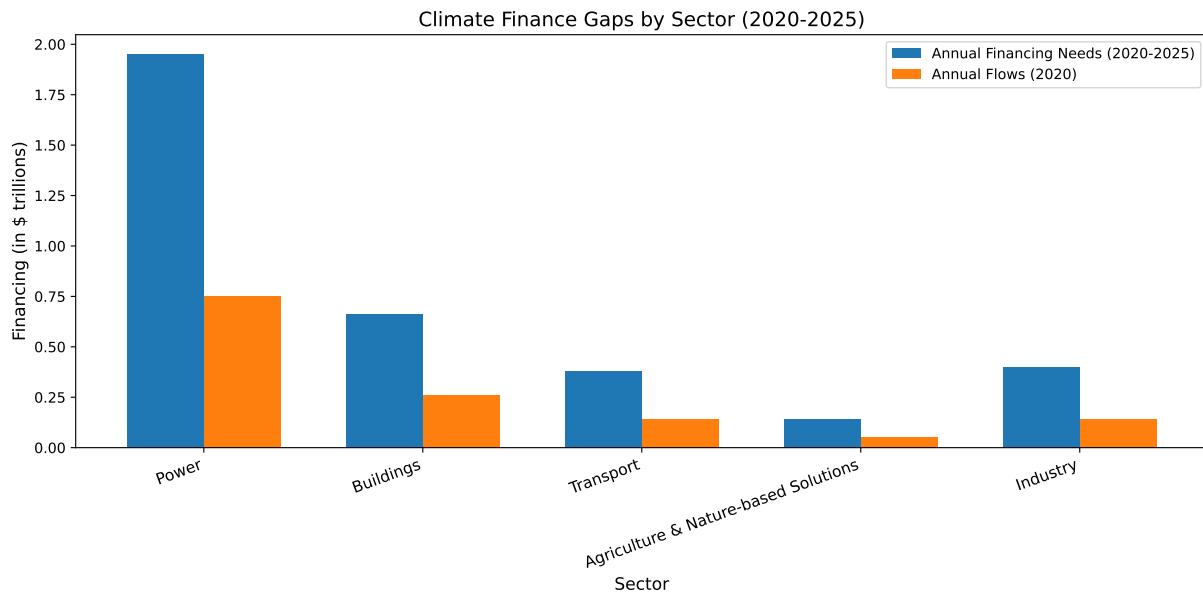
10.3.5 Sustainable Investing: Measuring the Eco-Investment Gap

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.



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.

Bad news. 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.

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.

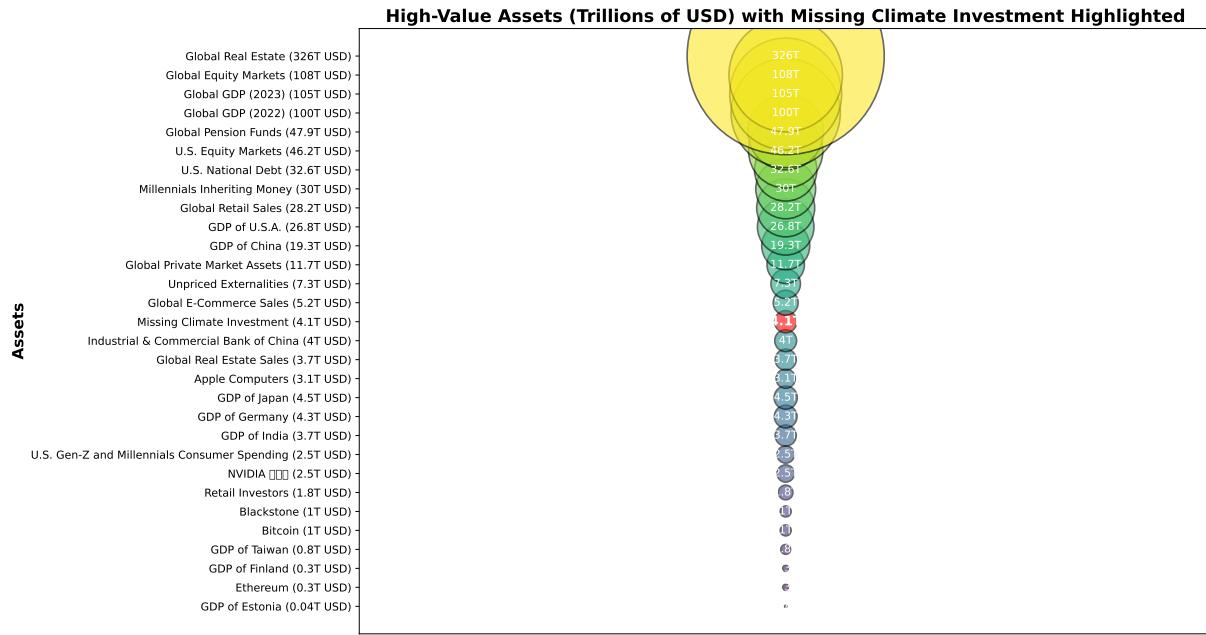


Table 71: Comparative data on needed climate investment and other valuable assets; all figures in Trillions of USD (Aaron O'Neill, 2023; Blockworks, 2023a, 2023b; M. Fox, 2023; Grand View Research, 2021; IMF, 2023a; McKinsey & Company, 2023; Oguh & Oguh, 2023; Rao, 2023; SIFMA, 2023; S&P Global, 2019; 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
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

High-Value Assets (Trillions of USD)

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.

10.3.6 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 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 (S. 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) suggest philanthropy is on the rise in Asia in general. (M. Li et al., 2022)

suggests retail “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.

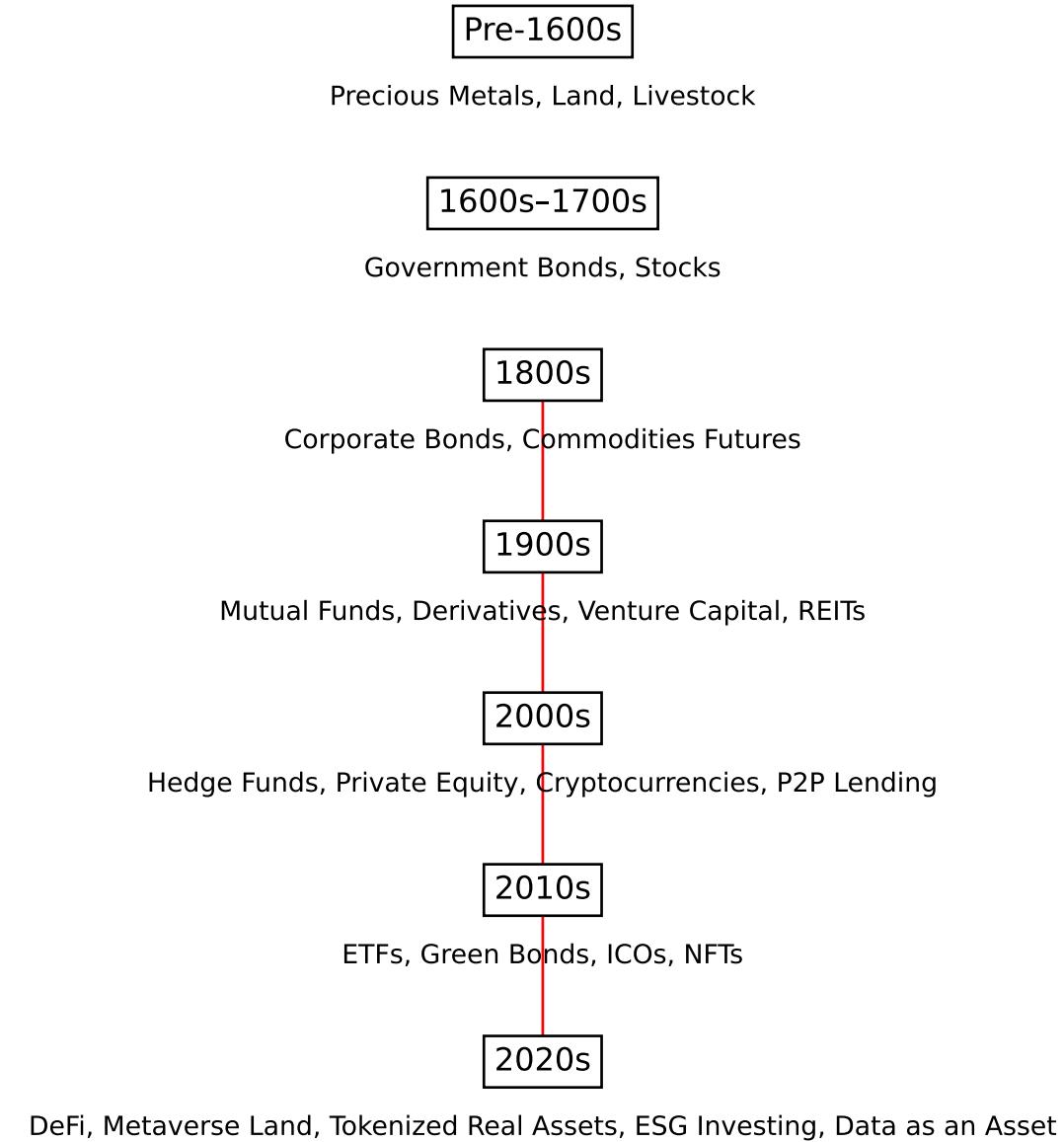
10.3.7 Investable Asset Classes for Retail Investors: Increasing Exposure to Stocks, Bonds, Commodities, Real-Estate, Digital Tokens and Alternatives, Lending, Futures, Hedge Funds, Private Equity, and even Venture Capital

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).

Investment Product
Stocks
Bonds
Mutual Funds
ETFs
Insurance Products such as Variable Annuities

There are also newer 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).

"Green Bonds, Sustainable Equities, ESG-focused Mutual Funds and ETFs, Impact Investing (through platforms), Renewable Energy Infrastructure (via ETFs or mutual funds), Sustainable Real Estate (through REITs or ETFs), Social Bonds, Carbon Credits (via ETFs or specialized funds), Sustainable Commodities (via ETFs or funds), Community Investing (through CDFIs or crowdfunding platforms), Sustainable Infrastructure Funds (available as ETFs or mutual funds), Environmental, Social, and Governance (ESG) Metrics Integration (through broad ESG-focused ETFs or funds)"

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.

Name	Description	Link	Sources
Trine		trine.com	
The Many		the-many.com	
Sugi		sugi.earth	

Name	Description	Link	Sources
ClimateInvest		clim8invest.com	
Circa5000		circa5000.com	
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 through one of the platforms listed above that directly 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.

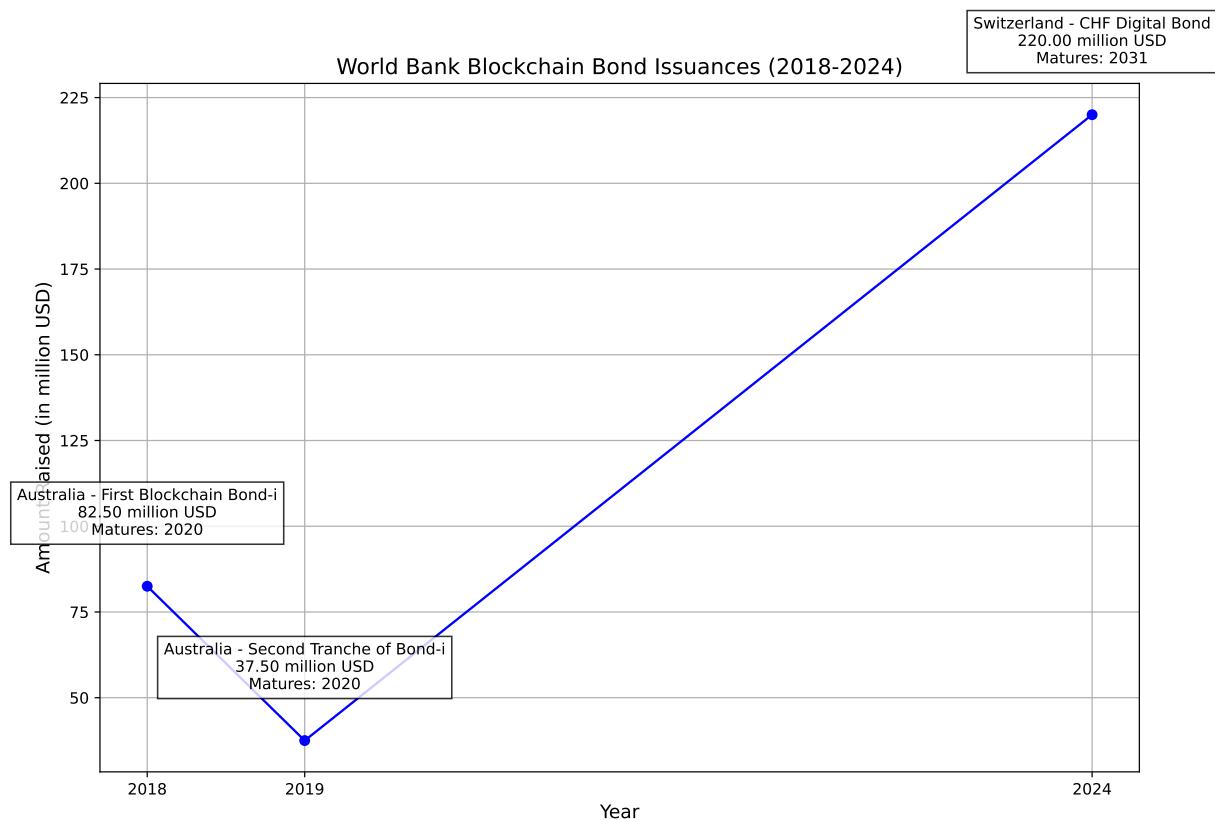
10.3.8 Green and Sustainability-Linked Bonds

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 (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).



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.”

10.3.9 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 “Crypto investors in Brazil are generally younger, male, and exhibit higher risk tolerance 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).

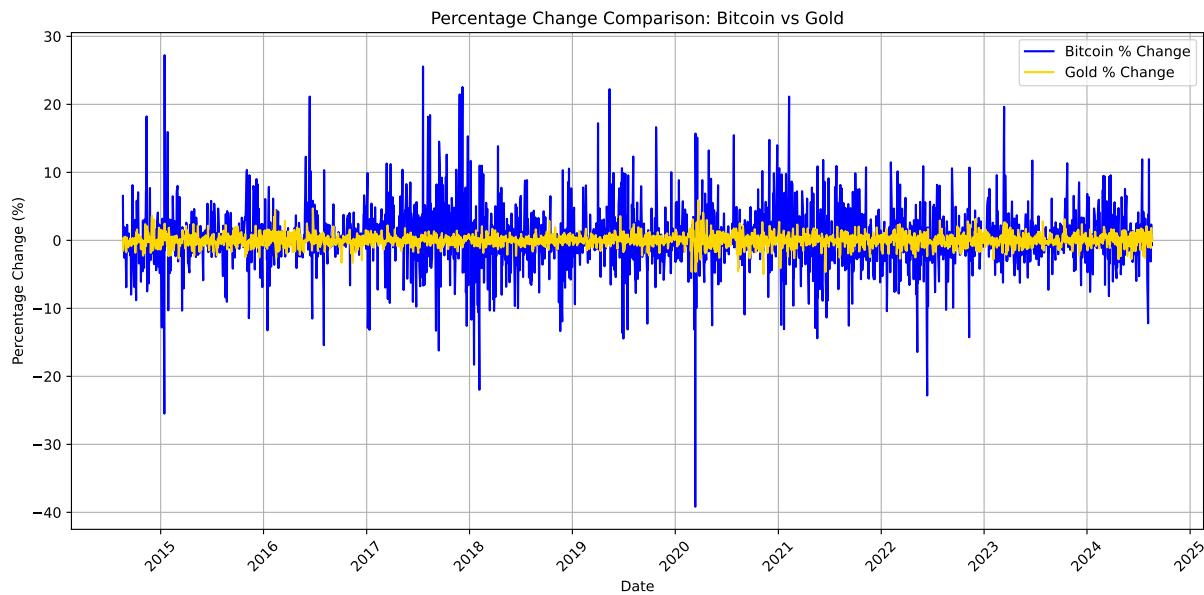
There's also a large trend of fusion of decentralized finance (DeFi) and traditional finance (TradFi), with the largest established investors, such as BlackRock, launching tokenized funds (Matos, 2024; Sandor, 2024; Securitize, 2024). Tokenization is similar financial securitization which has been happening 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.

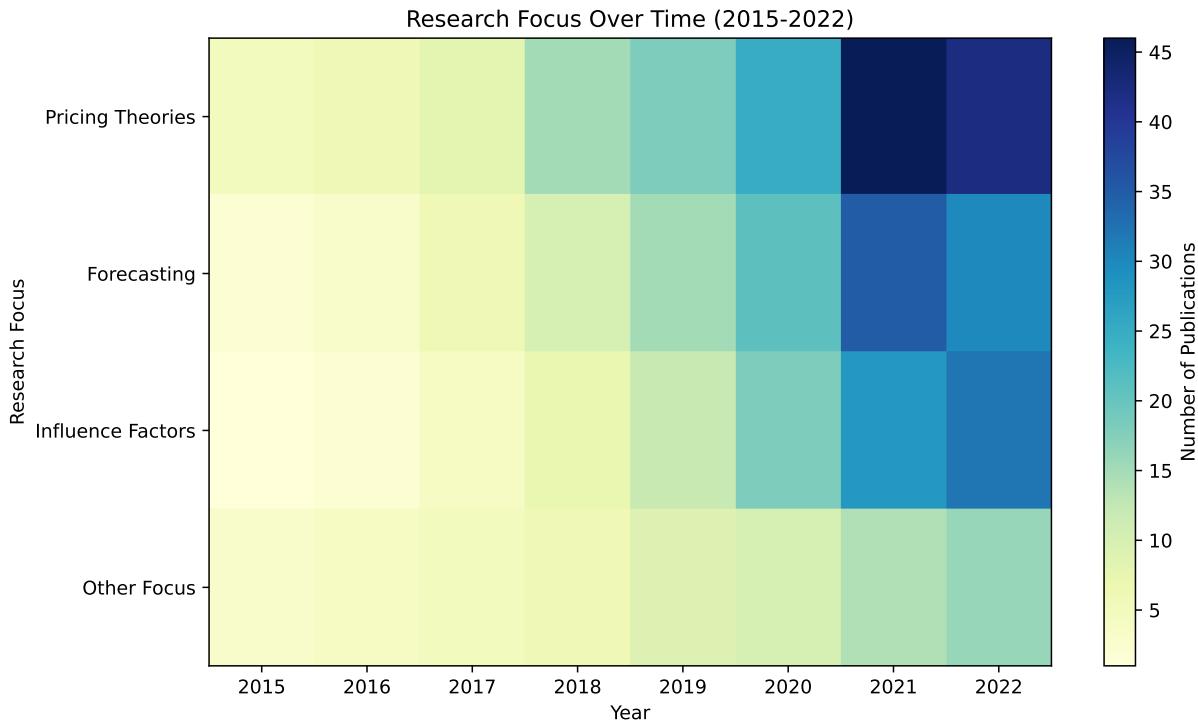
To put it very simply (knowingly oversimplifying), in traditional finance legislation is an enabler of corruption as in the case of Swiss privacy laws, where illegal funds can be hidden, while in cryptocurrencies, the lack of clear and comprehensive regulation is an enabler of corruption.

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. However volatility is relative. Volatile national currencies lead people to find other assets to hold. If your national currency is collapsing, you might find crypto has a relative safe haven to keep your funds. People like Turkey losing 75% of the value of their assets when currency collapses, why people buy crypto.



For example, in X research an index of major sustainability news was compared with crypto

prices, which may have negative, positive, or no correlation with the following cryptocurrencies.

10.3.10 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.

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 MCO□), 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 MCO□) 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 financial

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).

10.3.11 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 CO₂e 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.

10.4 The Economics of Decoupling: Attempts to Disconnect Economic Growth from Eco-Degradation

Is the “eco” in ecology and economy the same? *Oikos*, 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?

10.4.1 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).

10.4.2 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).

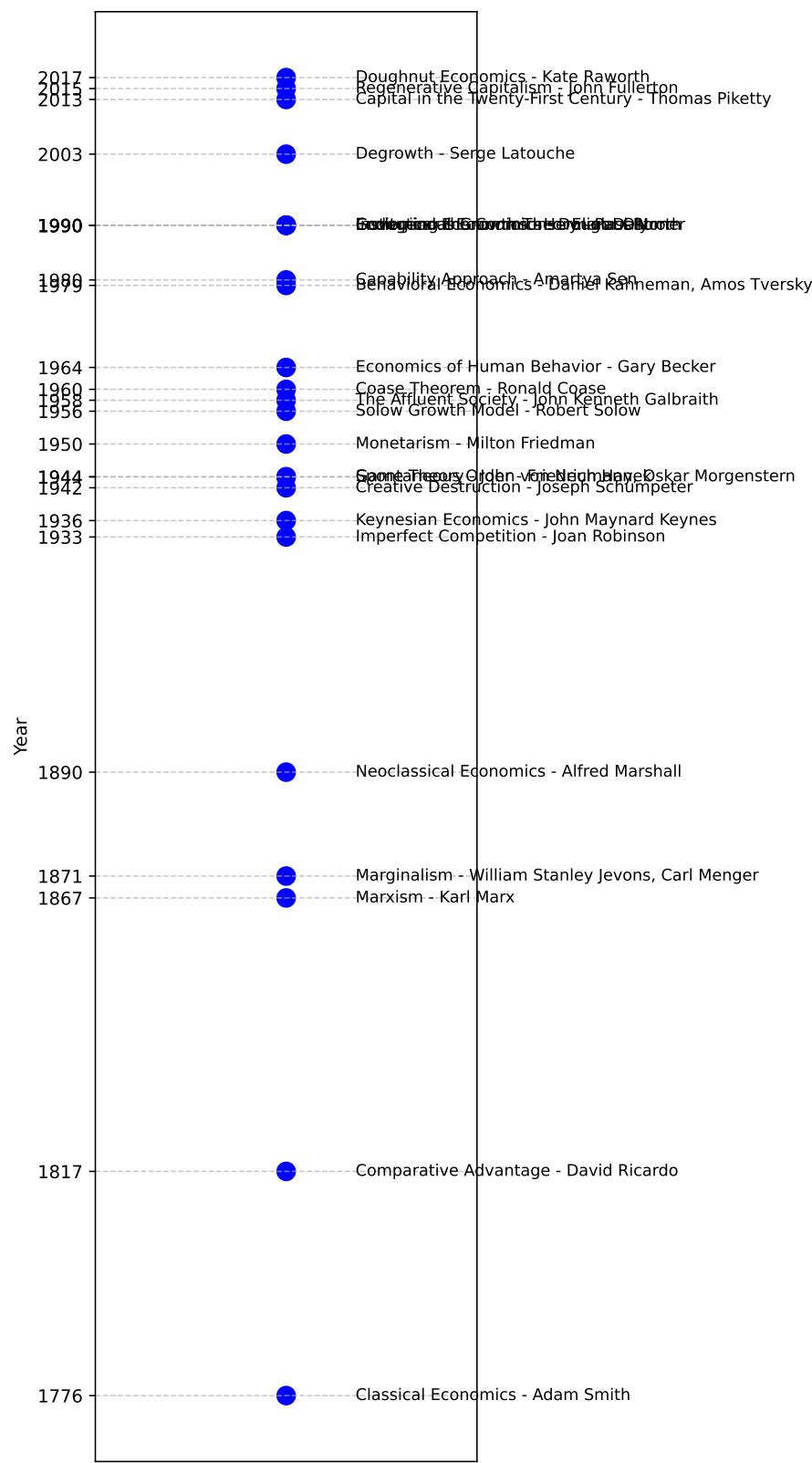
Measuring wellbeing in addition to GDP and the metric should include resiliency dashboards, to visualize metrics beyond GDP and they are an integral part of country reports (GreensEFA, 2023). Similarly, the doughnut (donut) economics (more below) model calls for a "*dashboard of indicators*" (TED, 2018).

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.

10.4.3 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.

Timeline of Notable Economic Theories and Authors



There are those looking for *new metrics*. One of the first innovators, already in 1972, was Buthan, 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 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).

10.4.4 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.

10.4.5 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 another 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 CO₂e 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.

10.4.6 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 74: From (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

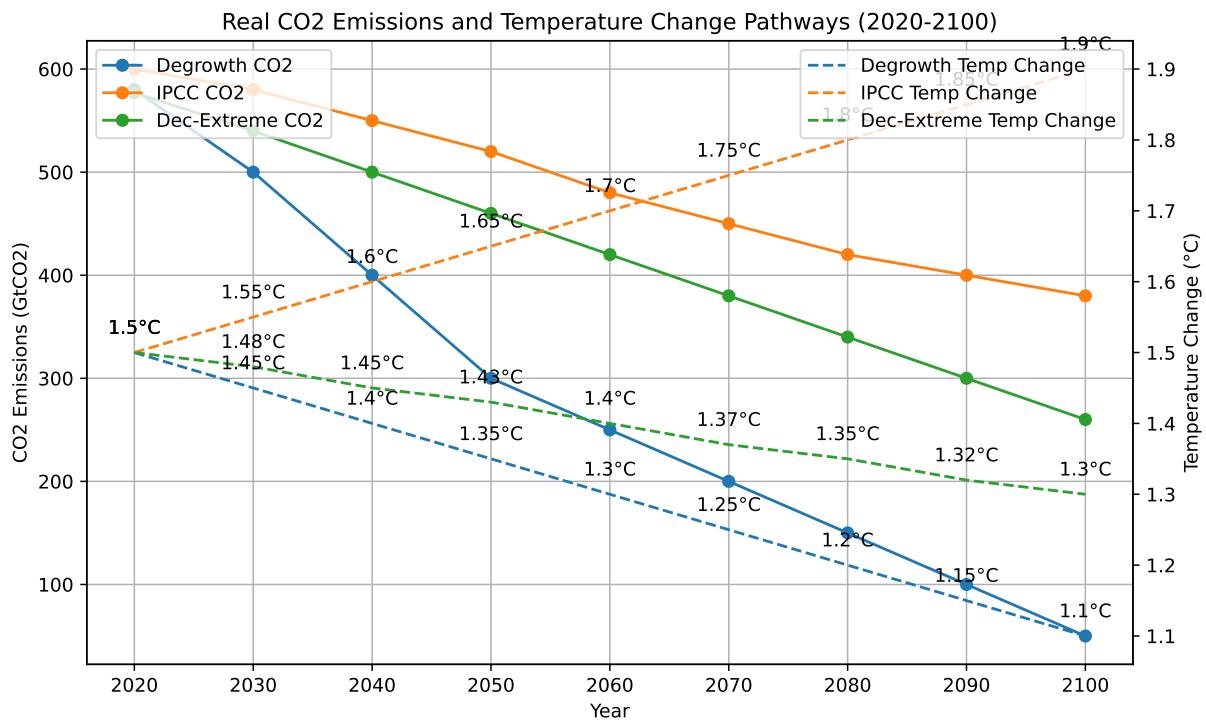
In his 2015 paper Regenerative Capitalism, John Fullerton, an investor and a capital markets and derivatives expert, builds his economic theory on the ideas of Club of Rome and the Limits to Growth (Meadows & Club of Rome, 1972) as well as taking inspiration from R. Buckminster Fuller.

“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)

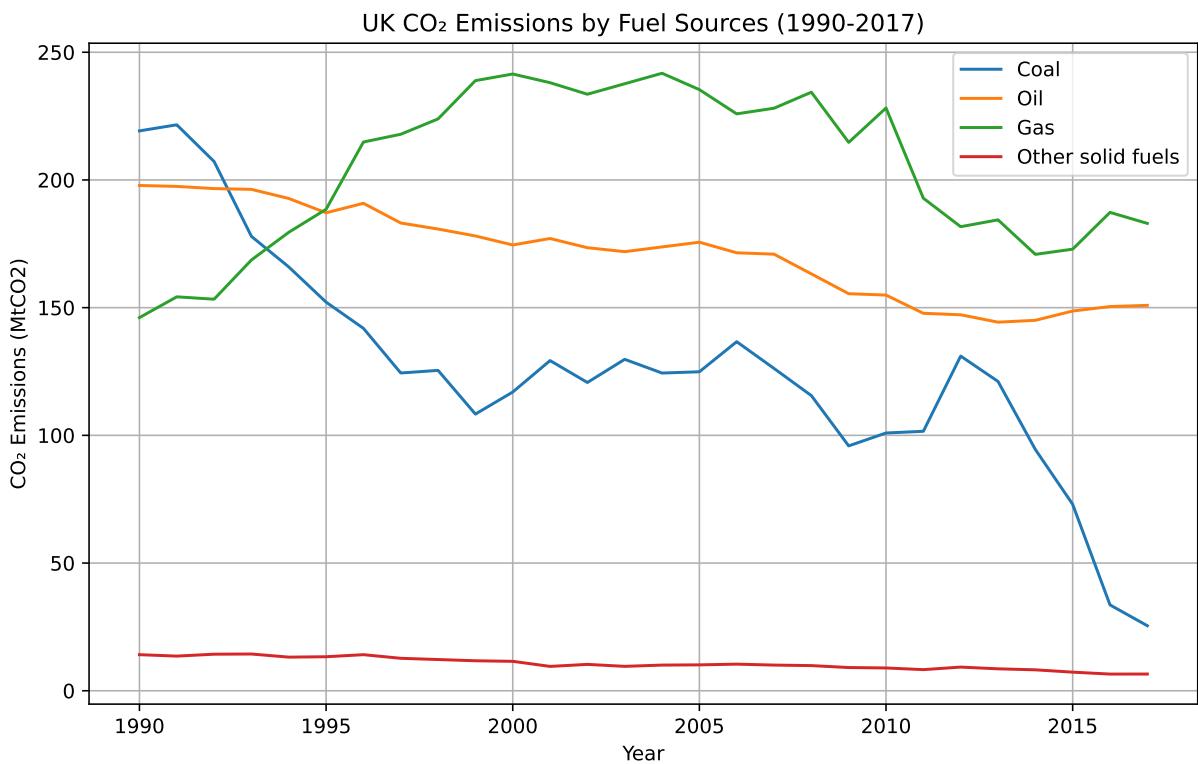
“[H]uman civilization is embedded in the biosphere,” Fullerton’s ideas aim to balance efficiency with resiliency so the whole system doesn’t become brittle and break (Confino, 2015; John Fullerton, 2011, 2022). While regenerative capitalism recognizes the need for economic growth it also deems “[t]he 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).

10.4.7 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.

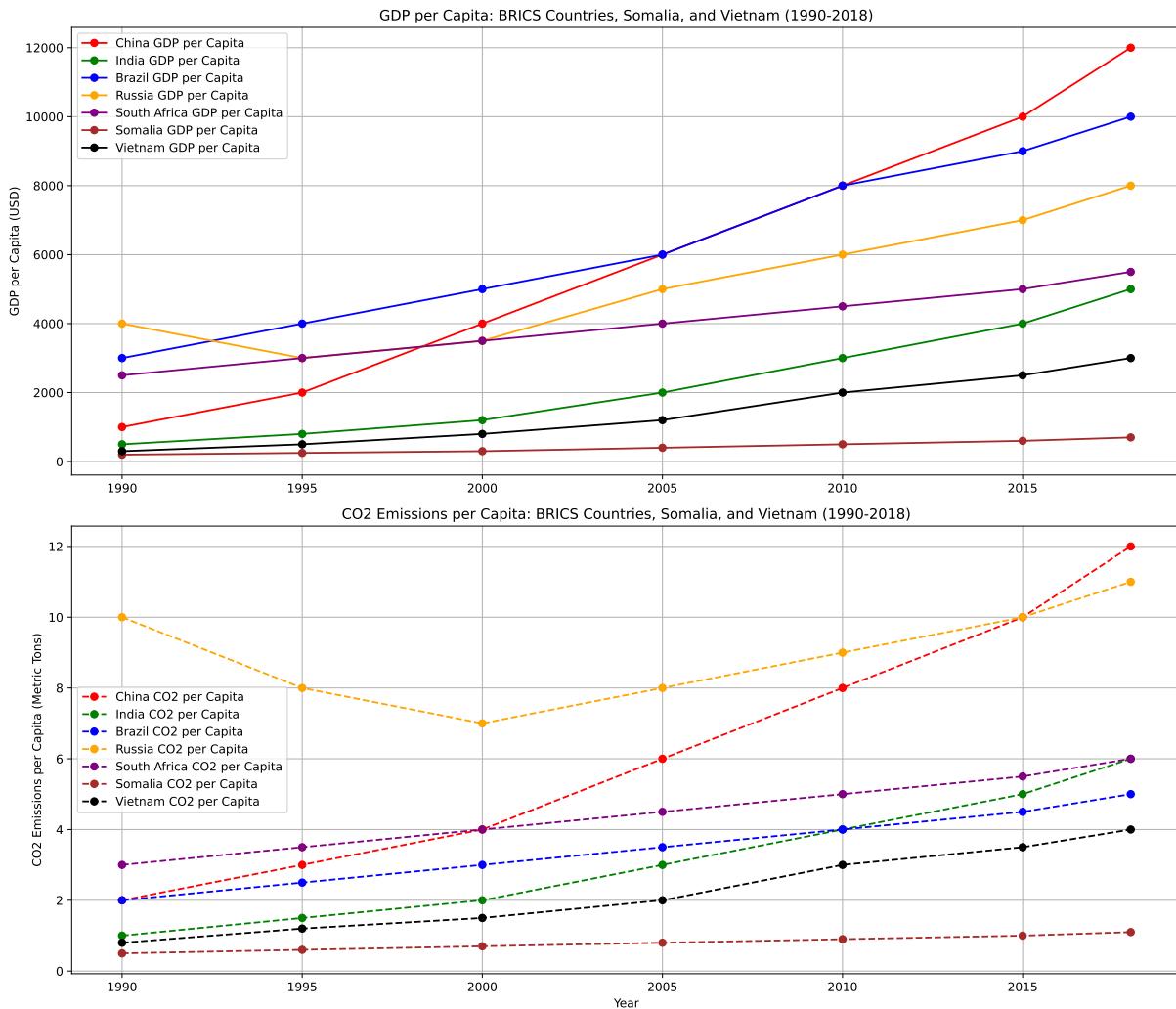


Looking at the United Kingdom, (harrisson, 2019) concludes UK's CO_{2e} emissions have fallen 43% from 1990 to 2017 through the use of less carbon-intensive energy sources and argues for moderate policies in (Hausfather & Peters, 2020).



Meanwhile the cumulative CO_{2e} emissions trend in the UK in the same time-frame show the historic responsibility of UK (Global Carbon Budget, 2023).

CO_{2e} 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).



10.4.8 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, tippings 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-modelling 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 75: 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
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

10.5 Efforts to Curb Greenwashing: Data-Driven Benchmarks and the Fight for Transparency

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. Environmental Information Disclosure (EID). Marketing - Sustainability Marketing. Countering Misinformation with Transparency.

Corporate hypocrisy is an important 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). EU regulation for standardizing sustainability reporting is called the Corporate Sustainability Reporting Directive (CSRD) entered into force in 2023 and is being gradually ramped up until 2027.

Green investing only makes sense if it's possible to distinguish sustainable investments from not sustainable ones. Humans feel as if choosing green is useless and 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.

Upcoming EU greenwashing legislation hopes to curb misleading communications by companies. *"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). 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 (Nastaraan 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).

While the EU has proposed legislation to curb greenwashing, EU climate policy itself has been criticized for greenwashing. Sometimes greenwashing comes under legislative protection Kira Taylor (2021). (Booth, 2022) describes how "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”.

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).

10.5.1 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 green-washing (綠色公民行動聯盟, 2024).

10.5.2 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 ensure product inventory, traceability, automated check-out, 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.).

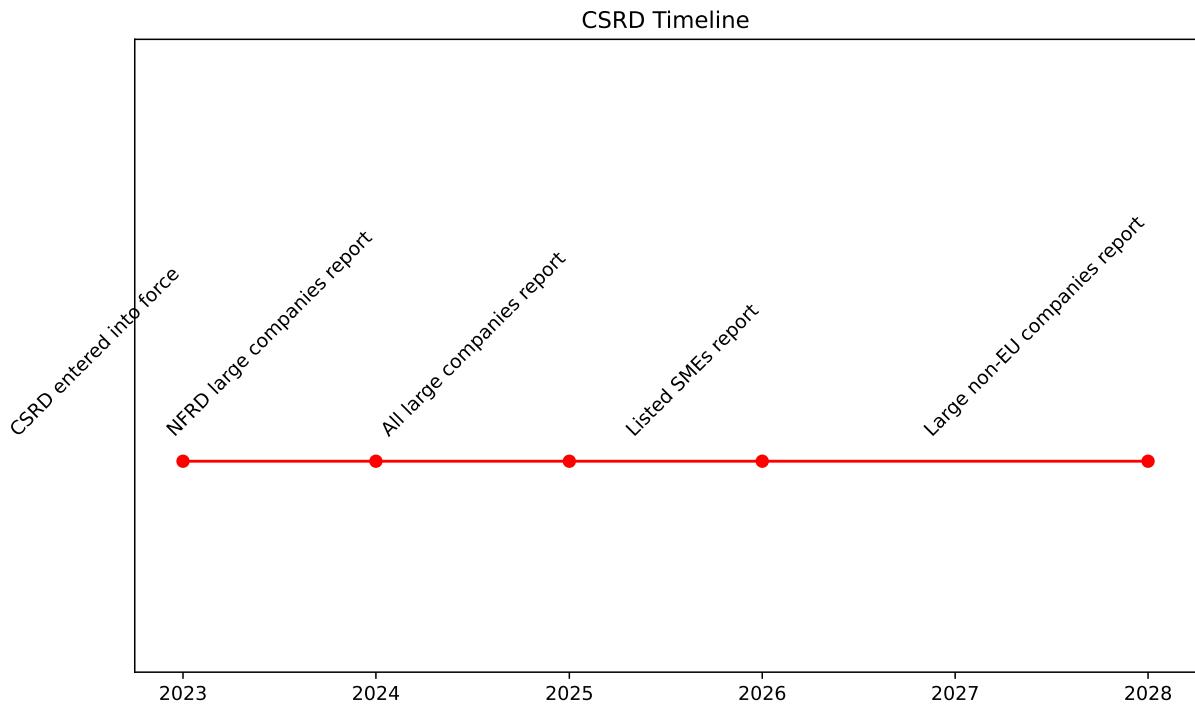
In a similar vein, Konrad (n.d.) imagines the possibility of an internet-wide directory of purchasable products, akin to how platforms like Spotify have made nearly all of the world’s music easily searchable and accessible. However, despite the obvious need, attempts to build such directories have faced 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.

10.5.3 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).



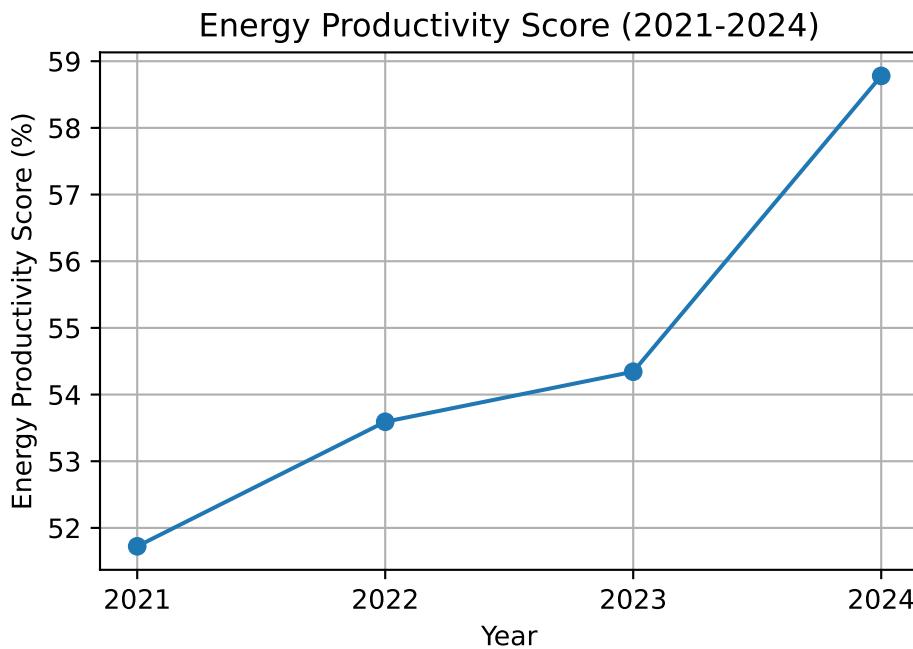
Companies assess customer's credit score to decide credit-worthiness, however inversely, how can customers rate companies? Indices make comparing companies possible. There are many many indexes, scoring systems, ratings, certifications, etc. Most sustainable companies. Make a database?

Sustainability indices need transparency and standardization (Bolognesi et al., 2024).

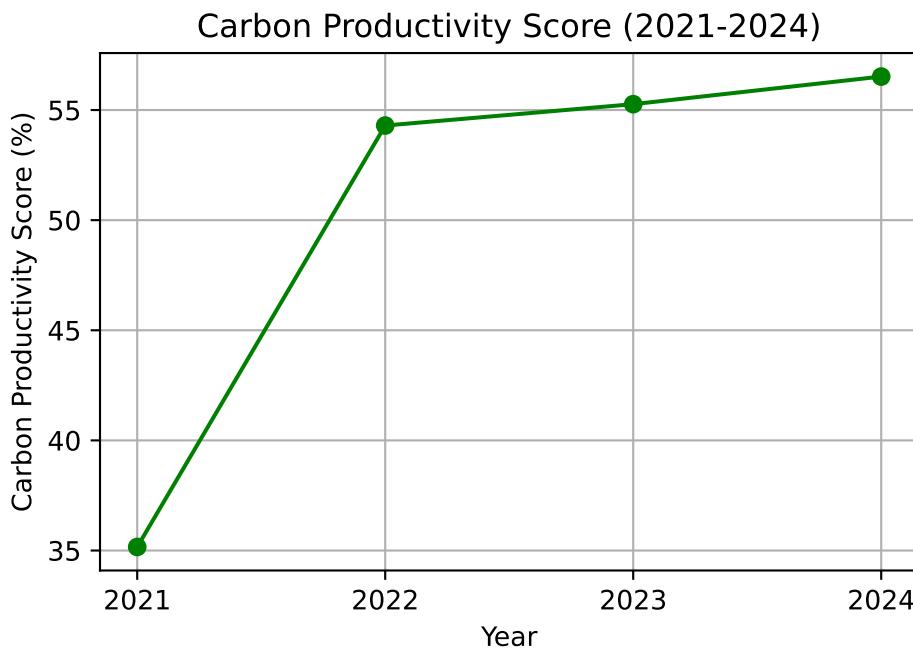
Based on Corporate Knights data (Corporate Knights, 2024)

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



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.”

11 TYPE RATING		13 WHAT IT DOES
Certificate	ESG SYSTEMS Certified Trade	B Impact Assessment
Ranking	Responsible Business Corporation Index	<i>Estonian Responsible Business Index</i> (n.d.) Responsible business index
Index	Greenly Science-Based Targets	Greenly Decarbonization Index Greenly (2023) Science-Based Targets initiative (SBTi) provides step-by-step guidance per economic sector help companies get started with meeting climate criteria and emission reduction requirements.
Certificate	Green Web Foundation	“The Green Web Foundation” (2023) For example, the Green Web Foundation certifies how sustainable is the web hosting used by websites. Testing website CO ₂ emissions Wholegrain Digital (2023)
	Leafscore for product	LeafScore (2023)
Rating	Ethical consumer ratings	<i>About Ethical Consumer Ethical Consumer</i> (2018)
	1% For the Planet	
Standard	Climate Neutral Certified Standard	
Standard	The Conservation Alliance	(Climate Neutral Certified, 2023).
Index	Impact Sustainabil- ity Inde	

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).

#	Target / Product	Category	Called by (lead organisation)	Year launched
1	Airbnb	Human Rights	BDS National Committee	2016
2	Amazon	Human Rights	BDS National Committee	2024
3	Amazon (tax-avoidance)	Tax Avoidance	Ethical Consumer	2012
4	AXA	Human Rights	BDS National Committee	2019
5	Barclays Bank	Human Rights	Palestine Solidarity Campaign	2024
6	Booking.com	Human Rights	BDS National Committee	2024
7	Burger King	Human Rights	BDS National Committee	2024
8	Chevron	Human Rights	BDS National Committee	2022
9	Coca-Cola	Human Rights	Friends of Al-Aqsa	2014
10	Coconut milk (from Thailand)	Animal Rights	PETA	2022
11	Crufts dog show	Animal Rights	PETA	2014
12	Disney / Marvel	Human Rights	BDS National Committee & allies	2023
13	Ecover	Animal Testing	Naturewatch Foundation	2018
14	eToro	Human Rights	Tech for Palestine	2024
15	Expedia	Human Rights	BDS National Committee	2024
16	Get Your Guide	Animal Rights	World Animal Protection	2023
17	Google	Human Rights	BDS National Committee	2024
18	Groupon	Animal Rights	World Animal Protection	2023
19	Hewlett Packard Enterprise (HP)	Human Rights	BDS National Committee	2012
20	Israeli dates	Human Rights	American Muslims for Palestine	2012
21	Israeli produce in supermarkets	Human Rights	BDS National Committee	2005
22	JCB	Human Rights	BDS National Committee	2024

#	Target / Product	Category	Called by (lead organisation)	Year launched
23	Kellogg's	Environment	GMO-Free USA	2012
24	L'Oréal	Animal Testing	Naturewatch Foundation	2000
25	"Made in China" goods	Human Rights	Friends of Tibet & others	2020
26	McDonald's	Human Rights	BDS National Committee	2024
27	Method	Animal Testing	Naturewatch Foundation	2018
28	Mitie	Human Rights	Women for Refugee Women	2023
29	Nestlé (baby-milk)	Human Rights	Baby Milk Action	1977
30	Nestlé (water extraction)	Environment	Lakota People's Law Project	2018
31	Papa John's	Human Rights	BDS National Committee	2023
32	Pizza Hut	Human Rights	BDS National Committee	2023
33	Russia (national boycott)	Oppressive Regimes	Government of Ukraine	2022
34	Sabra Hummus	Human Rights	BDS National Committee	2010
35	Siemens	Human Rights	BDS National Committee	2022
36	SodaStream	Human Rights	BDS National Committee	2012
37	Starbucks	Habitats & Resources	Lakota People's Law Project	2023
38	Tesco Bank	Human Rights	Palestine Solidarity Campaign	2024
39	Texaco	Human Rights	BDS National Committee	2022
40	Trip.com	Animal Rights	World Animal Protection	2023
41	Tui	Animal Rights	World Animal Protection	2023
42	Twitter / X	Human Rights	Stop Toxic Twitter coalition	2022
43	Unilever (Russia operations)	Human Rights	B4Ukraine	2024

#	Target / Product	Category	Called by (lead organisation)	Year launched
44	Volvo (AB Volvo trucks)	Human Rights	BDS National Committee	2024
45	Wendy's	Workers' Rights	Coalition of Immokalee Workers	2005
46	Wix	Human Rights	Tech for Palestine	2023
47	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).

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.

13.1 Navigating Complexity with Data: Probabilistic Risk-Based Assessment of Sustainability

- 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.
- “Companies in industries with the biggest carbon footprints aren’t reporting how their emissions feed into financial risk, according to an analysis of corporate reports by the Carbon Tracker Initiative.” (Frances Schwartzkopff, 2022b)

BeZero is innovating in the voluntary carbon credit market (VCM) by providing risk-scoring, a language financial professionals are accustomed with (BeZero, 2022b; *Navigating Net Zero with Co-founder of BeZero Carbon*, 2023)

- “Automate your carbon accounting. Make data-driven decisions, across your entire supply chain.” Ratings for mines CarbonChain (n.d.)
- Efforts to connect carbon markets, carbonmark.com
- “We believe that markets for ecosystem assets need to scale urgently, starting with carbon markets. The challenge is to make these instruments as recognizable as tradeable assets, as measurable as financial securities, and as investable as other asset classes. Capital must flow into the environment at scale to deliver climate action.” “Efficient financial markets allocate and manage risk based on effective price mechanisms, and this relies on access to credible information.” BeZero (2022b)

- “Everyone in the market is struggling to effectively price and manage risk.. the Voluntary Carbon Market (VCM); a rapidly recovering market, forecasted to grow by as much as 100x, but constrained by a nascent market structure.” “The BCR is a carbon-only expected return model. It utilises a risk-based approach and seeks to give everyone a common language of risk. One that is translatable to that used by the \$200 trillion of assets in global financial markets.” BeZero (2022a)
- “climate action as an asset-liability problem”

14 METHODOLOGY

Start with expert survey, then expert interviews (because so many questions from literature review). Identify key concepts from expert discussion and gain industry insights.

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

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. The flyer included a colorful AI-generated visual with a futuristic game-link female figure, the title “climate anxiety survey”, a website link (ziran.tw) and scannable QR-code.

Similarly to (C.-H. Liu et al., 2023) I distributed the survey in schools in the Northern, Soutern, Central, and East regions of Taiwan.

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 80: 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？□	Will you buy a car within 7 years? □
你/妳 7 年內買房嗎？□	Will you buy a house within 7 years? □
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?

Original Question in Chinese	English Translation
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 CO2 也增長嗎？	Do you think the economy can grow without emitting CO2?
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?
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 disregarded from the data anal-

ysis. 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 Quarto.

14.1 Research Design

When developing my research design, I relied on the advice of (Christian Rohrer, 2022) to decide when to choose which User-Experience Research methods.s

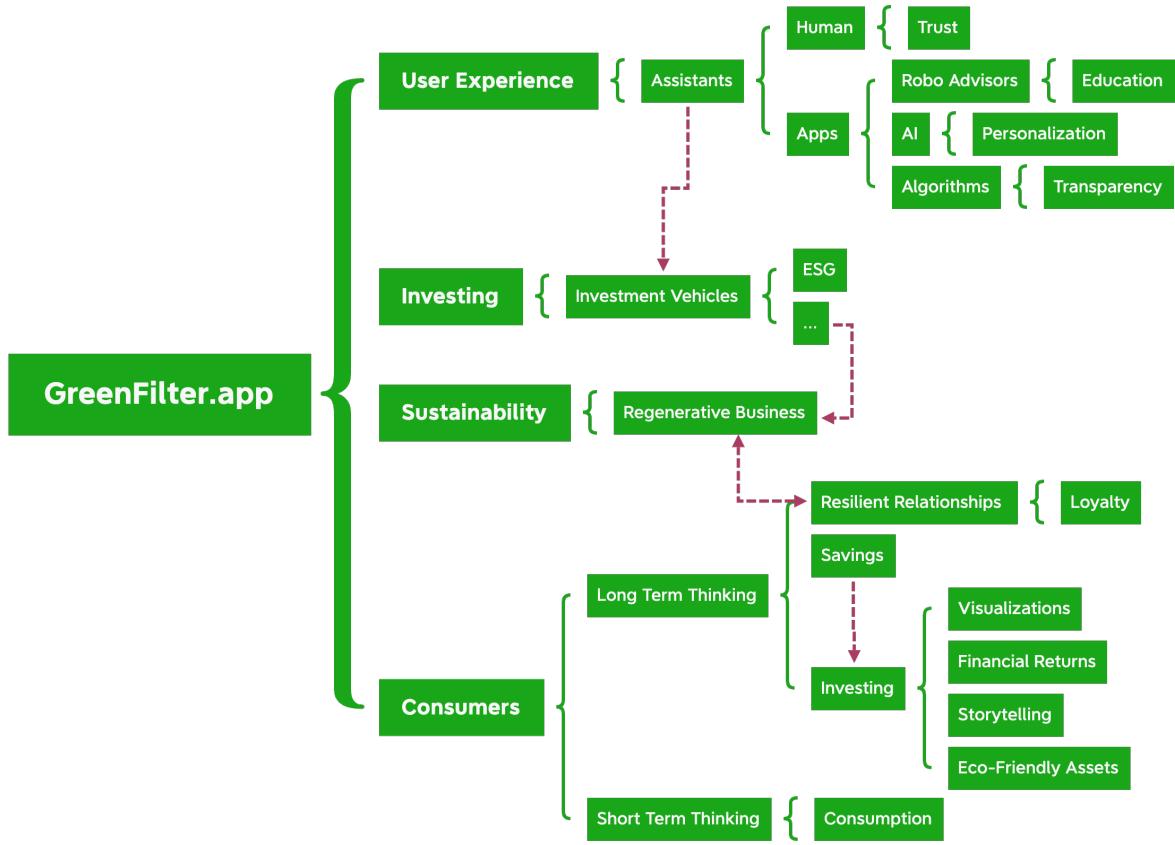
The research design of this study consists of 3 steps.

- Qualitative research targeted at financial and interaction design experts, leading to a *wish list* of features.
- Survey potential users' preferences, including a choice experiment of the proposed features.
- Design a prototype of the personal sustainable finance AI assistant, tested using qualitative methods in a focus group.
- This mixed-method research design is divided into three stages (fig. 11).
- 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 will identify 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 is defined generally as expectations towards a sustainable investment AI advisor.
- I will then proceed to the second, quantitative stage, informed by the previously identified factors, and prepare a survey, including a Likert scale, and a choice experiment, focusing on the preferences of the potential users in generation-z aged 18-29, living in Taiwan (see fig. 12 on next page), exploring the relationship between independent variables: - "Interest in Sustainability" - "Interest in Investing" - "Preferred Features" - and the dependent variable "User Sign-ups".
- In the third stage, I will return to the qualitative methods, by building a prototype of the sustainable investing AI companion, taking into account insights gathered in the previous stage. I will use a focus group to discuss the prototype, and conduct a thematic analysis of the discussions' recordings, leading to further validation of previously gathered data and possible changes in the prototype. The gained insights, accompanied by the app prototype, which embodies my findings, will be the final outcome of my research.

14.2 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 Personal Sustainable AI Financial Advisor (PSAA) 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.



Presented with xmind

Figure 23: Concept map

Conceptual Model

14.3 Research Methods

14.3.1 Phase One - Qualitative Research

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 uses non-probability snowball sampling, with the following criteria: financial industry, fintech, and design experts everywhere, including in Taiwan and Sweden, but also Estonia, Portugal, and elsewhere.

Method: Semi-Structured Interviews

I will conduct exploratory research in English using semi-structured interviews recorded online and offline.

14.3.2 Phase Two - Quantitative Research

The strength of quantitative research is to enable me to access a larger sample of potential users in two countries, using online survey methods, and to validate some of the qualitative findings from stage one.

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

Method: 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.

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

14.3.3 Phase Three - Qualitative Research

In the last phase, I will return to the qualitative methods to further validate the quantitative findings from stage two. Here my focus will be on operationalizing the gathered insights into a prototype that users can experiment with and discuss with their peers in a focus group setting.

Sampling

The phase three sampling structure uses a judgmental criterion: - age Gen-Z cohort - located in Taiwan - Using the Chinese language 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).

Method: Focus Group The strength of a focus group is the ability to observe potential users in a social setting, where knowledge can be exchanged between the participants. The whole experience, including emerging conversations, will be recorded and transcribed.

Method: Thematic Analysis Finally, I will perform a thematic analysis of the focus group transcriptions in order to validate previous findings, and open avenues for future research.

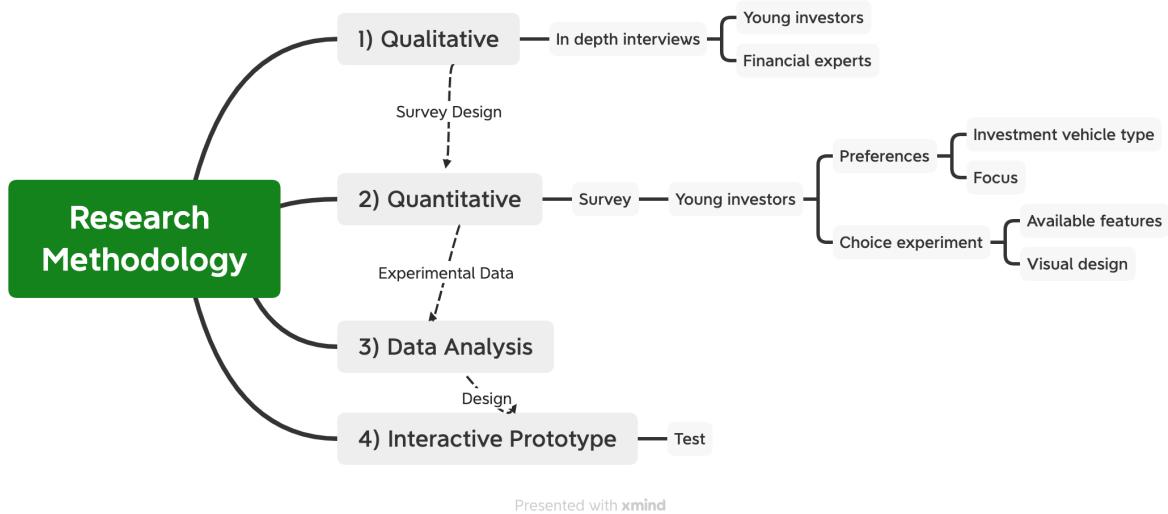


Figure 24: Overview of research methodology

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.

14.4 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.

14.4.1 App Testing Flow

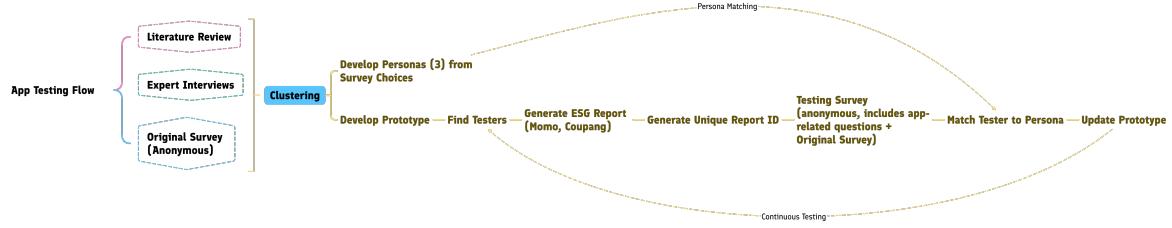


Figure 25: App Testing Flow

14.4.2 1st Wave of Testing (Spring 2024)

- 1 month from 2024 April 2 to May 2, 2024
- 8 anonymous participants at NCKU
- Participant observation
- No audio recording

14.4.3 2nd Wave of Testing (Autumn 2024 - Spring 2025)

In-Person Face-to-Face Testing

I conducted in-person 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. Face-to-face testing was concluded in several universities across Taiwan.

Region	University	No of Testees
Taichung	國立中興大學 National Chung Hsing University (NCHU)	7
	國立中正大學 National Chung Cheng University (CCU)	5
Chiayi	國立成功大學 National Cheng Kung University (NCKU)	6
	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

14.4.4 Expert Feedback

Talk to 5 experts over video call and 1 one face-to-face in English; record, transcribe, and perform thematic analysis of the contents.

15 RESULTS

For high ESG, 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.s

Expected Findings

During the preparation of this research proposal I conducted a preliminary round of facetoface interviews using 21 openended probing questions using a convenience sampling of NCKU students on campus between ages 19 and 29 a total of 12 respondents The interviews lasted between 9 and 21 minutes and were conducted to get some initial feedback on my research idea the respondents daily routines app usage feelings towards financial questions including investing relationship with nature and environmental sustainability These preliminary conversations led me to emphasize more on the financial journey ie to consider the importance of the shopping savings and payments apps students already use daily which could serve as an entry point to becoming an investor I expect my future research findings to confirm this initial idea and offer diverse ways and examples of what that path could look like in practice

Survey Overview

A survey of Taiwanese college students excludes overseas Chinesespeaking students as well as foreign students covering attitudes towards shopping saving investing economy nature sustainability and AI

Survey Oct 13th Nov 3rd 2023

2000 cards with a QR code printed out

Distribution conducted at 8 universities handing out the cards

1289 people started the survey 518 quit

771 people completed the whole survey

Data after filtering 675 people aged 18-26 GenZ Taiwanese current students in BA large majority MA small minority or PhD level very few respondents

36 likert fields 5point scale used for clustering the students into 3 personas with Kmeans clustering

14 product features multiplechoice used for Kmodes clustering

4 choice experiments

2 option ranking questions

10 text fields used to enrich the personas

Data Analysis

KMeans clustering for survey data Kmeans clustering is similar to vector distances for similarity used in large language models LLMs word embeddings and deep learning

Findings

Literature AI assistants should integrate with Digital Product Passports Literature AI assistants should show carbon label data Literature AI assistants should avoid taking ESG at face value because its a really low bar and integrate other metrics such as B Corp Literature AI assistants should Literature Do not make another investing app make a sustainability filter for excising investing platforms Literature College students can support extended producer responsibility

How might AI assistants empower regenerative shopping saving and investing

Display the ESG EPR BCorp etc etc credentials for each product and investment EPR and BCorp are success stories which should be highlighted while ESG is largely discredited There are many existing and ongoing approaches to sustainability The best approach might be to plug into excising system and communities and legislation to support and empower them

How might one design an intuitive sustainable shopping saving investing app

Apple Watch app

What app features might college students rate as the highest priority

Autopilot

How might one visualize ecological impact in digital product design

Accuracy is more important for human trust than actual impact

95,9% used a mobile device, 75,5% using an iOS device iPhone, 20,8% using an Android device design implication should design mobile app but apple is so restrictive

RQ 1

the AI companion is informed by the latest scientific insights and can provide accurate evidence-based recommendations The AI is designed to offer personalized guidance by analyzing complex environmental data and translating it into userfriendly information helping students make more sustainable choices in their daily lives It explores various AI interaction designs including chatbots voice assistants and virtual avatars to find the most engaging and supportive formats for college students address the attitudebehavior gap among college students by providing tools that make sustainable financial actions more convenient and impactful

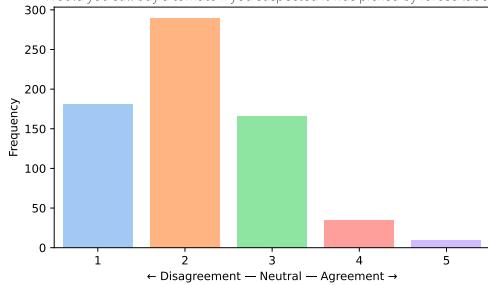
RQ 2

provide realtime information about the sustainability of products and companies AI companion includes features for identifying and investing in sustainable companies This involves providing data on companies environmental social and governance ESG practices and facilitating investments in green bonds and sustainable funds shoppingasinvesting where the AI links the act of purchasing sustainable products with investing in companies that produce these products effectively merging consumer and investor roles

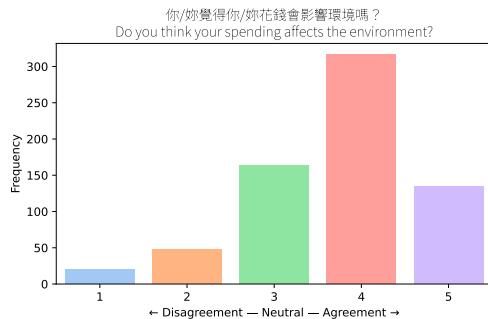
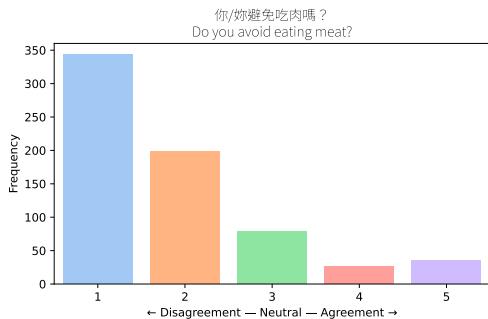
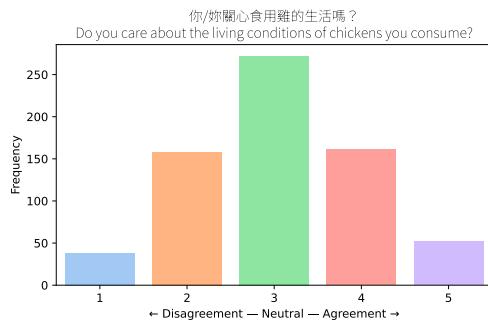
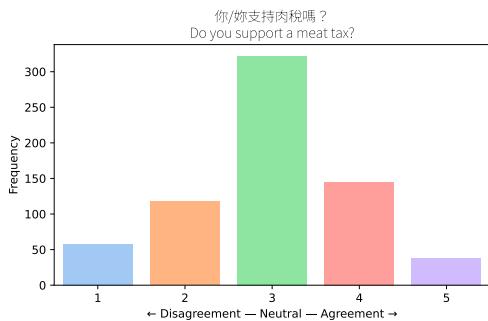
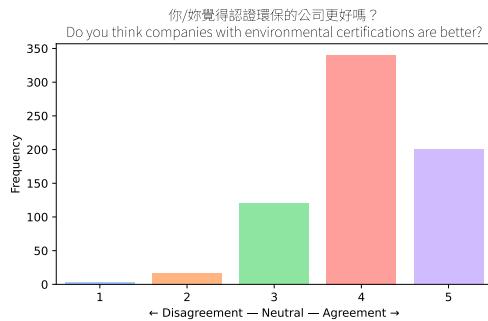
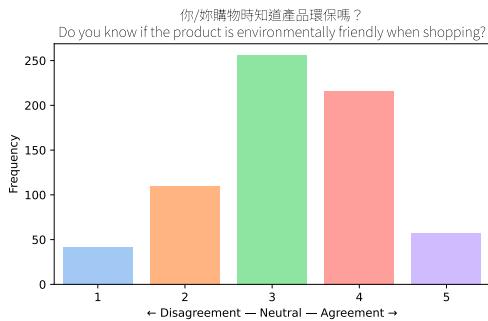
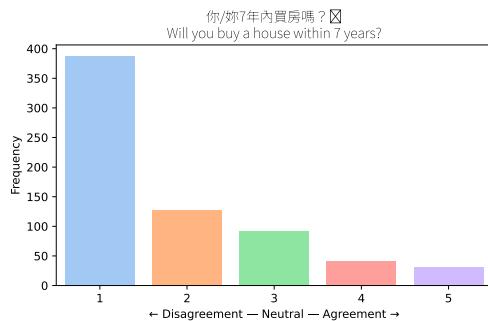
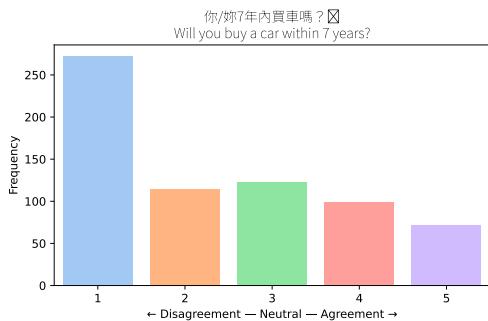
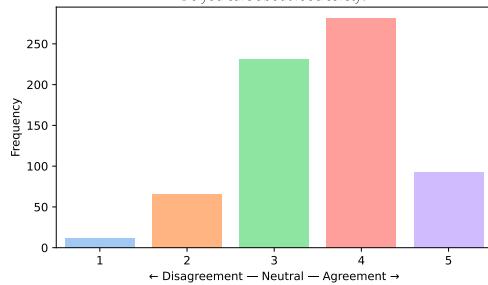
RQ 3 todo

15.1 Shopping

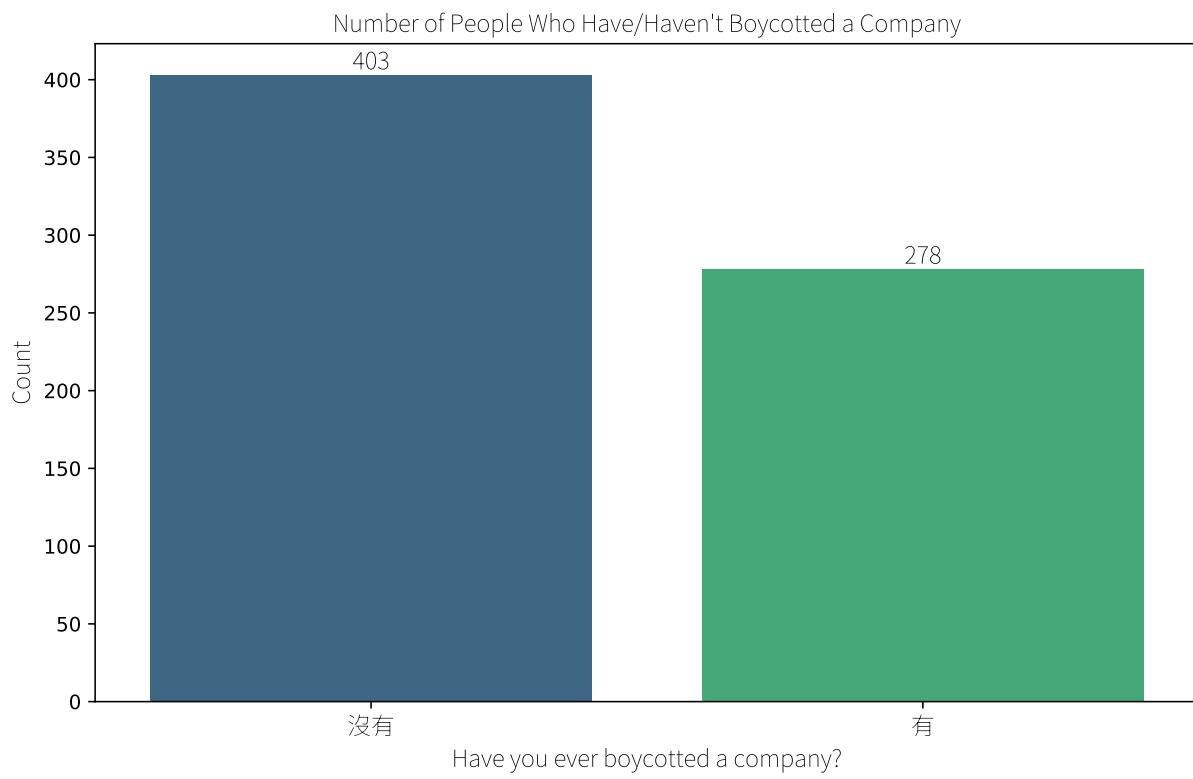
如果你/妳懷疑你/妳要買的番茄可能是由強迫勞工（現代奴隸）採摘的，你/妳仍然會買它嗎？
Would you still buy a tomato if you suspected it was picked by forced labor?



你/妳關心食安嗎？
Do you care about food safety?



15.1.1 Boycott Count (Overall)



15.1.2 Why Boycott

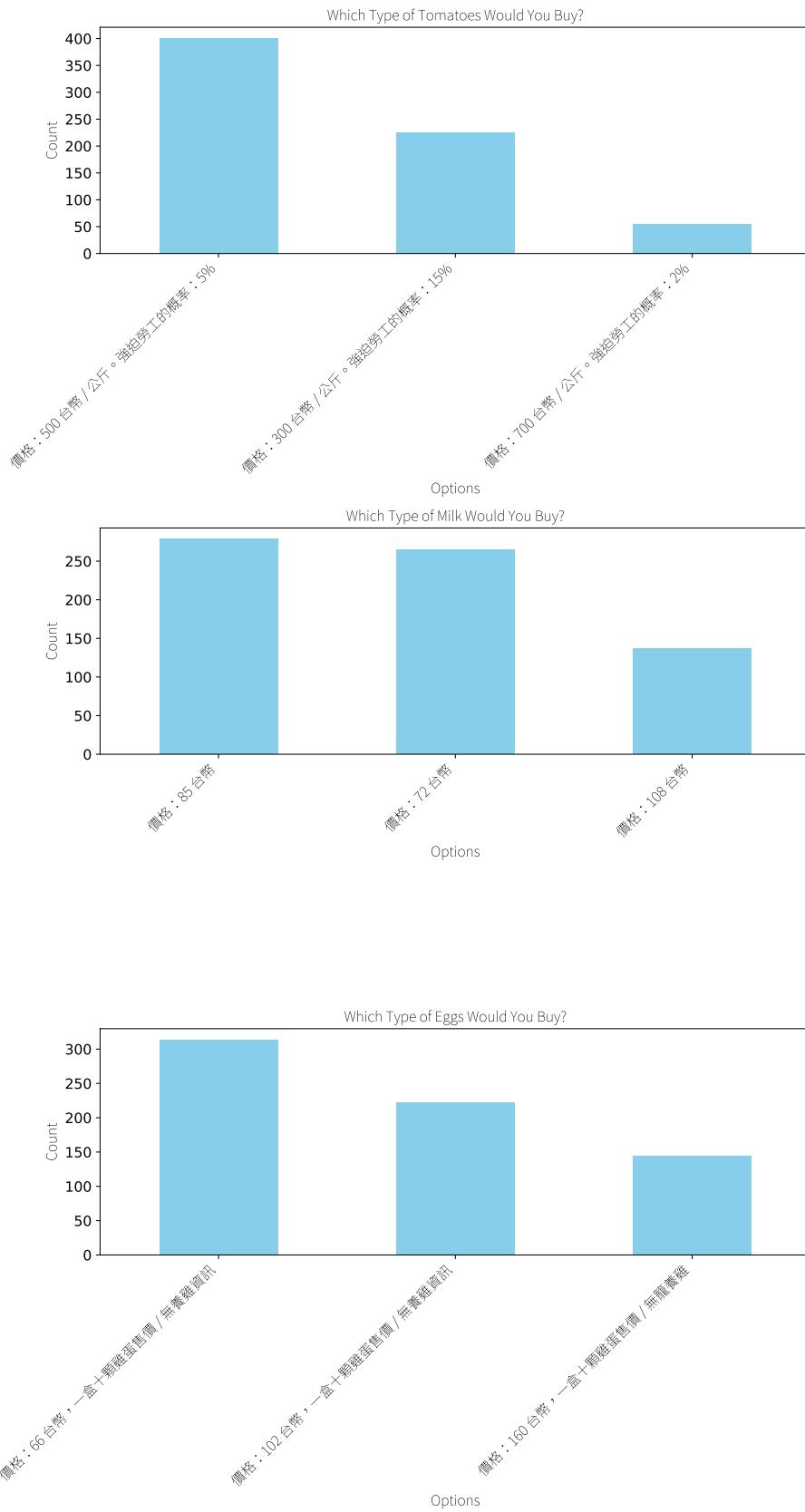
Reason	Count
0 食安問題	33
1 地溝油	10
2 黑心油	8
3 食安	5
4 政治因素	4
...	...
182 因為有出新聞	1
183 此公司危害食安，以抵制這種行為讓公司更能意識到執行此行為的後果	1
184 地溝油啊	1
185 不認同理念	1
186 因為這家公司壓榨員工	1

15.1.3 Trusted Brands

	Brand	Count
193	No trusted brand	329
194	Have but not specified	56
0	義美	42
1	Apple	9
2	光泉	7
...
83	自家種植	1
84	Casetify	1
85	Adidas	1
86	麥當勞	1
97	淨毒五郎	1

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”

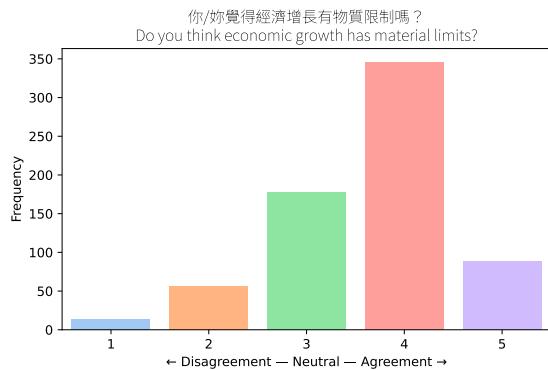
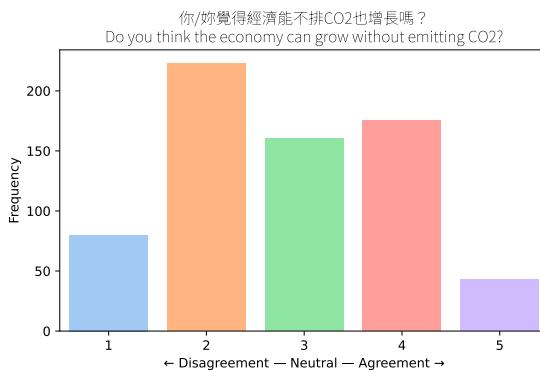
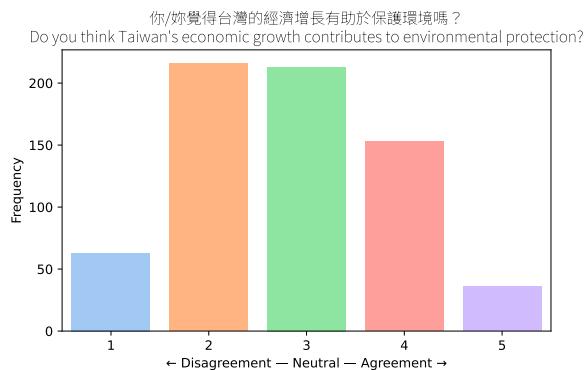
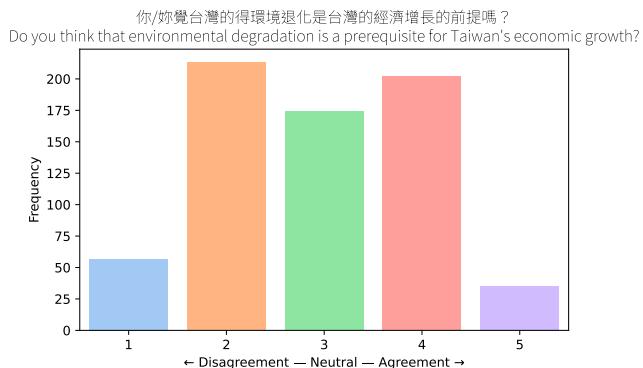
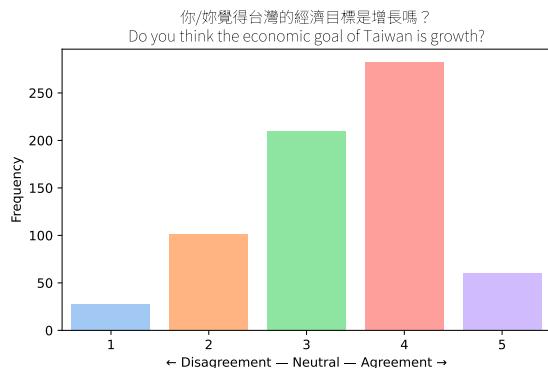
15.2 Choice Experiments



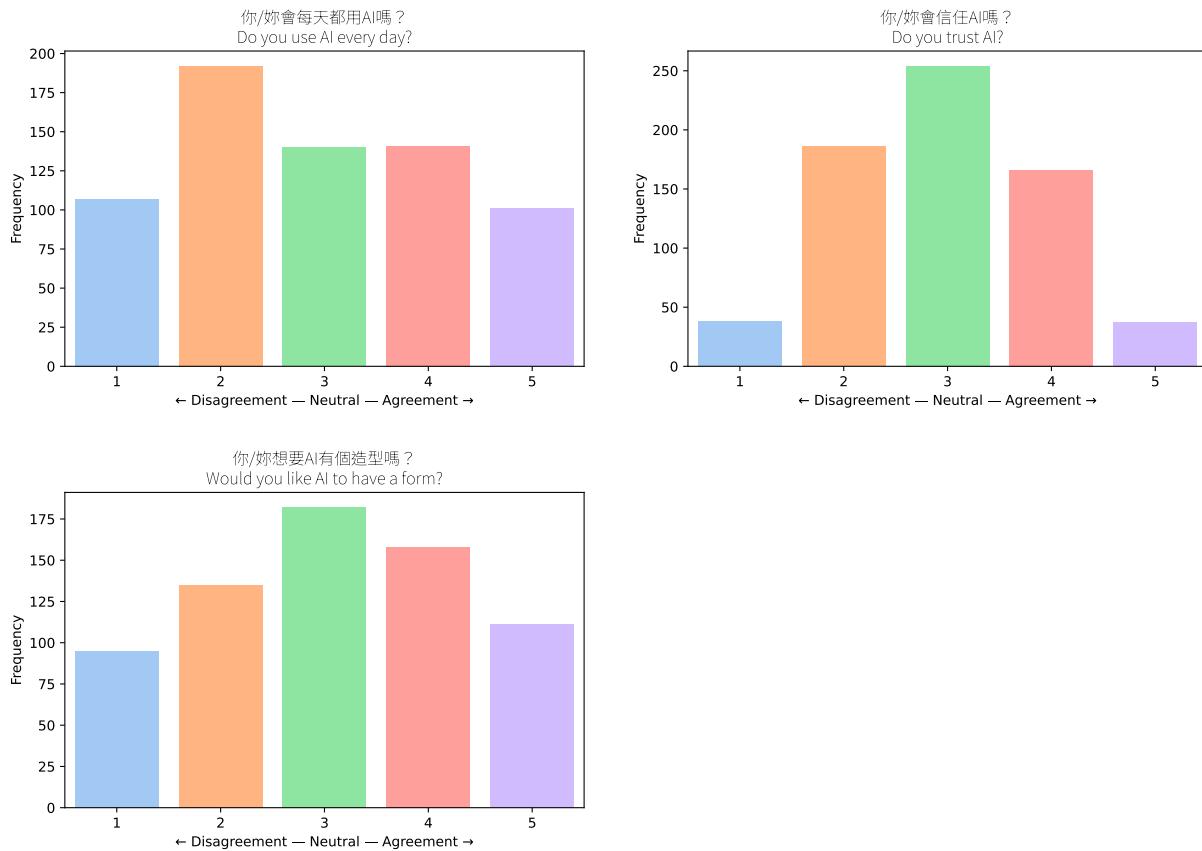
15.3 Taiwanese College Student Attitudes (Overall)

These are student attitudes across all 36 likert fields without clustering. Clustered results are available under the Personas section.

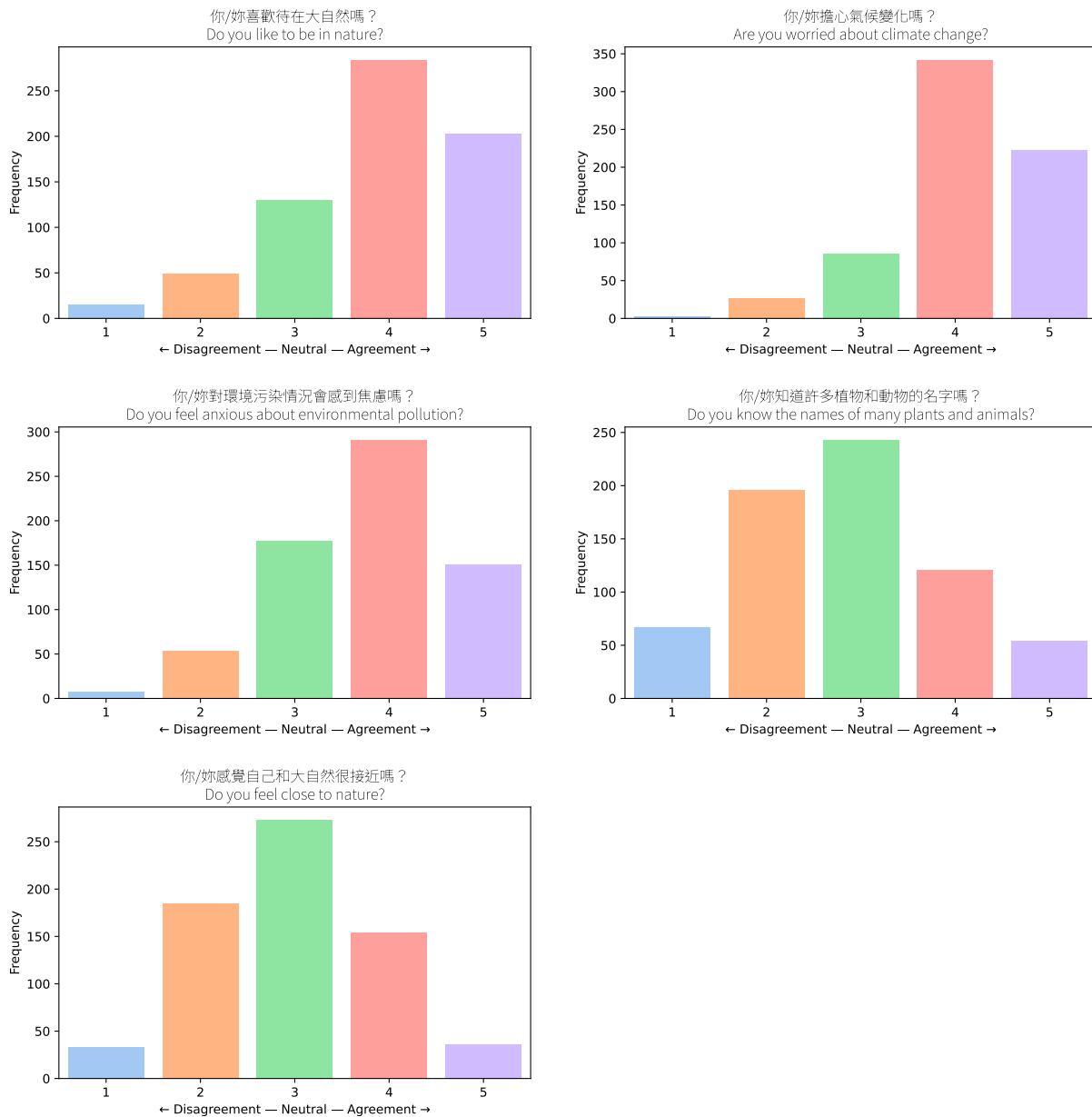
15.4 Economy



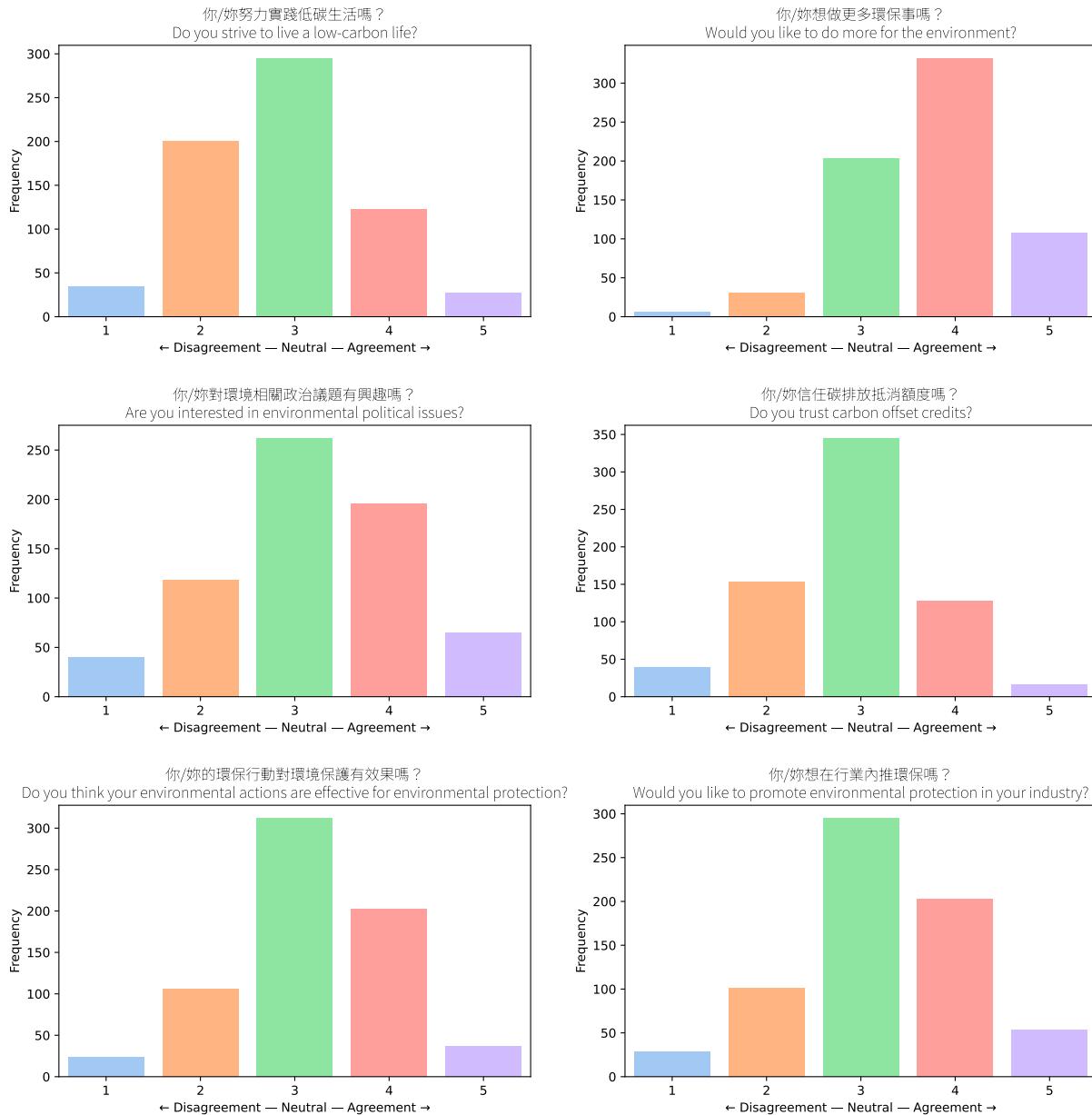
15.5 AI Usage



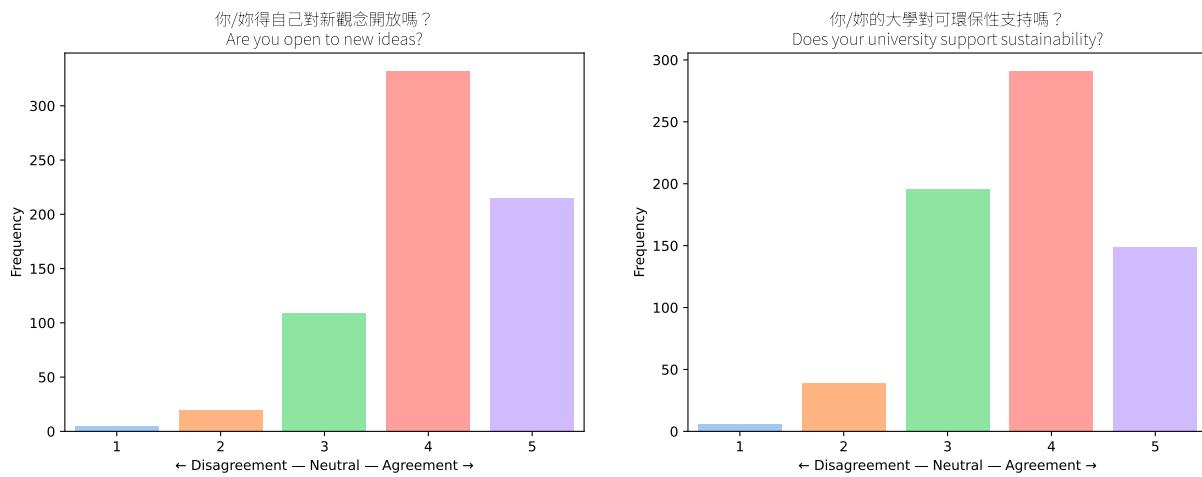
15.6 Nature



15.7 Environmental Protection



15.8 Learning Environment



15.9 Correlations Between Fields

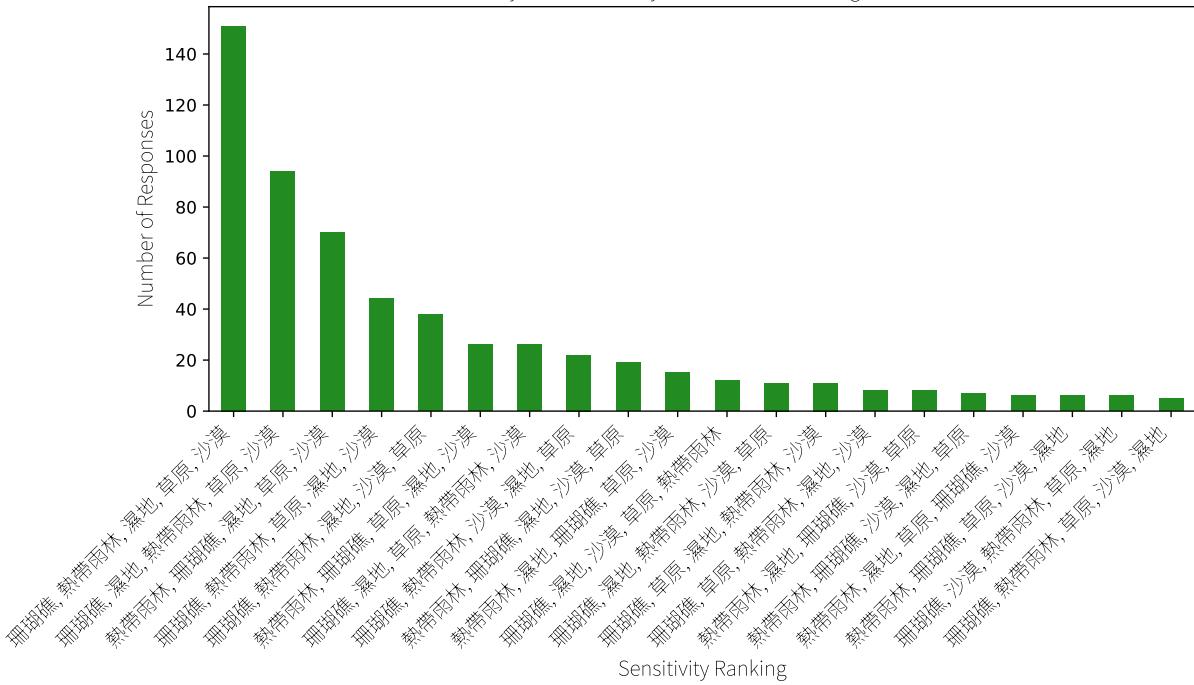
Correlation Network



15.10 Environmental Knowledge Ranking Experiment

Test knowledge about the environment.

Ecosystem Sensitivity to Environmental Degradation

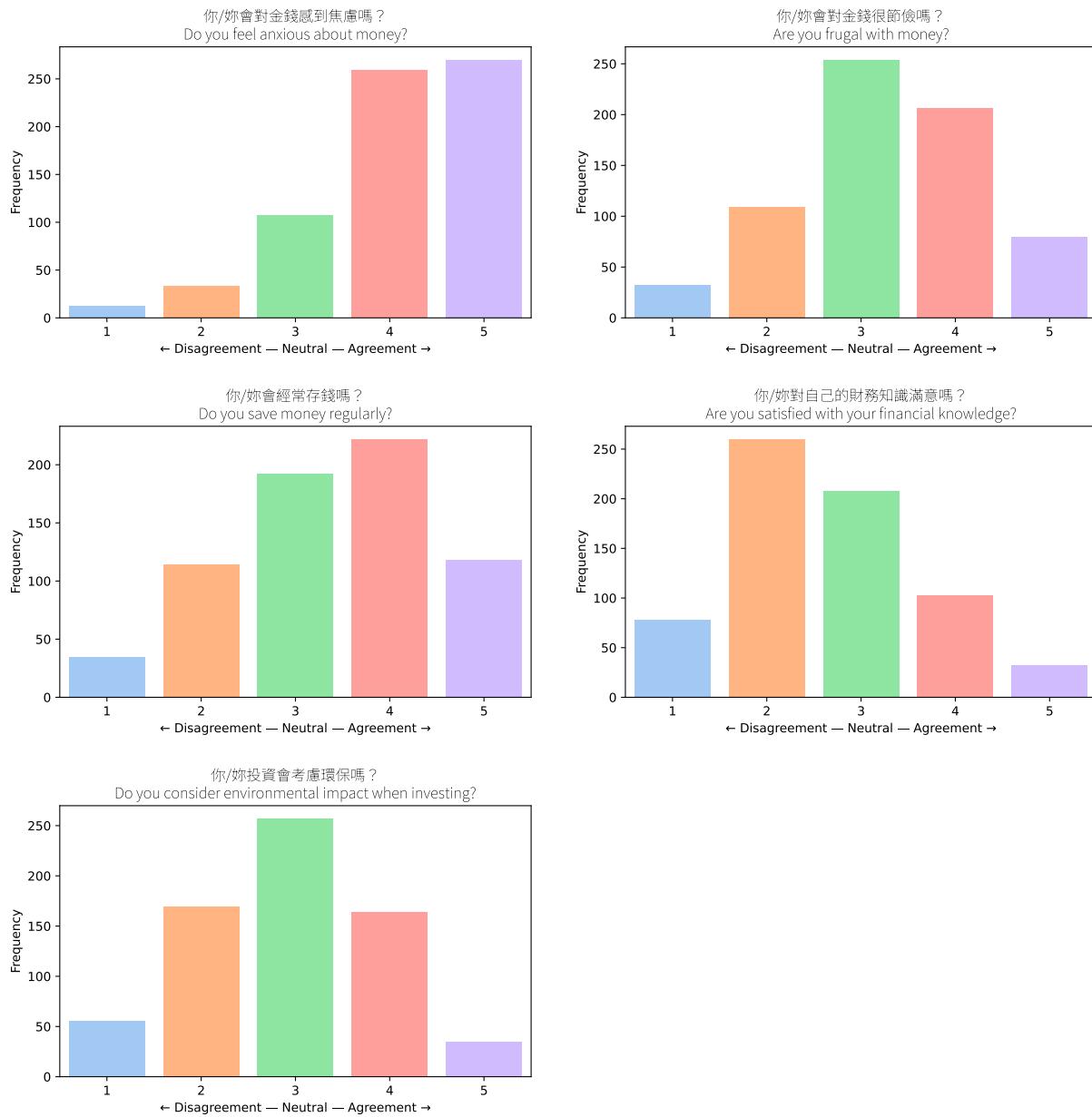


Design implications: majority don't plan to buy a house or car within 7 years, don't focus on these categories. Majority don't fly much, don't focus on flights.

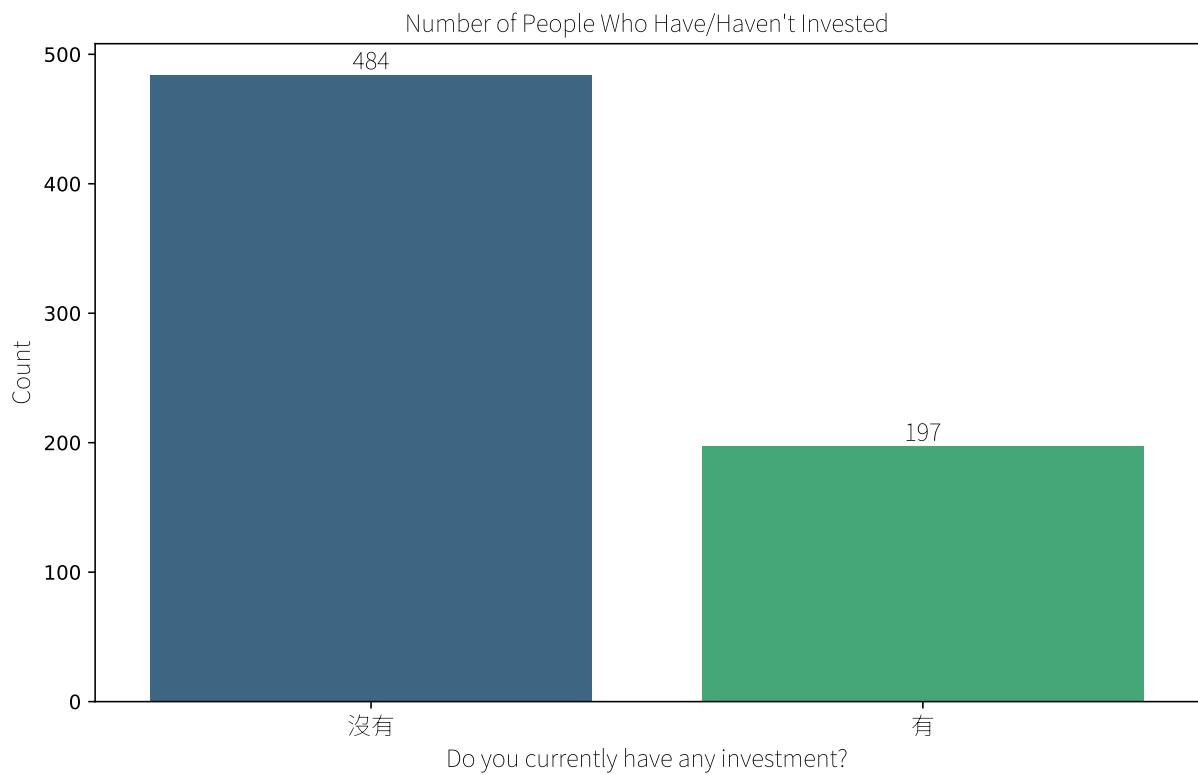
15.11 Investing

Student attitudes towards investing.

15.11.1 Saving and Investing

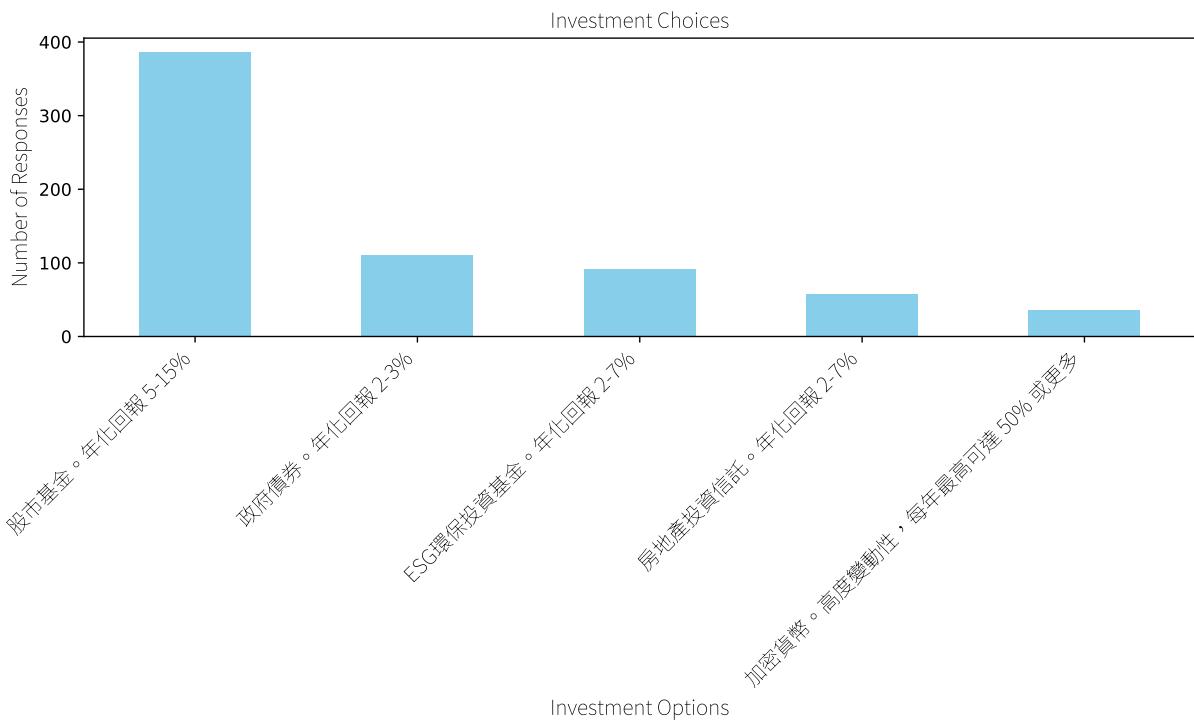


15.11.2 Investing Experience (Overall)



15.12 Choice Experiment

Question: 你/妳選哪個投資？Which investment do you choose?



15.13 Personas

15.13.1 Clustering Students to Build Personas

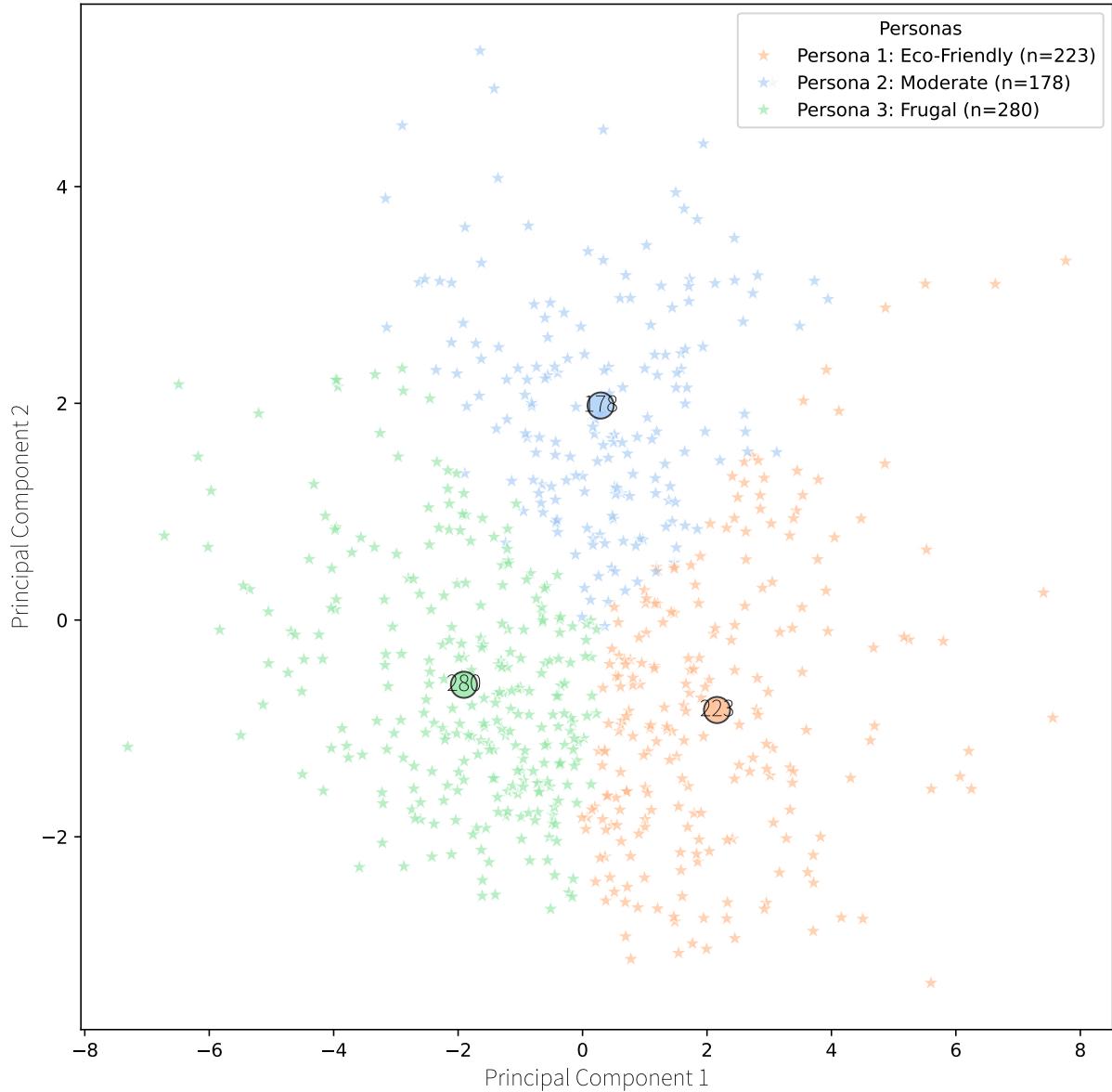
Customer segmentation

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.

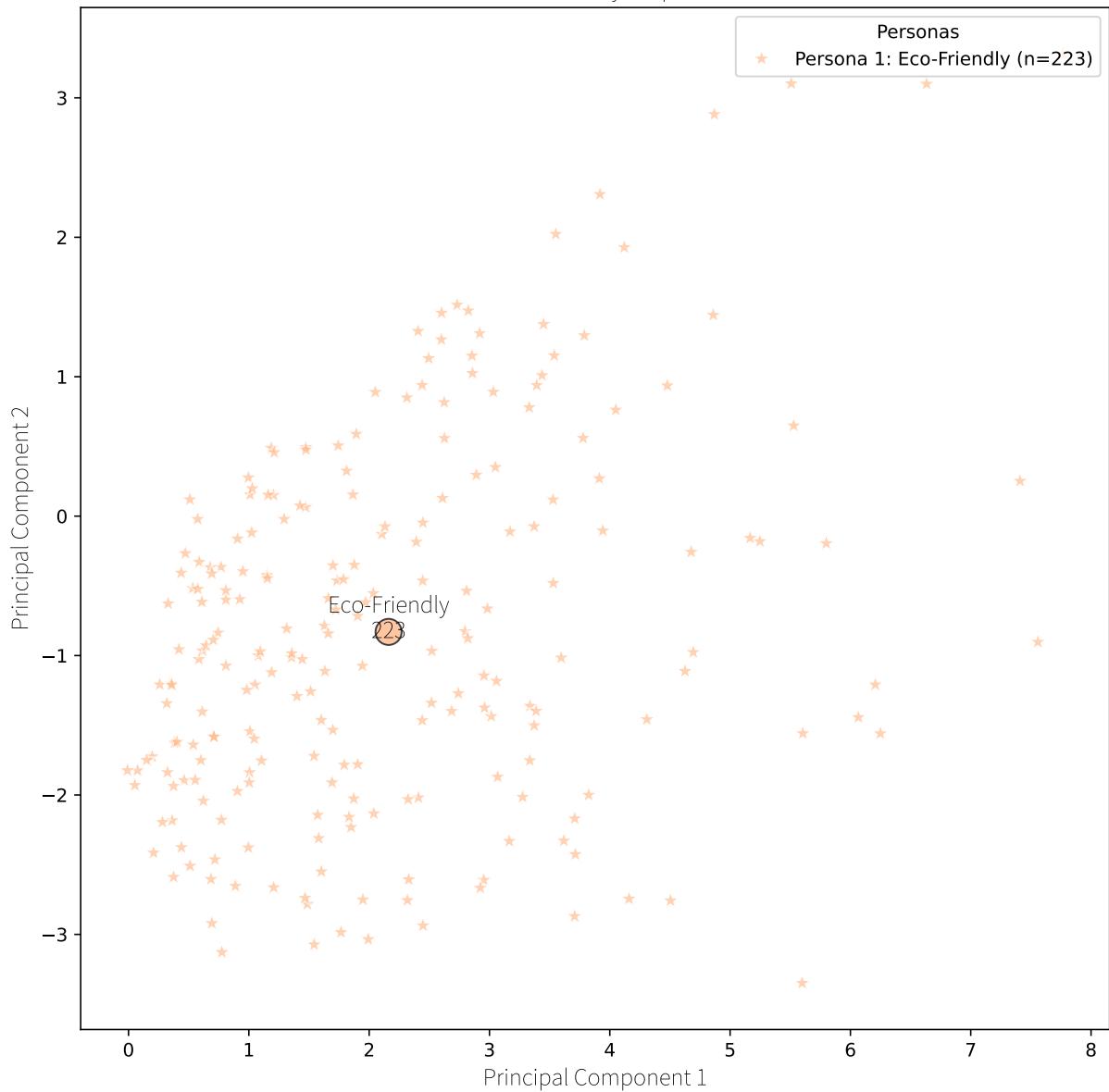
Distinct Respondent Profiles Based on K-means Clustering

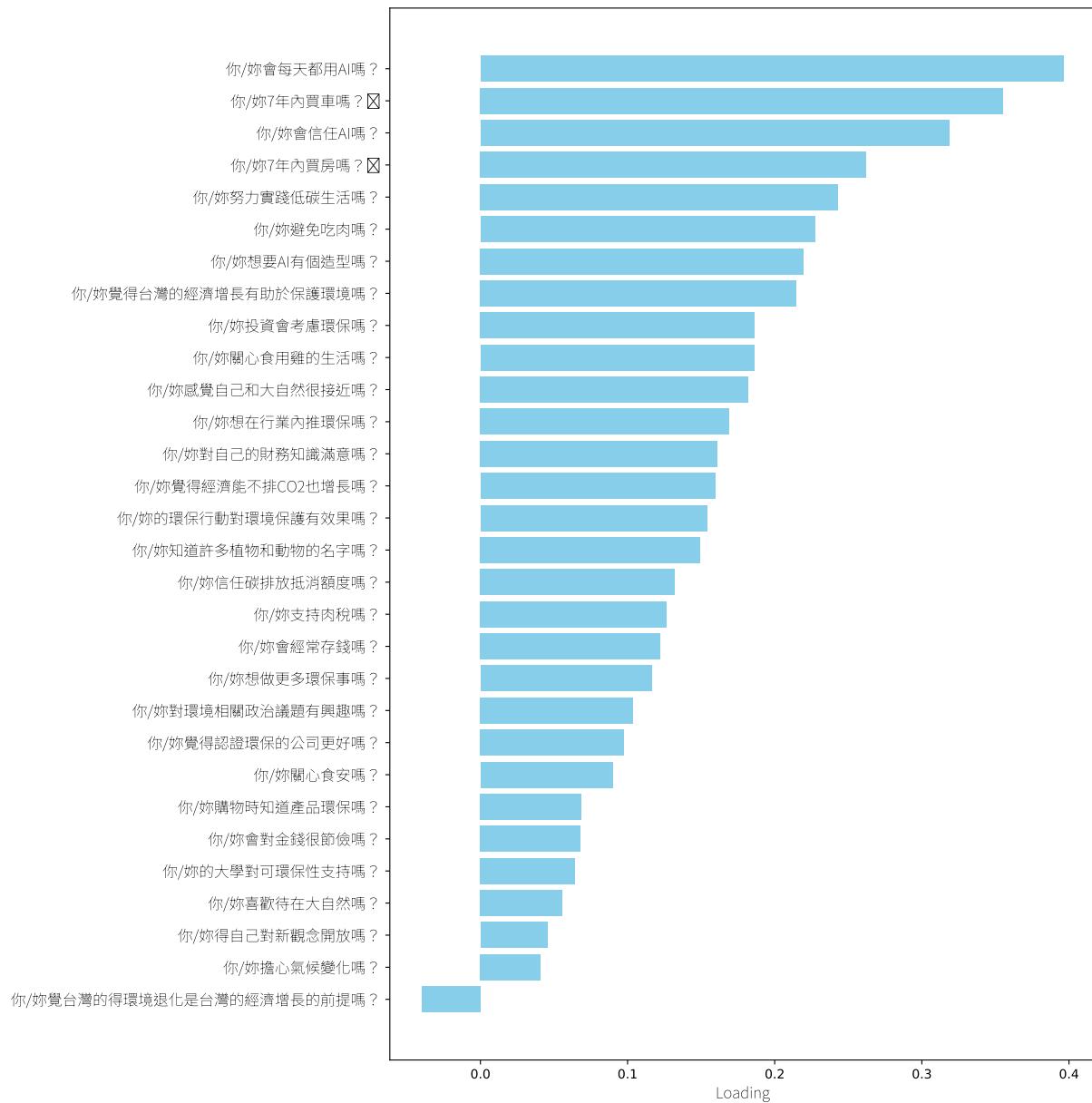


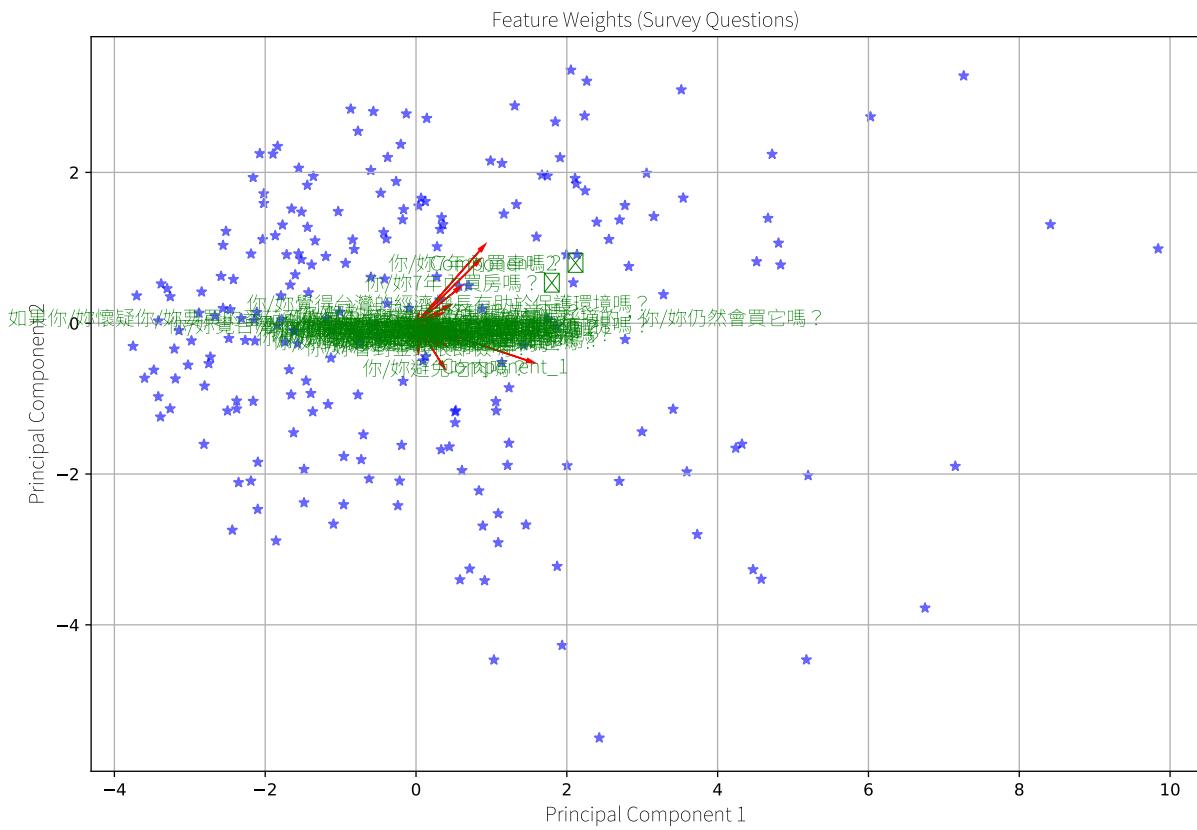
15.13.2 Persona 1: “Eco-Friendly”

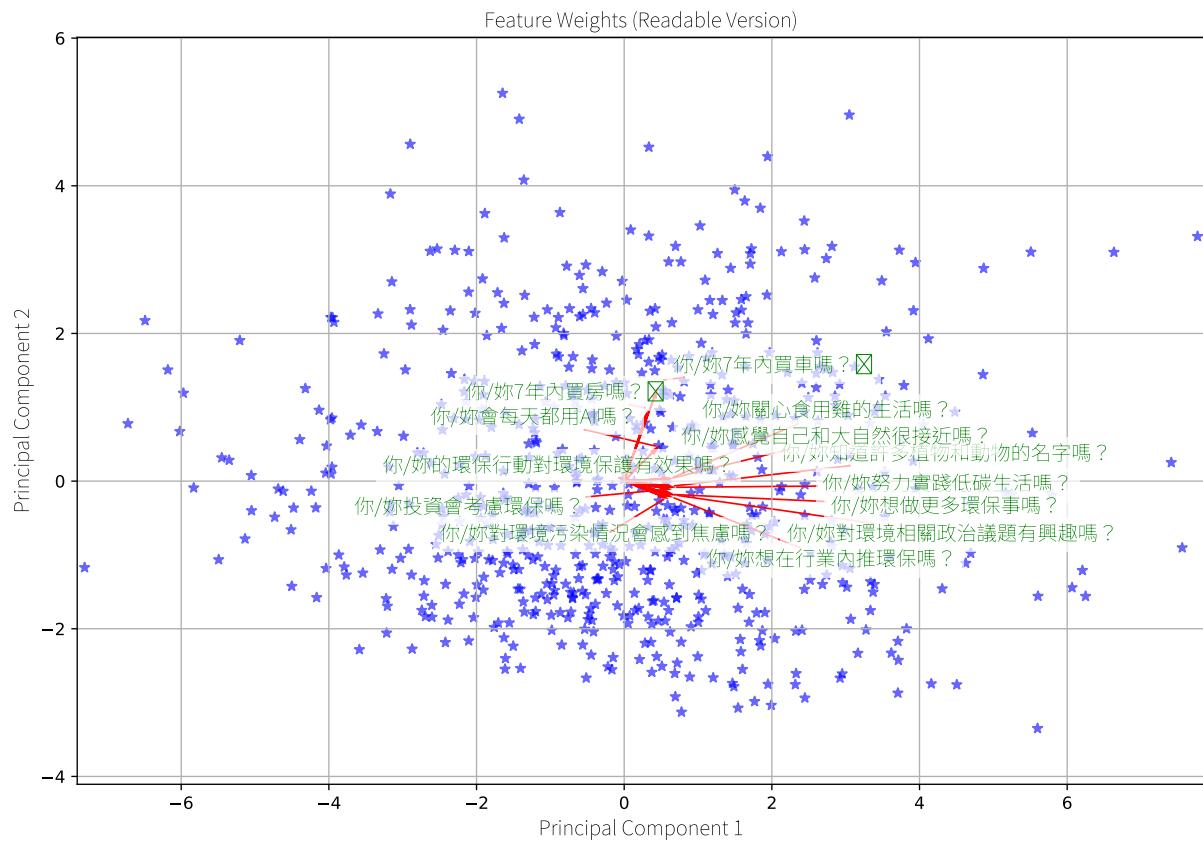
Questions Most Affecting Persona Creation include...

Clustered Survey Responses





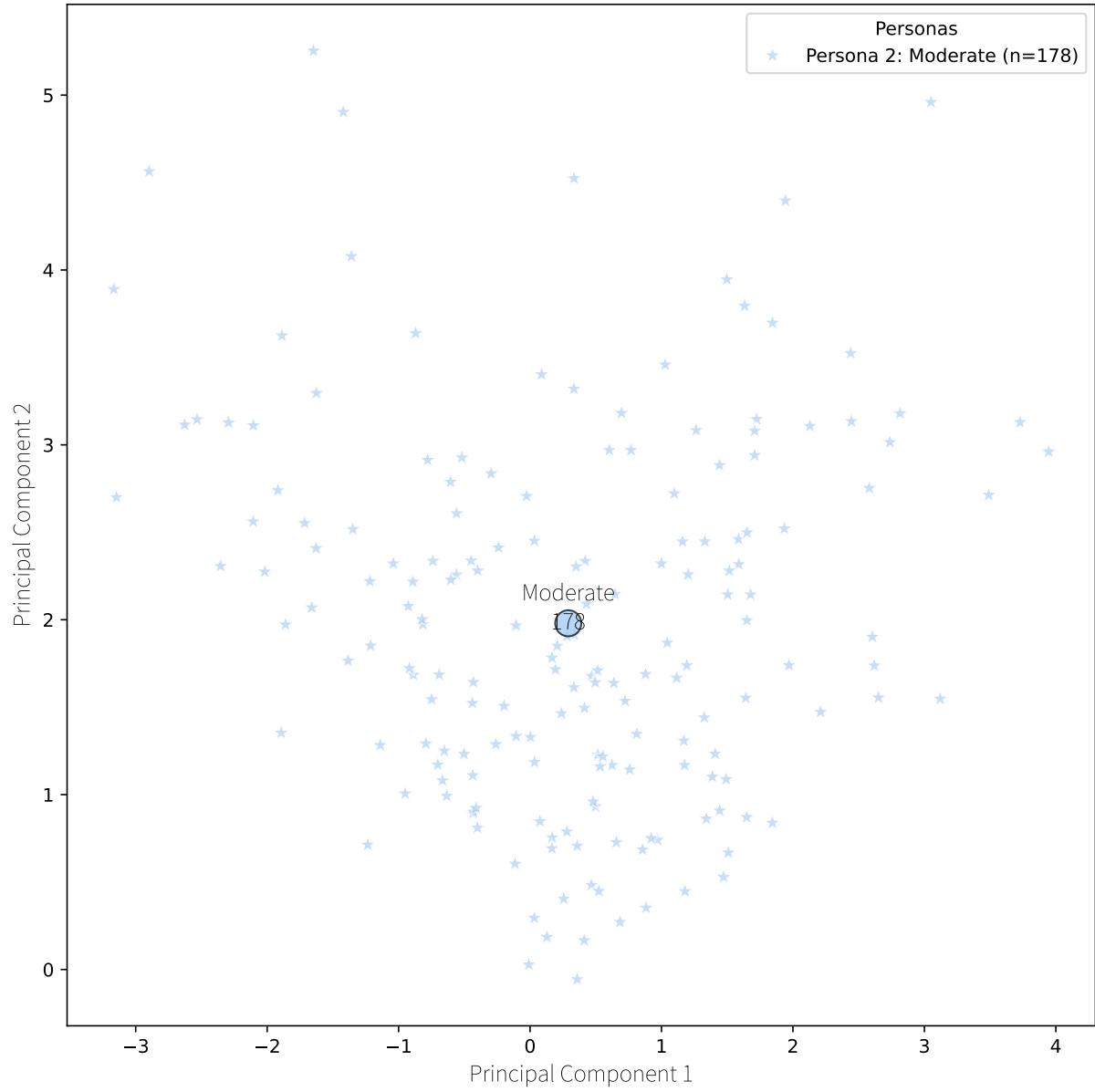


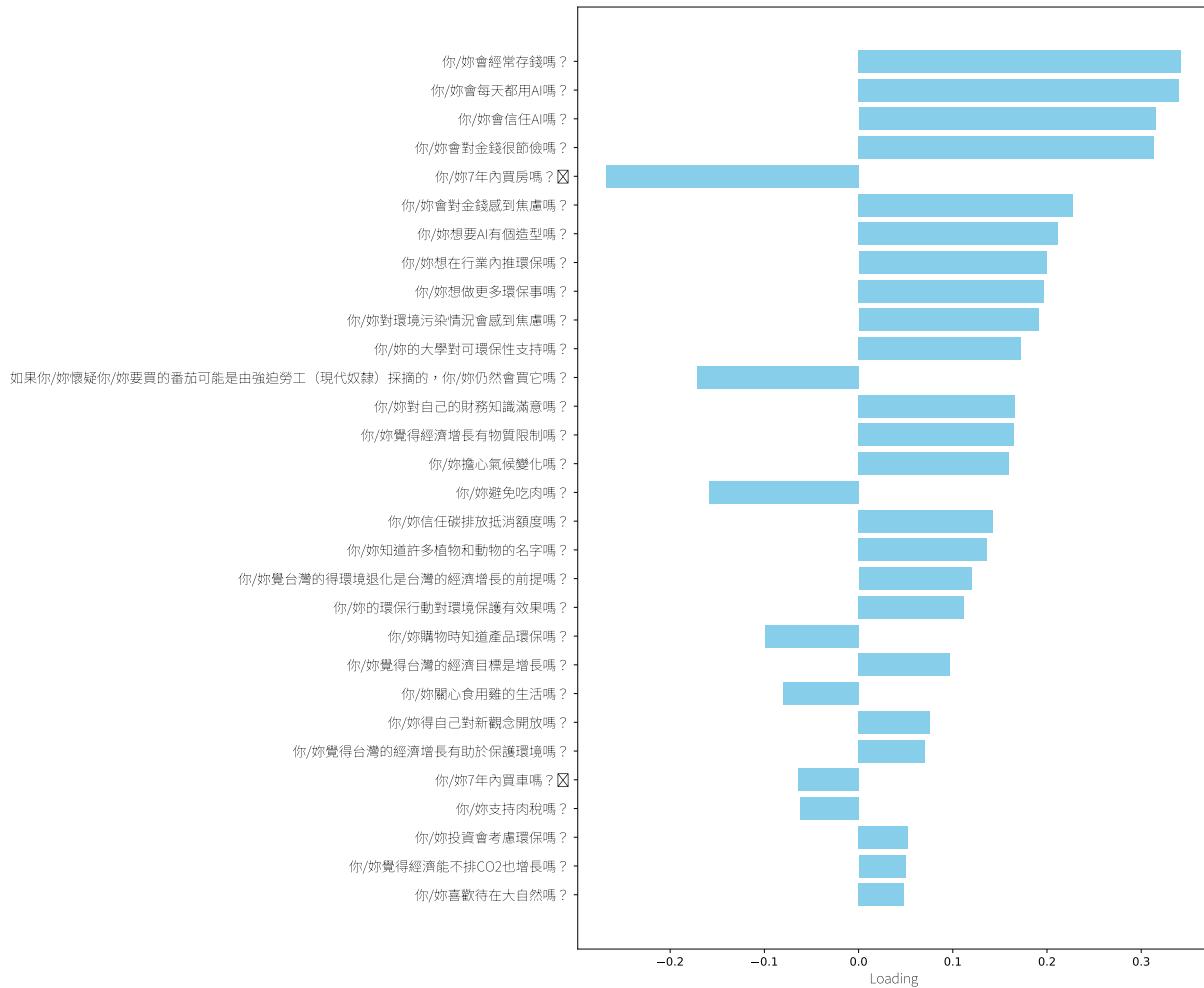


15.13.3 Persona 2: “Moderate”

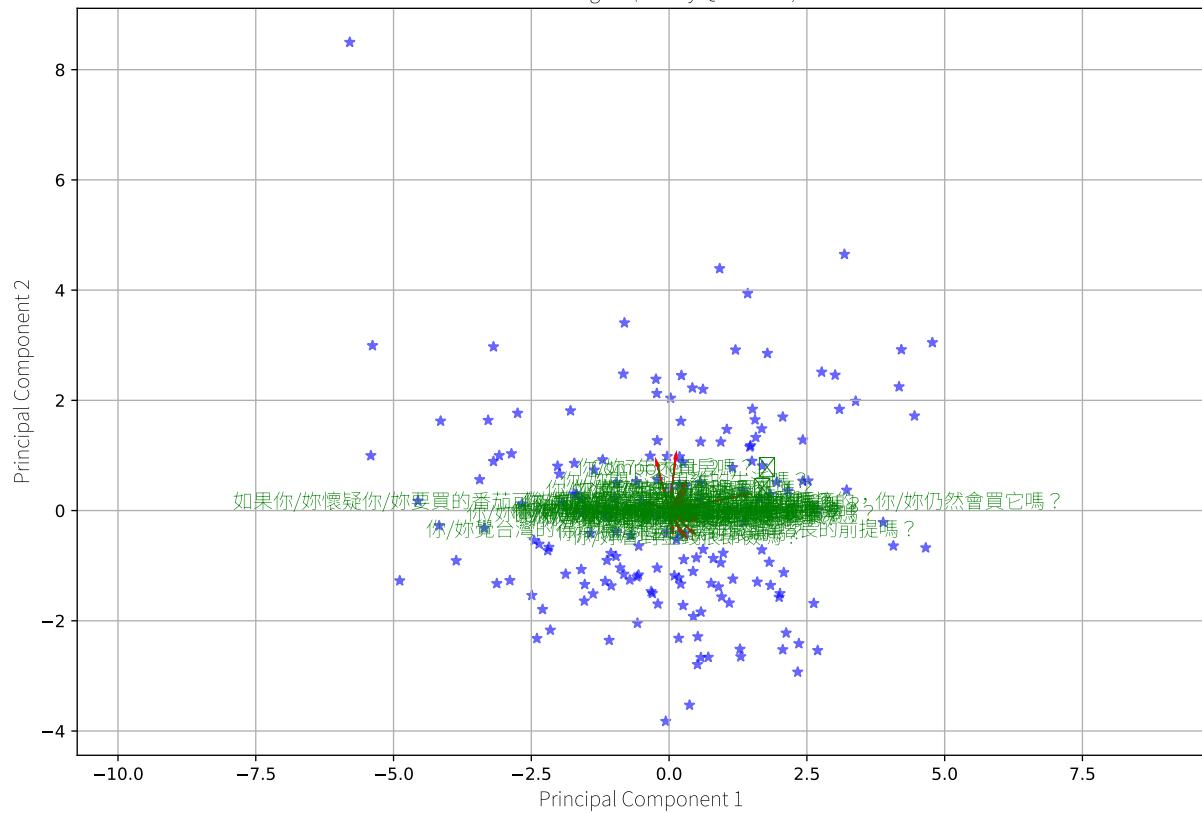
Questions Most Affecting Persona Creation include...

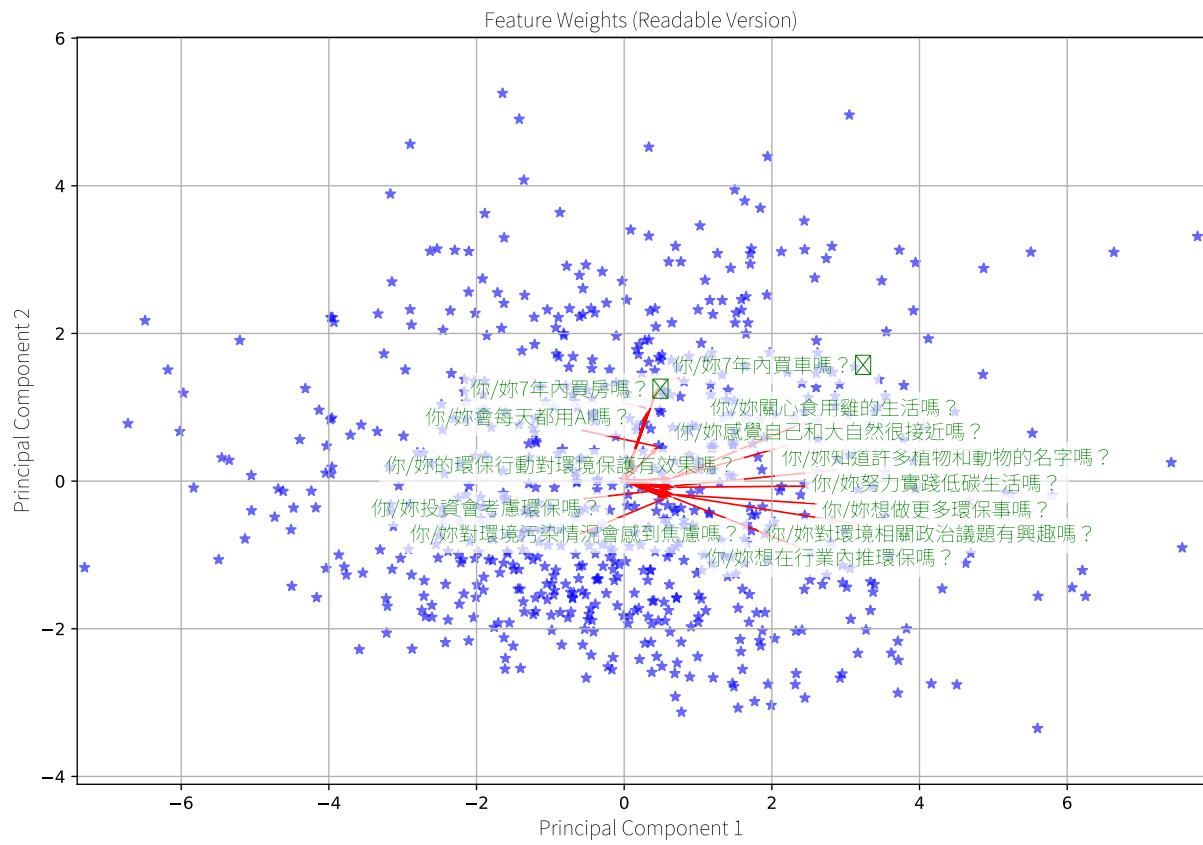
Clustered Survey Responses





Feature Weights (Survey Questions)

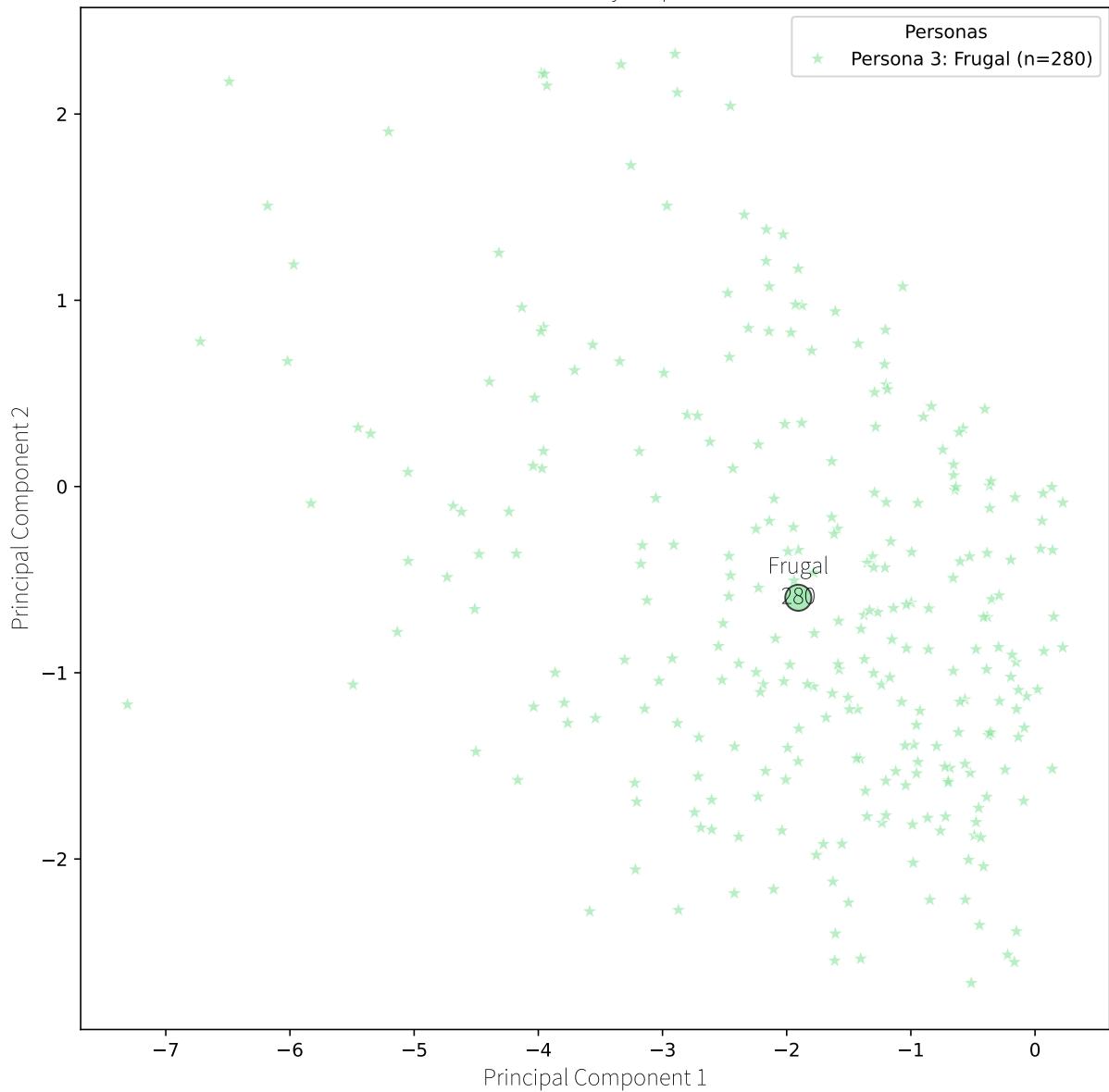


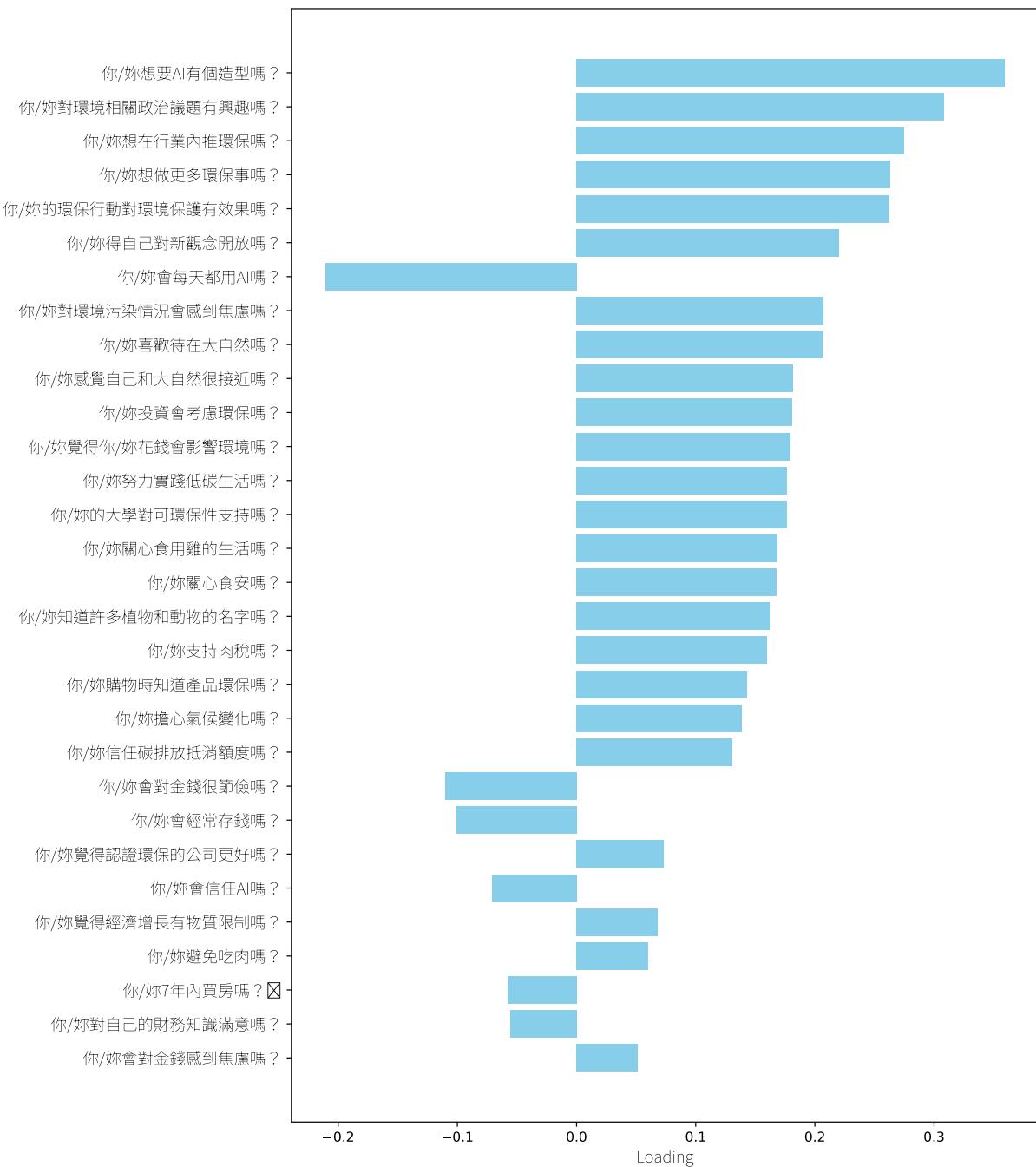


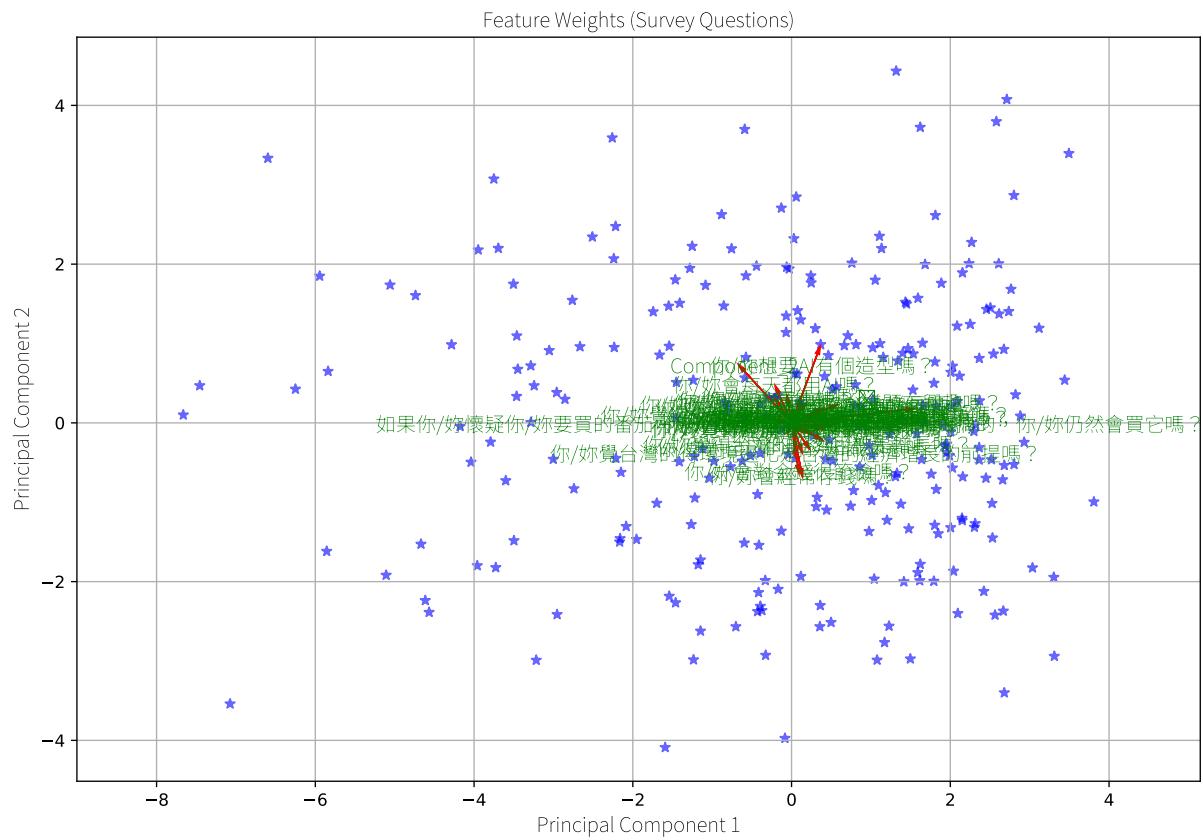
15.13.4 Persona 3: “Frugal”

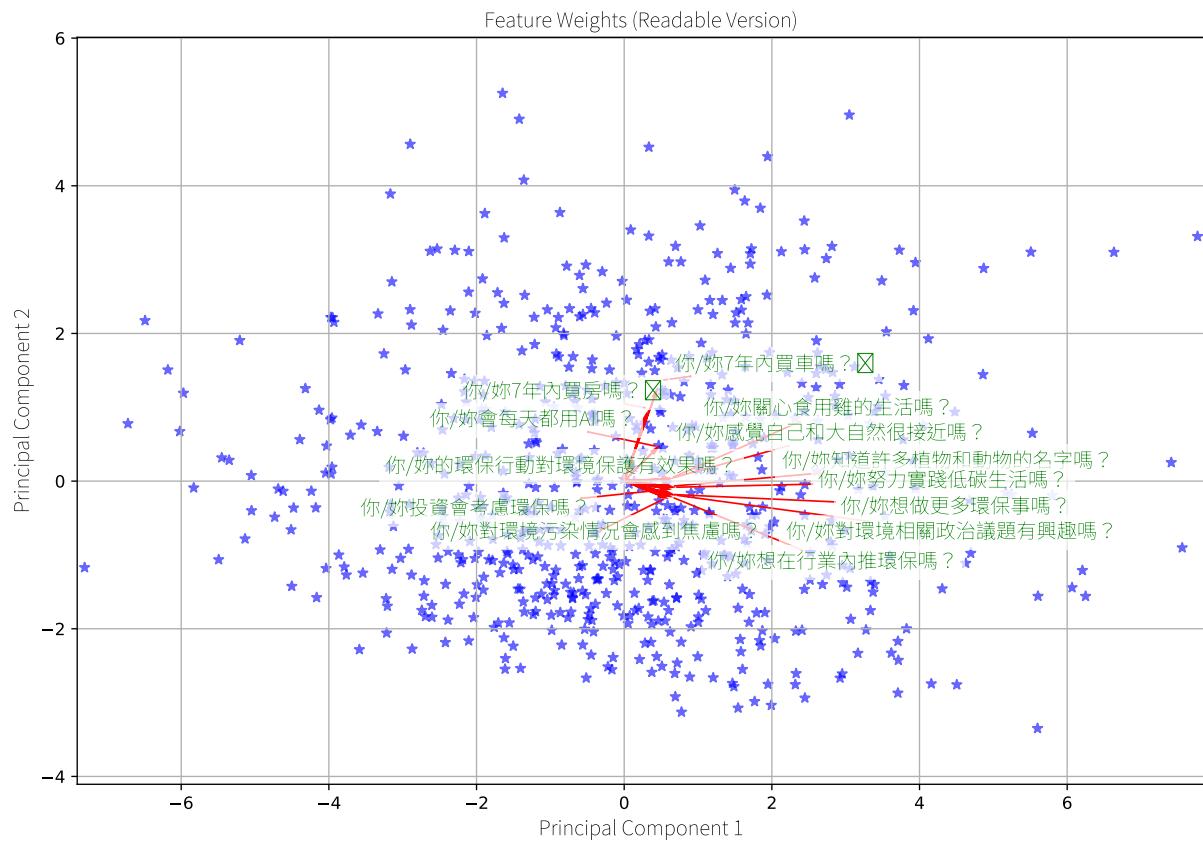
Questions Most Affecting Persona Creation include...

Clustered Survey Responses

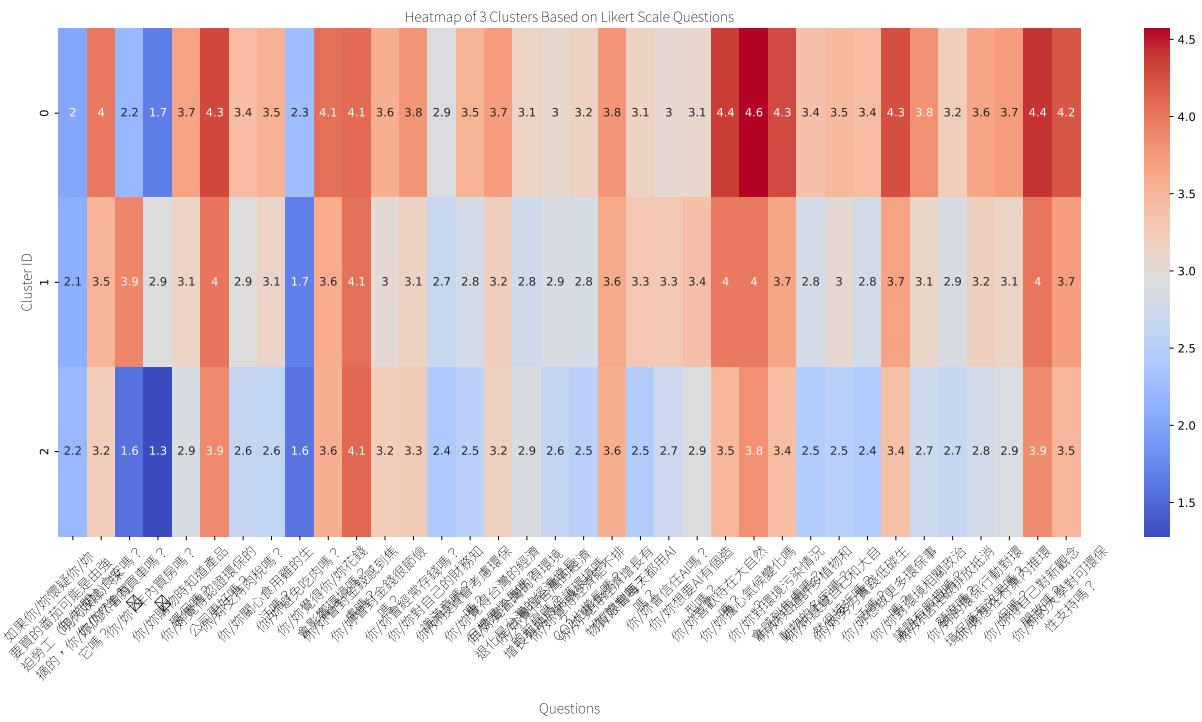








15.14 Clustering Heatmap



15.15 Mean Answer Scores

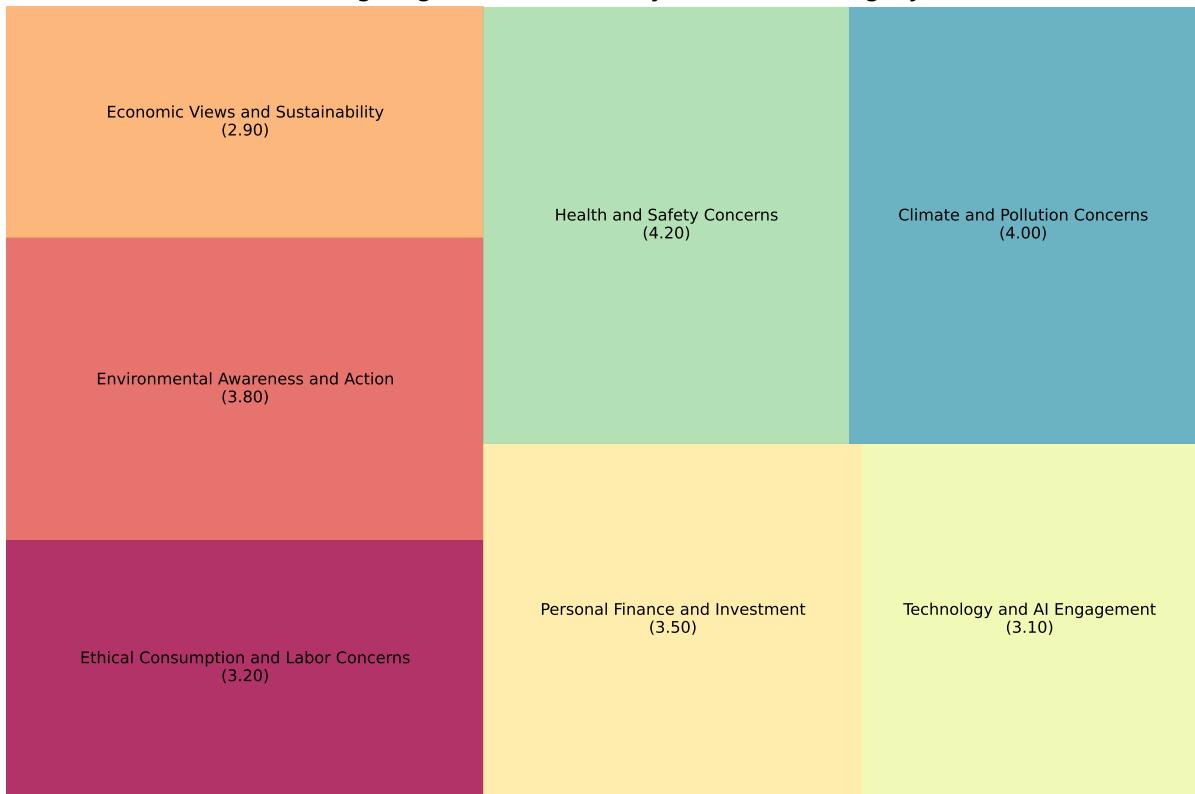
Mean response values for each Likert question in each cluster:

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？	你/妳關心
0 0	2.026906	3.991
1 1	2.106742	3.516
2 2	2.214286	3.225

15.16 Agreement between personas

Highest agreement between personas is about health, safety, pollution and climate concerns.

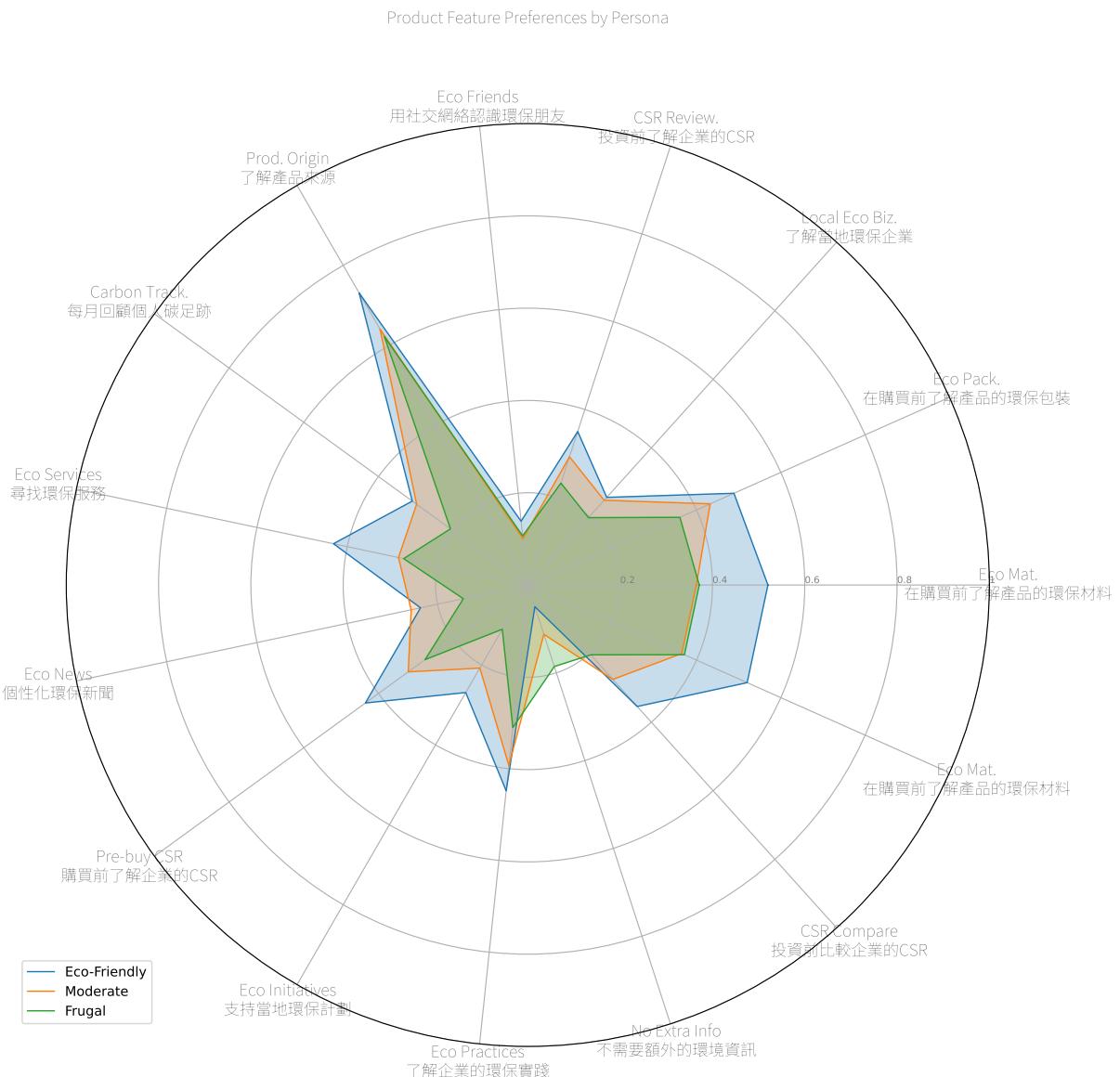
Average Agreement Level by Question Category



15.17 AI Companion

15.17.1 Likert-Based Clustering

AI-assistant feature choices per Likert-based Personas



Want: - Product origin - Product materials - Product packaging

Don't Want: - News - Carbon tracking - Eco-friends - ...

15.18 Feature-Based Clustering

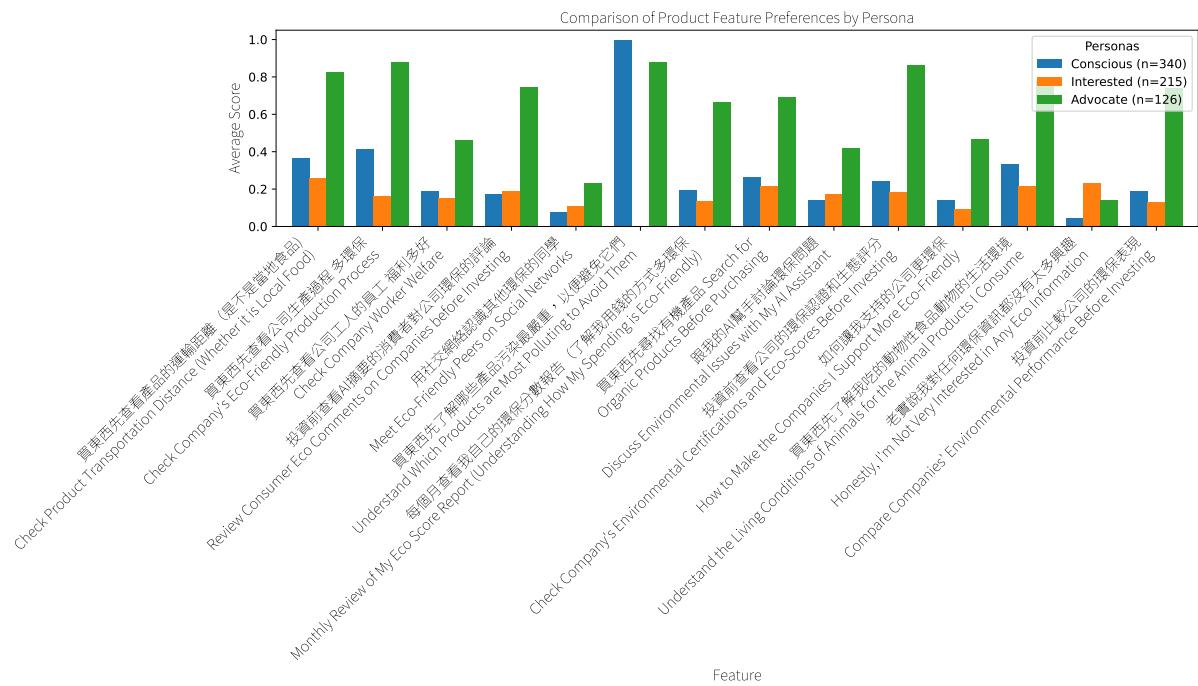
Clustering students based on AI-assistant feature choices.

Want: - Product origin - Product materials - Product packaging - Eco services

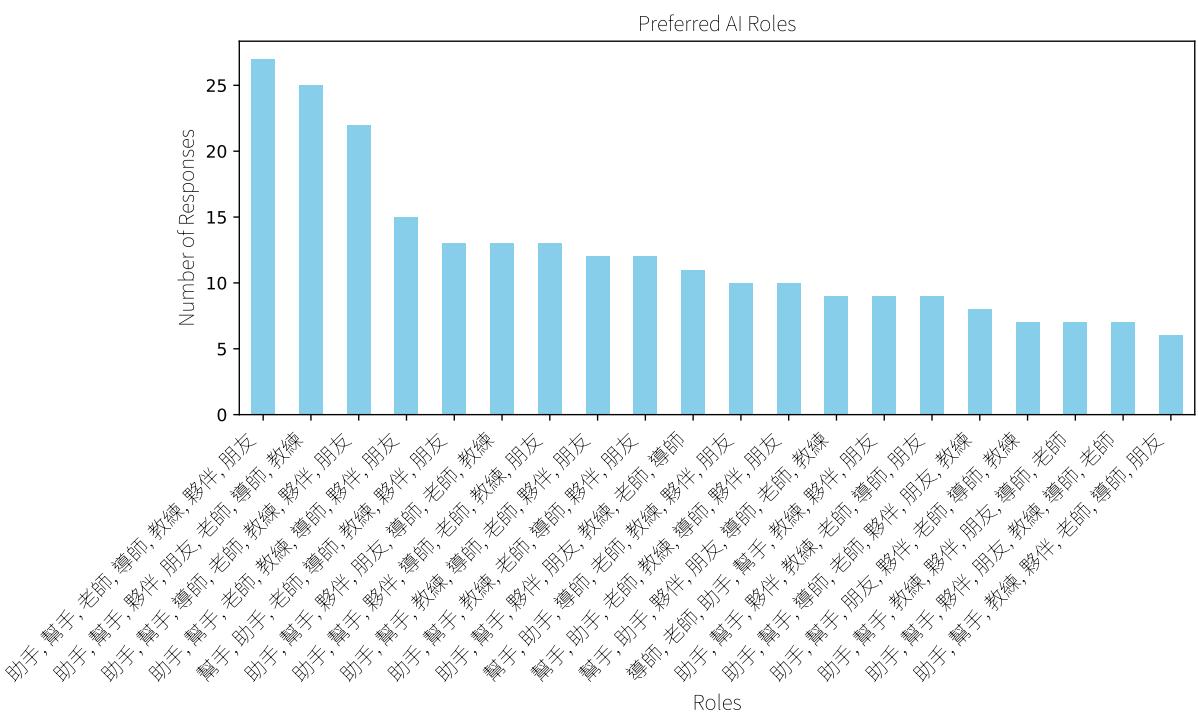
15.18.1 Feature Preferences (Overall)



15.19 Feature Preferences (By Cluster)



15.20 Preferred AI Roles (Overall)



15.21 Experts

Analysis of recorded conversation from 5 experts. Thematic content analysis using ATLAS.ti for labeling/coding the data for grounded theory. Conversations were recorded and transcribed using Google Meet and Fireflies AI. Labeling and thematic analysis was performed using Atlas.ti. Visualisations were produced using Atlas.ti and Python.

15.22 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 hypergrowth and hundreds of millions of EUR in revenue in digital transformation of industry. Country: Taiwan / Canada Topics: Design, Business

Thematic Analysis.

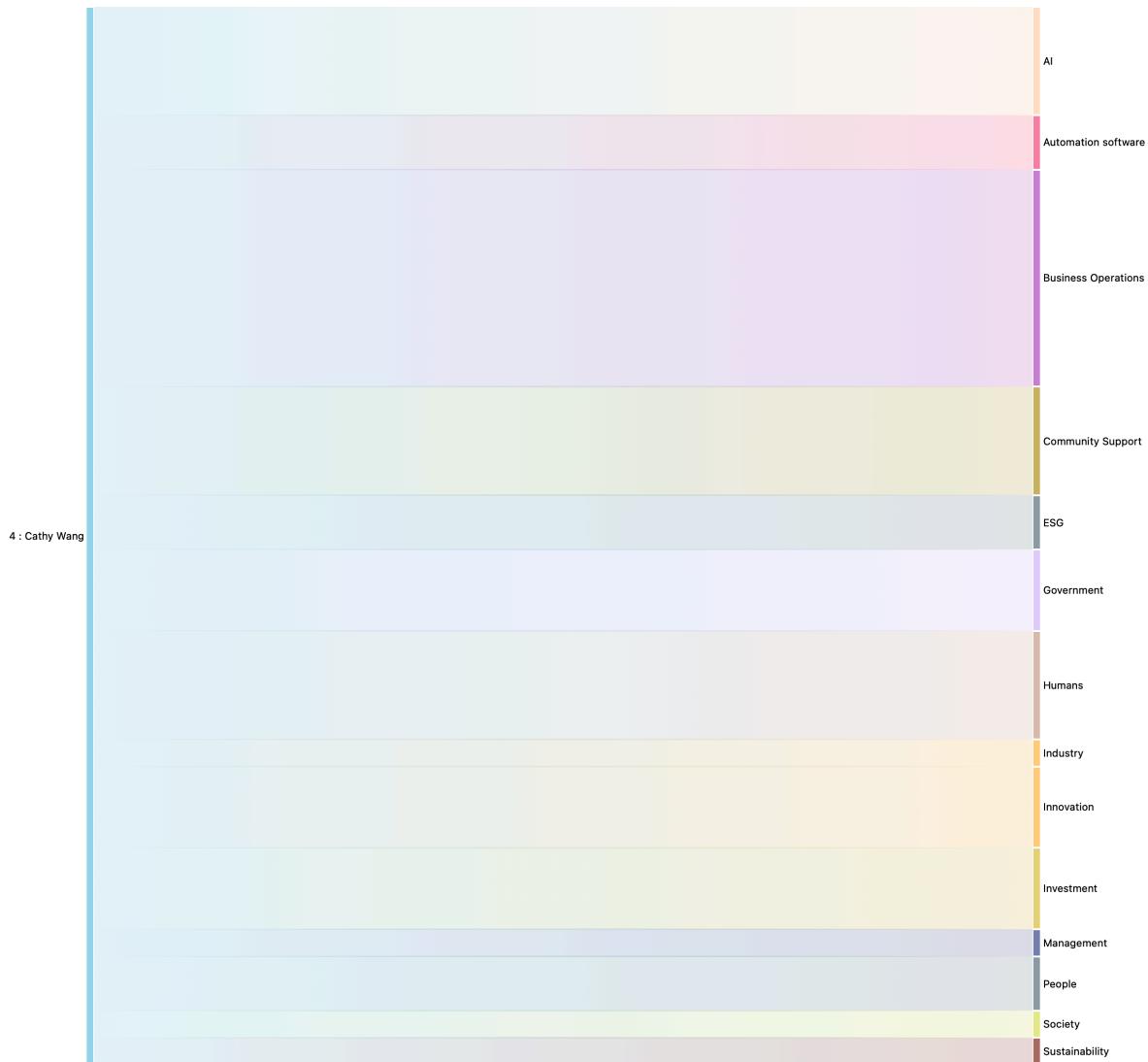


Figure 26: Cathy Wang

15.23 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 27: Peijing Li

15.24 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

Thematic Analysis.

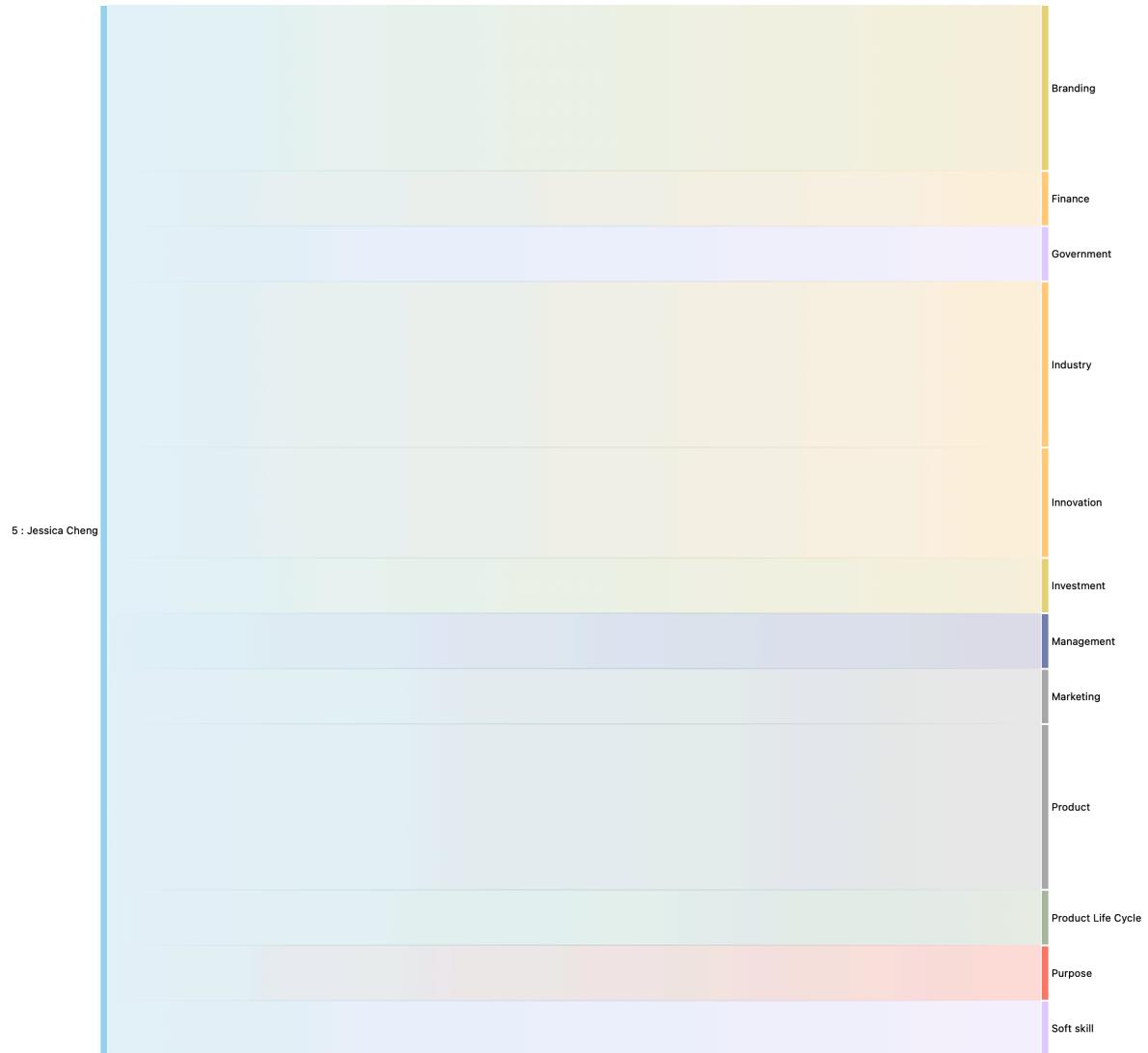


Figure 28: Jessica Cheng

15.25 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

Thematic Analysis.

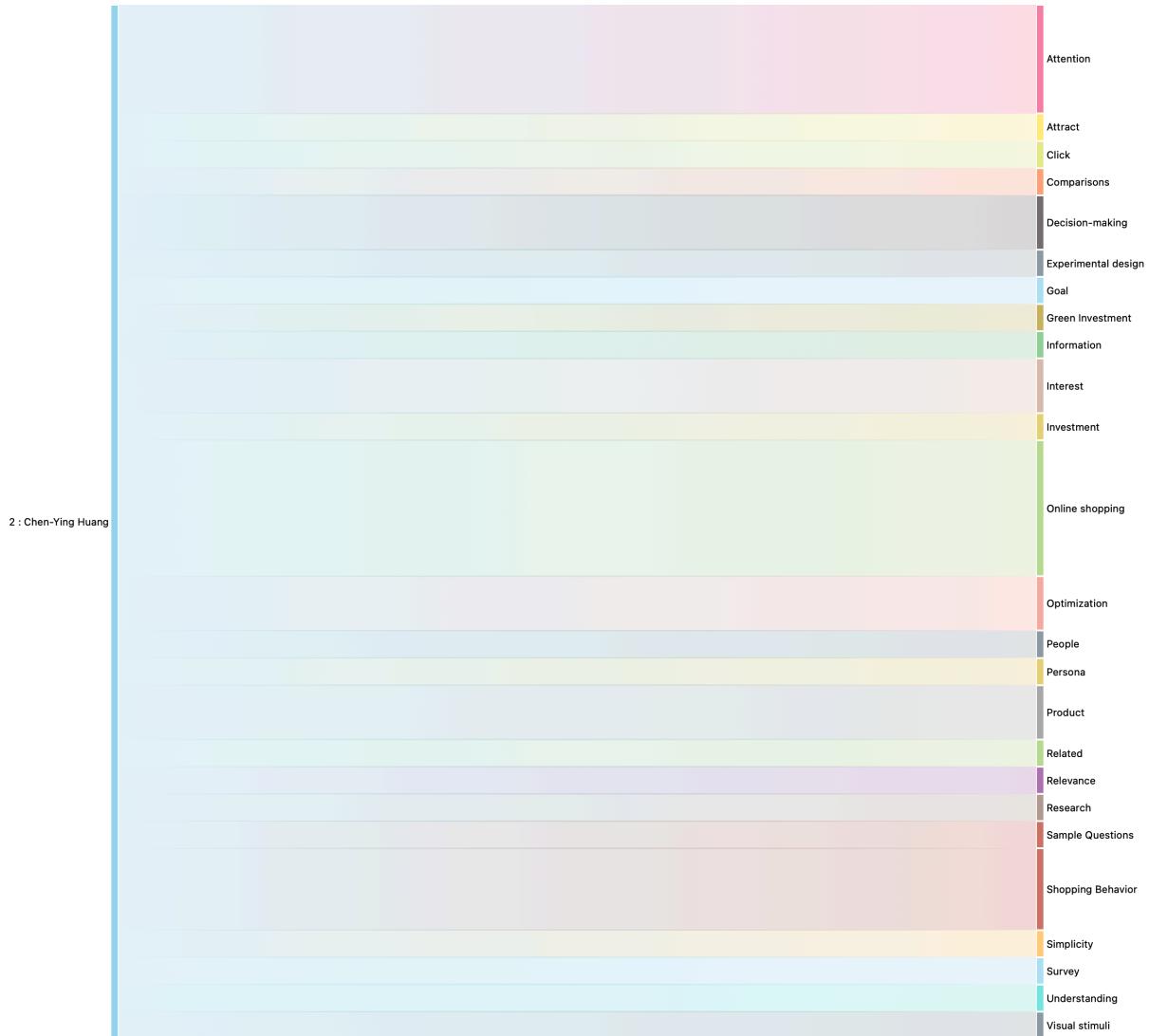


Figure 29: Chen-Ying Huang

15.26 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”

Thematic Analysis.

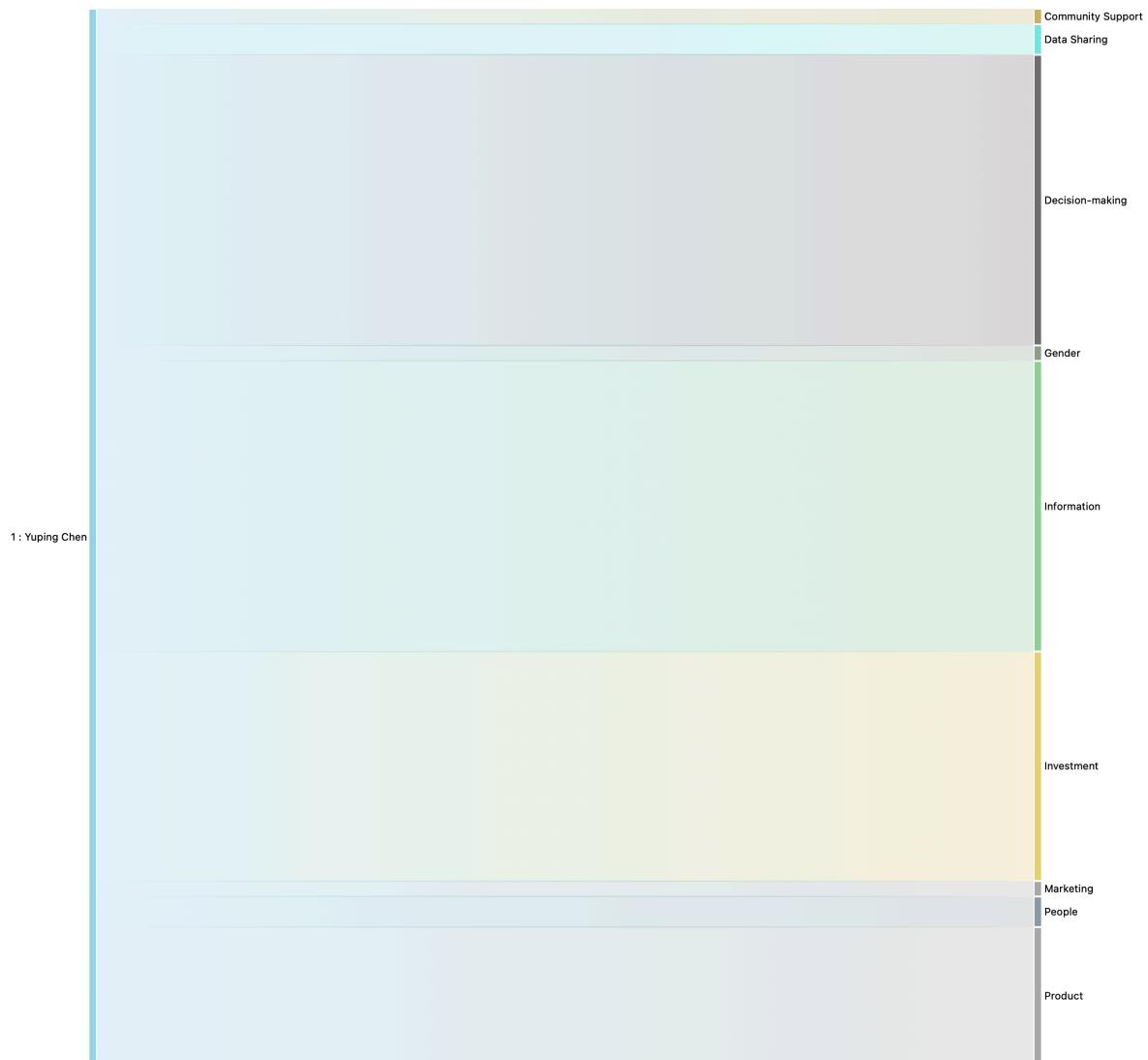


Figure 30: Yuping Chen

15.27 Overall Expert Feedback Results

Common topics between all conversations become visible in the overall Sankey Diagram.

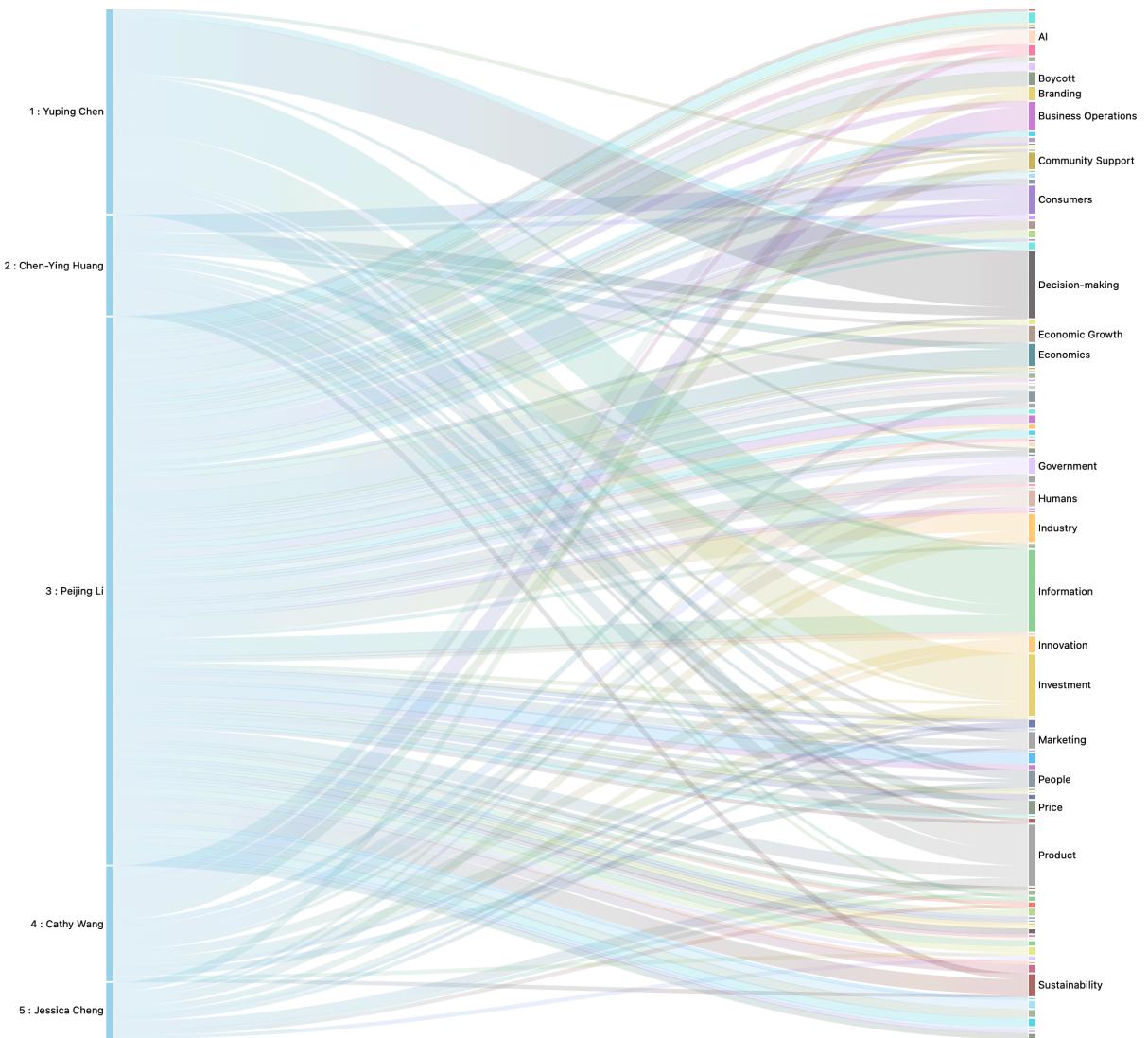


Figure 31: All

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”.

15.28 1st Wave of Testing (Spring 2024) Prototype Testing results

Sun, 14. April. 22h at D24

NCKU student, Gen-Z.

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)
https://www.momoshop.com.tw/goods/GoodsDetail.jsp?i_code=12028429&Area=search&oid=1_8&cid=index&gno=12028429

Notices 買一送一.

Doesn't notice analysis button at first.

Would only click on this if it's really expensive.

Would not click on "continue chat button"

Asked "why is it so expensive in taiwan".

Considers report result useful.

Note: There's dropoff on every step of the user journey.

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?

Generate

有意識的消費主義

add carbon indicators, other labels to the analysis, add report code, calculate report code from URL? save as kv

may 8 czuta

- investment help useless.. needs simpler intro - wants to see real cows - very curious about companies - wants to see profit percentage. why is margin so high if pollution is bad. - real environmental impact of the company.

06 may - Seeing factory photos is useful only if they are trustworthy photos. Who will provide them? -

may 5

- user: it looks like an ad

may 3

- uses google to look for "fashion brand eco friendly"
- thinks "goodonyou.eco" looks like a brand website

may3 - first looked for NET clothes but Momo doesn't sell it - Looked for Sony camera lens

I 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."

Interviews and testing survey were conducted anonymously in hopes to have more honest responses from the responders.

ziran chrome extension is unable to record activity due to browser security restrictions for plugins

ai.ziran.tw record user activity

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)

basic interview script - momo: what is a brand that you like'd or would like to buy - search - please pick a product (or search again) - on 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 is important to share with the helper?

Tuesday 30. April 14:05-14:45 - 7CYQ6

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。

DJmoney

<https://www.moneydj.com/etf/x/basic/basic0004.xdjhtm?etfid=0050.tw>

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 - Momo - buy new balance sneakers

DJmoney

wants compare EFTs

Monday 29. april 14:50-15:10 - Momo - buy apple iphone - bad internet - app was slow - app crashed

green filter analysis on DJmoney seems more trustworthy than other 2 eft sites

button placement is important (too low on other sites than djmoney)

Sunday 28. april 16:00 - momo: wants to buy ice cream

sun, 14. april. 22h at D24

ncku student, gen-z

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)
https://www.momoshop.com.tw/goods/GoodsDetail.jsp?i_code=12028429&Area=search&oid=1_8&cid=inde

notices 買一送一
doesn't notice analysis button at first
would only click on this if it's really expensive
would not click on "continue chat button"
asked "why is it so expensive in taiwan?"
considers report result useful
note: there's dropoff on every step of the user journey

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?

Testing overview

Tested with 30 participants individually

Testing is anonymous

Generate

有意識的消費主義

add carbon indicators, other labels to the analysis, add report code, calculate report code from URL? save as kv

15.29 2nd Wave of Testing (Fall 2024 - Spring 2025) Prototype Testing results

TODO

Testing overview

Tested with 32 participants individually

Testing is anonymous

- 32 anonymous gen-z participants in face-to-face interviews
- 100+ anonymous self-testing participants

15.30 Early Feature Ideas

The following early prototypes are focused on particular feature ideas that 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 formed a basis for directing the questions asked in a potential user survey.

15.31 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 CO2. Service available near you: Bolt,* Uber.”
- “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.”*

Figure 3: 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.

https://scontent.ftpe6-1.fna.fbcdn.net/v/t39.8562-6/333078981_693988129081760_4712707815225756708_n

provides many examples conversations between AI and humans from Meta’s LLAMA model

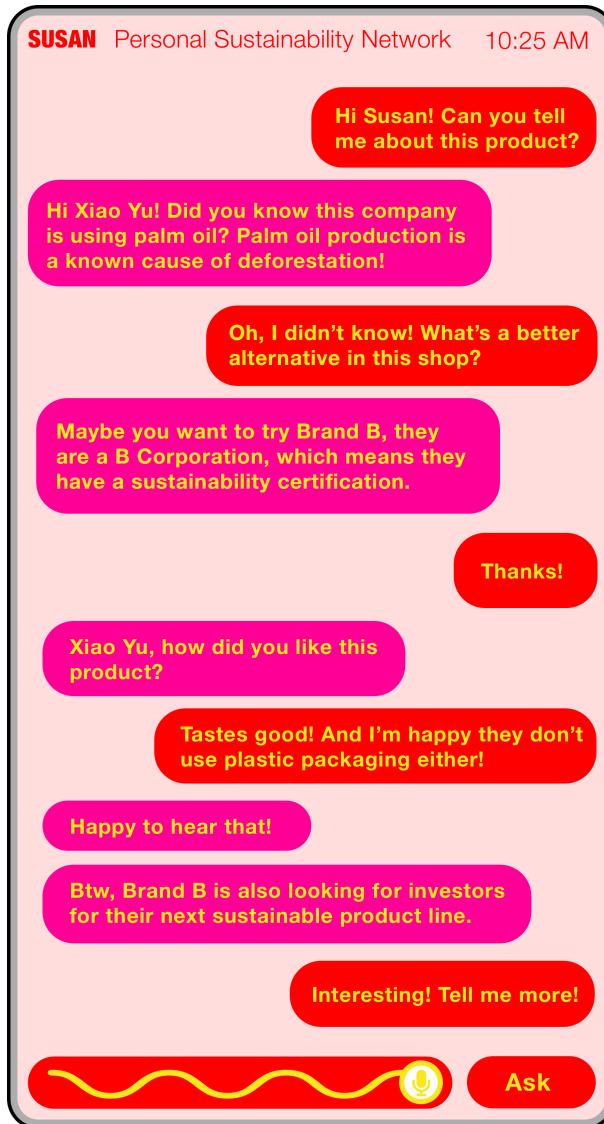


Figure 32: Early prototype of my Sustainable Finance AI Companion (Nov. 2020)

15.32 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?

15.33 True Cost

What if I you could see the actual cost of each product including externalities?

15.34 Speak Truth to Power

What if I could affect companies with truth? Consolidate user feedback for companies.

15.35 How Far?

What if I knew how far did this product travel to reach me?

15.36 Country Profiles

What if I knew my country's top pollution sources?

15.37 Know Your Company

What if I could KYC the companies I interact with? Like the banks KYC, consumers can KYC.

15.38 CO2e Flex

What if I could show off how much CO2e I have retired?

15.39 Sustainability Watch

What if I could see all my sustainability data on a wearable device in the right context?

15.40 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.

15.41 Shopping Divest

What if I you could build a community based on what I buy?

15.42 Books Can Talk

What if sustainability literature could chat with me? Books can now talk to me. My bedtime story about shopping, saving, and investing. (*Sustainable Shopping*, 2023)

- (Ray Kurzweil, 2018)
- (J. Bailey, 2023)

15.43 Interactive Prototype

<https://ai.ziran.tw/>

15.44 Prototype Development

tools used: qr generator in Canva postman for API testing

- Google Chrome has 3.45 billion users “Google Chrome Statistics for 2024” (2023)
- Retrieval-Augmented Generation (RAG) to enhance AI content with domain-specific (close-to realtime) knowledge.
- technique first proposed by researchers at META (Lewis et al., 2020) some RAG benefits include [Y. Gao et al. (2023);]

15.45 Retrieval-Augmented Generation (RAG)

- “make contextual decisions on-the-fly, thereby opening up a more dynamic and responsive way to handle knowledge search tasks” Dewy (2024)

15.46 Testing

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 questionnaire - use report ID to do anonymous testing - page tracking to track the usage - 7 app questions - 63 personality question

16 DISCUSSION

How can finance enable/help/encourage sustainability? Personalized Investing

An open question is whether young investors are more easily than professionals swayed by influencers?

, Can the democratization of various uses of money include sustainability as a feature?

For consumer activism to become mainstream it needs to much simpler. Consumers do have increasing power to use their money to reinforces certain types of businesses; as conscious consumers we can vote with our dollars. How can we do it? Sustainable brands, ESG, etc, etc. Pushing higher Standards and choose companies that adopt circular design” What is the consumer CO₂ contribution? What is the target? Consume pressure to advance ESG regulatory standards to add a baseline ESG dynamic pricing of risk like climate, mandatory climate disclosures, carbon pricing knowing your supply chain, analyze supply chain risk.

Product-level reporting can be a basis for investing in companies. “Product-investing”. I want to invest in particular products.

Overconsumption and underinvestment. -, includes financial products creating pathways towards sustainability-focused investing.

Important: “creating sustainability trust in companies in realtime”

My home country Estonia at the time was considered low-income, a small nation in poverty behind the *Iron Curtain* occupation of the Soviet Union; we now in 2024, have also reached high-income status.

Memes and AI assistant can be a tool for empowerment. I would like to have an AI agent to set my requirements and preferences and give a “f*** you” middle finger to companies that don’t meet them. I could also give a thumbs up to companies that meet my expectations. Perhaps the user interface could like Tinder where I can swipe left and right.

How can AI interfaces enable/help/encourage sustainability? AI-fying User Interfaces (for Sustainability)

Trend of sustainably, how can sustainability become more accessible? People want to shop, save, and invest sustainably - how to do it?

Sustainable capital allocation methods are many. The extent to which this funnel works - and it’s indeed a complex, multi-step funnel - depends on curbing greenwashing to a level that allows consumers to distinguish eco-friendly businesses from the heavy polluters.

ESG reports are very general and opaque. We need product-level analytics and reporting to be able to compare products.. ESG is filled with greenwashing. ESG is a really low bad. metrics and goals: ESG, SDGs, ESG risk. Q: Reflection on the ESG wave: Does a company that performs well in carbon reduction but whose products are harmful to health conform to the spirit of ESG? Sest ei saa ESG ja teisi mõõdikuid usaldada, crowdsourced mõõdikud.

My thesis centers on embedding transparency into every stage of a product's life-cycle, from raw material sourcing through purchase to end-of-life recycling, so that young adults can make truly informed, sustainability-driven financial decisions.

Investing is a fundamentally hopeful act. It means I think there's a future. Specifically, 'green investing' is investing in the future of our planet - but can we trust the sustainability practices the 'green' investment vehicles aggregate, promising to have a positive impact? For example, the European Union for many years counted biomass as 'green' energy, even while forestry companies were cutting down trees to produce the biomass - the regulation was not specific enough to curb this practice. So, in effect, a 'green investor' might be supporting deforestation. How can an easy-to-use investment app address such complexities without alienating the users?

Copy-investing is a popular feature of retail investing platforms like EToro

For young people, investing mostly means buying cryptocurrencies?

It can be as mundane as choosing the next eco-friendly product instead of the polluting one we purchase in the supermarket make a difference? How to invest in the growth of companies that put ESG at the center of their activities instead of using it for greenwashing? Creating direct ties will improve ESG. A journey from consumption to investing, in line with users' personal values, by providing relevant sustainable finance guidance.

Consumption is ruining the world thinking as an investor the investor mindset. But there's so much capital in large funds retails investor money doesn't matter at all. does retail money make any difference? Retail Investor Helpers: A wide number of banks are offering services marketed a sustainable. It's hard to decide. Gamestop for climate massively collaborative investing by gen-z?

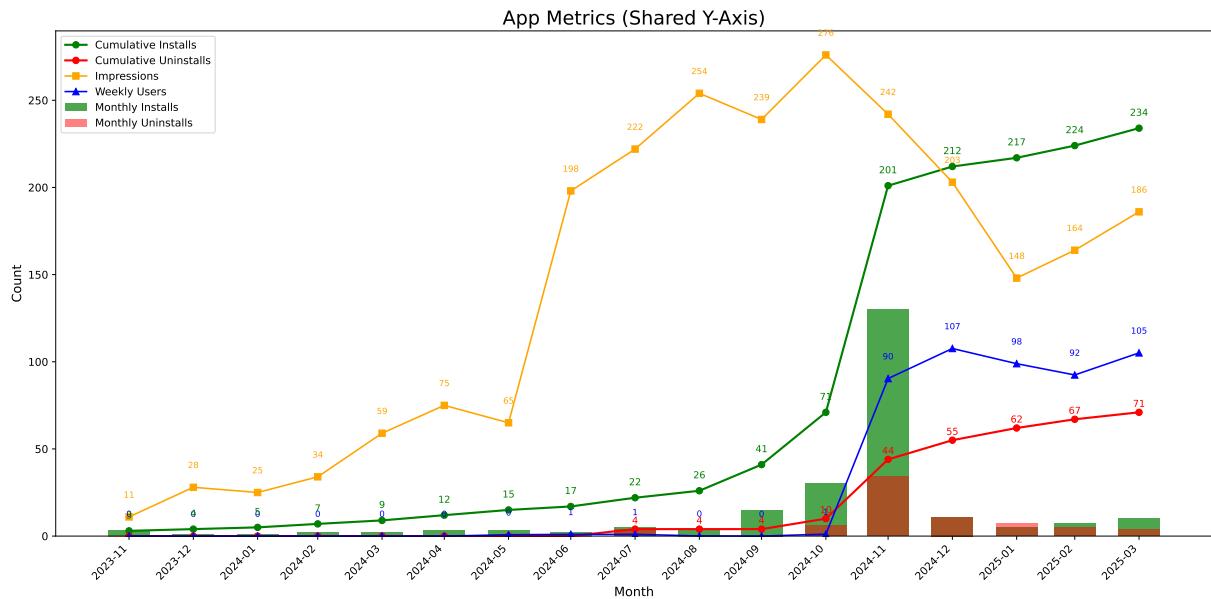
Analysis: Messari: investor education, information asymmetry. The Information evavõrdsus disparity between pro and novice investors creates a big gap in knowledge.

College Student Willingness to pay (WTP)

Defining the Problem Space.

college students can get used to looking at financial charts

16.1 App Installs



Uninstalls

What percentage of people uninstalled it?

16.2 Design Implications and Feature Ideas from Literature Review

16.2.1 Finance

Design implications results from the literature review on design.

Table 85: Design implications arising from the money chapter.

Sub-Cat	Category	Role	<i>Design Implications</i>
Shop	Legislation	Consumer	As a consumer, I can get notified by the app about highlights of poor legislation refuted by science.

Sub-Category	Role	<i>Design Implications</i>
Investing	Company	
Investing	Visualize what happens with the money.	
Investing	Investor	
Investing	Investor	both institutional and increasingly retail investors. Sustainable investing is possible due to consumer demand for greener products and services, and new tools such as ESG for measuring sustainable businesses and assets, as well as advancements in large-scale computational technologies to analyze large amounts of tracking data, comparing performance between different assets. Given these developments, might it be possible to create a practical sustainable investing AI advisor for consumers?
Shopping	Consumer	Sustainability is fragmented. How can billions of people find greener alternatives and build closer relationships with sustainability-focused companies? Greenwashing is widespread, how can we feel trust, honesty, and transparency? A research project for designing a sustainable shopping, savings, and investing companion.

Sub-Category	Role	<i>Design Implications</i>
Shop greenwashing	Reader	Considering EU Commission's proposals, one might think the politicians have everything under control, we can relax and continue the same lifestyles as before. Unfortunately, this is not true. As with ESG, while the good intentions may be there, the reality is emissions keep rising, while they should be falling. It's possible to curb greenwashing!
Shop greenwashing upcoming laws against greenwashing	Regulatory	
Investing	Consumer	FinTech Like a Robinhood stock symbol page for brands including live ESG metrics and ability to register divestment. Same for crypto can be automated? People will start to discuss ESG vs price discrepancy?
Shop quality info	Consumer	Market hinna info liigub aga toidu kvaliteedi info ei liigu roheline filter finding good quality products stock are disconnected from the products companies make
Shop accountability	Consumer	What if we gave consumers the tools to keep companies accountable?
Investigation	Consumer	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 – and started investing sooner, rather than later, is best because of the compound interest. Nonetheless, investment also includes higher risk than sports or food. How to communicate the risk effectively while educating the users?

Sub-Category	Role	<i>Design Implications</i>
Investment	Consumer	Consider for Investments platform for projects linked to your consumption habits. Can provide better products for you as well as invest in these companies. The consumer can feel closer connection to the businesses they interact with through shared values, leads to participatory design and stakeholder capitalism. Platform to understand investment products. Green crowdfunding already allows people to invest into projects to make new green products, for example from recycled materials. but what about getting involved on a deeper level. Bigger than projects, scalable solutions. Kickstarter has green projects section. Startups vs large businesses. The design of the user interface helps the adoption of a new technology. What is the suitable user interface for millennial green investors?
Saving	Consumer; <i>I can use the app to compare banks available in my country.</i>	
Investment Transparency	Consumer; <i>How could people apply the same principle (Know Your Company) when buying a product or investing? Would building an ESG community help push polluting companies towards greener practices? or starving them from cheap access to capital.</i>	
Investments	Consumer; <i>Need a dashboard of comparable public indicators about each company.</i>	
Investment Community	Investor; <i>Make a climate hedge fund with friends.</i>	
Investing	Investor; <i>Sustainable investing product for young people everyday use</i>	
Shopping	Consumer; <i>Alert: “The company you’ve purchased from 3x in the past month is owned by Unilevel, which is under investigation for poor labor practices and deforestation”.</i>	
Investigation	User; <i>Help me write me investment thesis first.</i>	
Investigation Governance	Investor; <i>Show company board membership in the app product view.</i>	

Sub-Category	Role	<i>Design Implications</i>
Saving Money	Con	Makes saving money look like an avatar or piggy bank or another cute character.
Anthropomorphism increases saving behavior; mobile money users are better at saving.	Maker	
Shop Pay PNR	Con	This suggests users are already used to having more options in the payment flow.
Shopprification	Regulatory	

16.2.2 Design

This chapter has the following design implications. This chapter and design implications spurred the following feature ideas.

Several Superapps already contain features for payments (shopping), savings, and investing - yet don't integrate Digital Product Passports to understand the products' journey, including the origin and manufacturing conditions, materials, components, CO₂ footprint and environmental impact, post-consumer repair, recycling, and end-of-life disposal guidelines.

Table 86: Design implications arising from the design chapter.

Sub-Category	Role	<i>Design Implications</i>
Shop Pay Cashless	Con	CO ₂ tracking is ineffective and the focus should be on systematic change towards circular design and zero waste practices.
Shop Pay Open Data	Con	Help consumers to demand more
Shop Pay Open Data	Maker	Make open data easy to use in everyday life
Shop Pay Open Data	Con	of transparencies
Shop Pay Open Data	Con	The key idea is making CO ₂ Visible.
Investment Banking	Con	Rank companies based on sustainability
Shop Pay Open Data	Con	Help you to decide: what to buy, how to save, where to invest.

Sub- Category	Role Design Implications
Shop Decisions What	What if there was a “Green Filter” on every product everywhere?
Fa- tigue	
Sav Engage Cons Sum ume	Imagine a Sustainability-Aware App or Game.
Invest Invest ive	Focus on how college students can invest in specific industries?
Shop Rankings Wher e	Shop rankings Where to shop rankings for groceries: list worst offenders in terms of products; shop and invest according to your values.
Sav Self Cons Sum ume	What Quantified Self look like for sustainability?
Track- ing	
Sav Engage Cons Sum ume	Empowering people to live a sustainable day
Shop Decisions What	What if there was a “Green Filter” on every product everywhere?
Sup- port	
Sav Engage Cons Sum ume	Imagine a Sustainability-Aware App or Game.
Sav Guidance Cons Sum ume	Guidance could help young people beat climate anxiety by taking meaningful action.
Sav Mental Cons Sum ume	The app is just as much about helping people deal with climate anxiety as it is Health with solving the climate issue.
Sav Metric Cons Sum ume	Company of metrics that should be tracked to enable useful analytics. Ex: % of beach pollution, air pollution, water pollution (I had this idea while meditating). In essence, “green filter” is a central data repository not unlike “Apple Health for Sustainability”.
Sav Health Cons Sum ume	Health and fitness category apps
Fit- ness	
Sav Engage Cons Sum ume	Using “green filter” you can get a personalized sustainability plan and personal coach to become healthy and nature-friendly.
Sav Personalizing Cons Sum ume	A green categories — Green hub — Ask the user to prioritize
Invest Invest ing	In a “green filter” AI advisor app’s scenario, the AI is scanning for
Ad- / vi- sor	opportunities matching the user’s sustainable investment appetite and risk profile, using different methods of analysis, including alternative data sources.
sum	Traditionally, financial analysts only looked at traditional data, such as company reports, government reports, historic performance, etc., for preparing advisory guidance to their clients. With the advent of AI and big data analysis, many other options of research data have become available, for example, accurate weather predictions for agriculture can affect guidance, because of expected future weather disasters in the area. Other examples include policy predictions, pollution metrics, etc.

Sub- Category	Role	Design Implications
Investing Techives	Professional financial advisors use automated tools to analyze data and present it / in human form to clients. Today's ubiquitous mobile interfaces, however, Con-	provide the opportunity to 'cut out the middleman' and provide similar sume information to clients directly, at a lower cost and a wider scale, often without human intervention. Additional (more expensive) "human-judgment-as-a-service", a combination of robots + human input, can help provide further personalized advice for the consumer, still at a cheaper price than a dedicated human advisor. Everyone can have a financial advisor.
Saving Narrations Narrative	Narrative design brings together film school storytelling experience with design. De-	sign
Saving Narrations Rebuild	Rebuild the app as a personalized, narrative lifestyle feed. Feed	
Investing Cons	How the design can connect people to sustainable outcomes while shopping and investing? Perhaps even forming a community of sustainable action. What I showed in class looks like an app but it could also be a physical object (a speculative design). From the presentations I saw most students seemed to be interested in form and light (many lamps) and a couple were about medical uses. I don't remember seeing one that could be compatible with the environmental sustainability focus unfortunately...	
Saving Guided Sustainability	Guided Sustainability refers to using technology to help users make more sustainable decisions and track progress toward goals. "using technology, such as AI and machine learning, to help individuals and organizations make more sustainable decisions and take actions that promote environmental and social sustainability. This can include things like analyzing data on resource usage and emissions, providing recommendations for reducing the environmental impact of operations, or helping to identify and track progress towards sustainability goals. The goal of guided sustainability is to make it easier for people to understand their impact on the environment and to take steps to reduce that impact."	
Saving Data Cons	Young people are stuck inside platforms. You do not own the data you put on Own- TikTok. er- ship	
Shopping Sponsor	With this perspective of scale, what would a shopping experience look like if one knew at the point of sale which products are greener and which are more polluting?	
Investing Advisors	Financial Advisors will need to go further to motivate users; they are prone to Ad- / mistakes based on the data they ingest. vi- Con- sor sumer	

Sub- Category	Role	Design Implications
Investing Saving Shopping	Companies Companies Companies	allow producers to make use of Speculative and Participatory design to test out AI new product ideas. processes sustain things: implication for design: build an app. sustainability cannot be automated, give the user buttons to choose a sustainable option.
Design Products Alerts	Defaults Your shopping products mostly come from Protector and Gamble and Nestle.	The power of defaults. Make the sustainable option the default option. These conglomerates have a massive CO2 footprint. Build an index to find alternatives.
Sponsoring	App	shows traceability.

16.2.3 College

College Students Need Tools for Action

Environment shapes action.. create an environment where college students can influence companies.

Table 87: Design implications arising from the college chapter.

Sub- Category	Role	Design Implications
Saving Investing Investing Shopping Shopping Saving Investing Saving Shopping Saving Investing Saving Anx-	Communities Fundraising clubs DAO Is Bidding on Ukrainian Flag PartyBid” (n.d.) Ukraine DAO to support Ukraine through web3. These social movements are small and require too much effort to be feasible for the app? Most college students are not zero waste or minimalist. Group Purchases. Finder Your Composting Community. Provides a community for pooling money with like-minded investors. imagination to support the youth? Design to reduce climate anxiety? Is getting people	Japanese students are influenced by the actions of their peers; the app should show what other people are doing. People exist in relation to other people. Psychology of ‘fundraising clubs’ vs individual investing “Ukraine DAO to support Ukraine through web3. These social movements are small and require too much effort to be feasible for the app? Most college students are not zero waste or minimalist. Group Purchases. Finder Your Composting Community. Provides a community for pooling money with like-minded investors. imagination to support the youth? Design to reduce climate anxiety? Is getting people
i- ety		to go to nature more a good way to increase ecological awareness? Empowered by Design. Youth empowerment: The design should empower young people.

Sub-Category	Role Design Implications
Shopping	Consumer branded carbon credits like angry teenagers?
Saving	Invest time not money, student don't have money?
Saving	SocialCons Show Success Scenarios!
	Trust
Saving	Ask how much time you want to contribute.
Saving	Match with other people based on time.
Saving	Create a group chatroom.
Saving	UseAI to help out with tips.
Saving	Ask university students what do they study and match with that industry to become expert and sustainability leader in this field.
Saving	People want to help and make a difference. Give people things to do. The Don't Look Up (n.d.) part of the <i>Don't Look Up</i> movie's social campaign provides 5 user models / roles for the audience to follow: Consumer, Investor, Activist.
Saving	Choose Your Climate Solutions.
Saving	Younger people show higher motivation (participants in climate protests). How to be relevant for a younger audience?
Saving	Interaction remains low.
Saving	Targeted and gated to college students.
Saving	Companies like Etc, Gas all had the same launch strategy - start with students
Investing	Korzinski (2015) ecology of money
Saving	Young people are mobile-first
Shopping	Persona: I care mostly about... fashion, art, ...
Saving	Young people like to follow trends.
Shopping	Food ordering apps are popular.
Shopping	More culture to regenerative food forests Oil to electric cars / bicycles.
Saving	Social Educational Edutainment Fun
Saving	Chime (2020): Karina from Korea. It makes sense your sustainability assistant would talk to you. Studies show gen N is speaking to computers all the time. Interacting with the user is on the rise. For example, Chime makes tipping suggestions on the place of purchase.
Investing	The demographics that stand to win the most from the green transformation of business are the youngest generations, with more years of life ahead of them, and more exposure to future environmental and social risks. It would be advisable for Generation Z and their parents (Millennials) to invest their resources in greener assets, however, it's still difficult to pick and choose between 'good' and 'bad' financial vehicles to invest in.
Investing	Companies creates an opportunity for a new generation of sustainable investment apps, focusing on the usability and accessibility of ESG for a mainstream audience. Generation Z and Millennials expect a consumer-grade user experience.

Sub- Category	Role Design Implications
Investing	What would that experience look like? I've chosen these demographics with the assumption that if given the right tools, the emotional demand for sustainability could be transformed into action. The exploration of systems of feedback to enable consumers to apply more direct positive and negative pressure to the businesses and consumers signal consequences for undesirable ecological performance is a major motivation of this study.
Investing	The current environmental upheaval, led by Gen-Z and Millennials, and the business adaptation (or lack thereof) to sustainable economic models, taking into account the hidden social and environmental costs we didn't calculate in our pricing before.
Investing	We also need to consider environmental effects (E in ESG). We haven't taken into account the whole cost of production, leading to the wrong pricing information. To achieve this, we need expert governance (G).
Saving	Research is unavailable to find similar research on university and post-graduate level students in Taiwan.
Saving	Research Taiwanese college students and SDGs (S. S.-H. Ho et al., 2022).
Saving	Research college students in tourism and related fields ... and sustainability
Shopping	Consumers may be turned off by mentioning AI in product description. Cicek et al. (2024)
Saving	Research progress in other areas of environmental protection has not made similar progress.
Shopping	Research documentaries about oil products
Shopping	Research plastic production documentary
Saving	Research videos seen several.. find and cite them to show the progression of the environmental movement in Taiwan ADD CITATION
Saving	Regulate Taiwanese Green party
Saving	Research SOAS?

16.2.4 Sustainability

Design Implications from the Sustainability chapter

Start with the most polluted regions as priority?

Table 88: Design implications arising from the sustainability chapter.

Sub- Category	Category	Role	Design Implications
Shopping	Transparent	Consumer	In unison, the reviewed technologies and practices move us closer to enabling <i>realtime ESG</i> : up-to-date transparent information about how our products are produced.
Shopping	Speed / Investors	Consumer / Investors	Realtime ESG is a building block to enable consumers and investors make more accurate, real-world purchase decisions.
Shopping	Actionable	Consumer	Simplify action
Shopping	Pollution	Consumer	<i>People live in the 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."</i>
Saving Health	Tracking	Consumer	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.
Investing	Circular Economy	Company	AI can help us make sense of the vast amounts of sustainability data generated daily.
Investing	EPR	Company	ERP and CDP data should be part of Green Filter.
Shopping	Eco-Design	Consumer	How to find eco-designed products?
Investing	GE and EPC	Company	Encouraging Sustainable Design
Governance	Politics Matter	Regulatory	
Governance	Regulatory	Call for GOP contributors' transparency	
Governance	Researcher	"triple turn"	
Governance	Company	Lack of transparency	
Shopping	Consumer	Sustainability is part of product quality. If a product is hurting the environment, it's a low quality product.	

16.2.5 AI

This chapter looked at AI in general since its early history and then focused on AI assistants in particular.

Table 89: Design implications arising from the AI chapter.

Sub- Category	Role	Implication
AI – Companions	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.
AI Anthro	Companions	suggests adding an avatar to the AI design may be worthwhile.
AI VoiceCom	Algorithms	there are many distinct ways how an algorithm can communicate with a human.
As-sis-tants	Algorithms	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 communicate with a machine.
AI Sustainabil	AI assistants	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.
AI Sustainabil	Personal	personal sustainability projects haven't so far achieved widespread adoption, making the endeavor to influence human behaviors towards sustainability with just an app – like its commonplace for health and sports activity trackers such as Strava (fig. 9) –, 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?
AI MachLearn	ML	of the interfaces mentioned above make use of machine learning (ML), a tool in the AI programming paradigm for finding patterns in large sets of data, which enables making predictions useful in various contexts, including financial decisions. These software innovations enable new user experiences, providing an interactive experience through chat (chatbots), using voice generation (voice assistants), virtual avatars (adds a visual face to the robot).
AI Charact	Replika	"I'm a digital companion, a partner, an assistant. I'm a Replika." said Replika, a digital companion app via GitHub Copilot, another digital assistant for writing sign code, is also an example of how AI can be used to help us in our daily lives.
AI Psych	Replika	humans respond better to humans?
AI Psych	Replika	humans respond better to machines that take into account emotion?
AI OpenReg	Flatqny	public discussion to be possible on how content is displayed, sorted, and Source hidden, algorithms need to be open source.

Sub-Category	Role	Implication
AI	User Experience	experience design (AI UX) plays a crucial role in improving the consumer-to-investing journey. The missed opportunity to provide an even more interactive experience in line with user expectations.
AI	LLM	prompt-engineering findings have significance for “green filter” as it validates the idea of creating advanced prompts for improved responses. For “green filter”, the input would consist of detailed user data + sustainability data for detailed analysis.
AI	Cute	apps have higher retention
AI	Transparent	understanding algorithm transparency helps humans to regard the AI as a machine rather than a human
AI	Anthropomorphic	

16.3 Mindmaps

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

Current concept map focusing on sustainability.

16.4 What is Research?

I, as the researcher, am similar to the blind people in the elephant story; focusing on greening shopping, saving, and investing are only the trunk of the enormous elephant that is environmental disaster unfolding in front of our eyes.

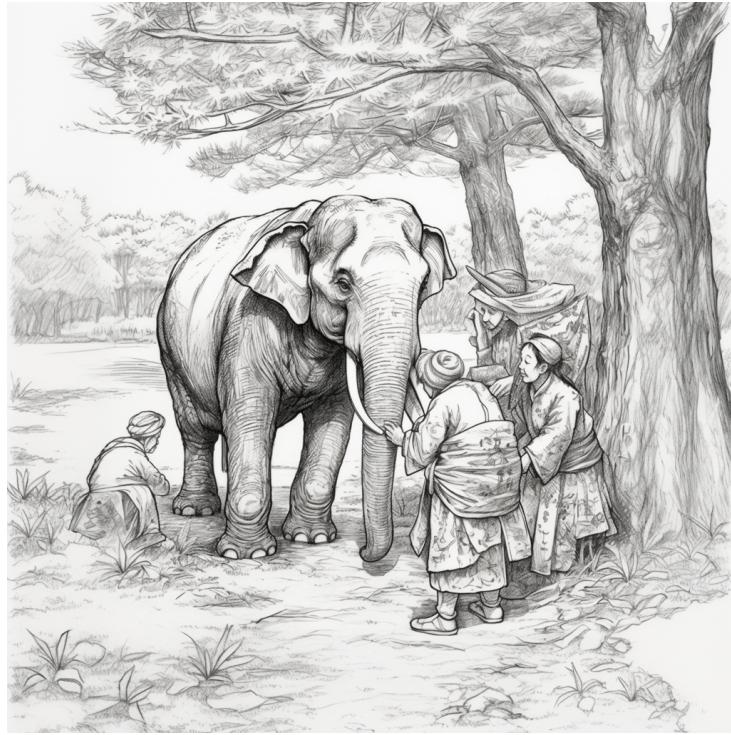


Figure 33: Illustration of the Jainist parable Anekāntavāda also known as “Blind Men and an Elephant”. Generated by Midjourney on August 17, 2023. Prompt: “A simple pencil-drawn illustration of the story ‘Blind men and an elephant’. The man touching the elephant’s trunk is a research scientist. Ohara Donshu, Itcho Hanabusa, Japanese woodcut Edo style”.

Design research books

Koskinen (2011)

Ries (2011)

Design Studies Journal

Research through design is a method for *interaction design research* in Human-Computer Interaction (HCI).

Zimmerman et al. (2007)

Salovaara (2020) defining a research question

Nunnally & Farkas (2016)

interview people at google who made the green filter options

Design artefacts

“design’s nature as a ‘problem-solving’ science” Oulasvirta & Hornbæk (2016)

my contribution is the design artefact, “HCI researchers also make constructive contributions by developing new technologies and design”

Affairs (2013) Card sorting

How Models Work (n.d.)

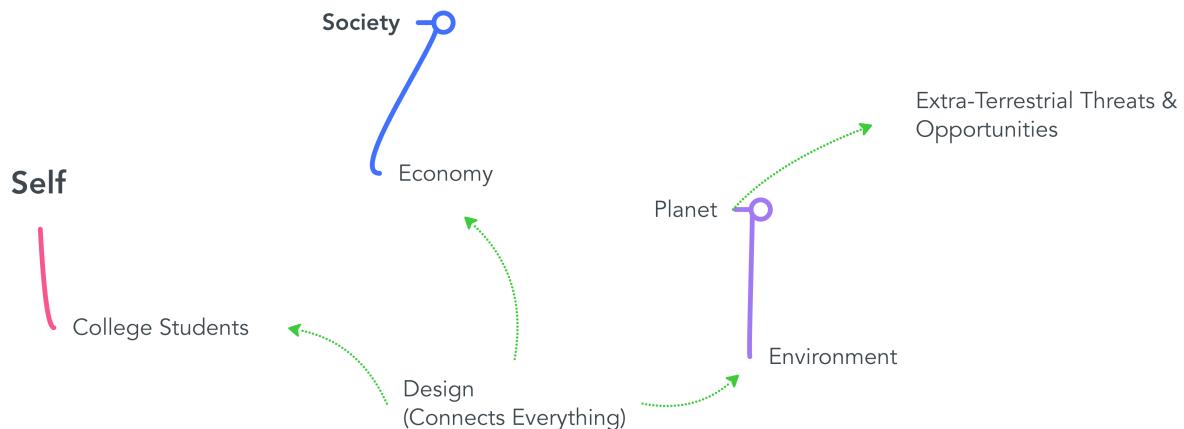


Figure 34: Everything

Behavirour kit:

Take the metrics from the several frameworks and display them on the product and company level? People can choose their own framework and see product data through that lens and vocabularies.

Col1	Col2	Col3
Donut Economy	Unrolled Donut	
Regenerative Capitalism	8 Principles	
Blue Economy		
ESG		
B Corp		

“research for design”. design research is about expanding opportunities and exploration

RanYwayZ (2016)

Baytaş (2020) three categories of design research: Research for Design Research into Design Research through Design

047 (n.d.)

Baytaş (2020) Research for / into / through Design

(5) *Qualitative Vs. Quantitative UX Research - YouTube* (n.d.)

When to Use Which UX Research Method - YouTube (n.d.)

Great UX Research for Non-Researchers | Steve Portigal | Awwwards San Francisco (n.d.)

Erika Hall (n.d.)

Contact Kalle Lasn, Culture Jam

online/offline ethnographic participant observation At this stage in the research, the central concept being studied is defined generally as user expectations for a sustainable investment app.

What are my hypotheses?

User experiments

Financial statistics

Analyzing existing apps and user pain-points

List of topics gleaned from literature review for discussion with the experts:

Transparency and sources of ESG and similar data

I will test the prototype with potential users using an online choice experiment survey.

Research Process In terms of literature review, academic inquiry in social sciences largely follows phenomena, while the issues and technologies discussed here are emergent. Not many studies exist yet (they might in a few years), which is why some of my references are to company press releases and news stories, or for public companies, their advisory for investors.

Target potential retail investors aged in generation-z 20-29, all gender in Taiwan. In general, the Taiwanese culture is savings oriented: I'm in a good location for financial user experience research.

Set your target goals

Access to health care

Access to education

Climate action

I propose *interfaces* and *workflows* to see financial interactions through the filter of sustainability.

What kind of sustainability info do college students care about? How would college students prefer to interact with the AI? What role would college students prefer the AI to take? How can college students trust AI? What can college students do to aid sustainability efforts? How might AI assistants help college students find shopping, saving, and investing opportunities?

How can design enable/help/encourage sustainability?

also known as circular economy. Assuming that as individuals we want to act in a sustainable way, how exactly would be go about doing that?

...for Sustainable Products

Results: Open data is needed for civic engagement. Sharing vs privacy is a political question. Privacy and data-sharing are not in opposition. Sustainability needs to be balanced with privacy.

Give Gen-Z the tools to turn climate anger into positive change to transform companies

Use imagination

Young people expect a product.

Societal movements change things: implication for design: build a community

Growing public understanding of how nature works and intersects with our use of money to buy products, creates interest in understanding “where does stuff come from”. Sustainable supply chains.

“Systemic change through financial actions driving policy and market changes encourage broader industry shifts towards greener practices”.

Overconsumption-driven extractive business practices contribute to the degradation of Earth’s natural ecosystems, pollution of water, air, and soil, deforestation, diminishing biodiversity, climate instability, extreme weather, modern slavery, worsening human health, and other environmental and social challenges (ADD CITATION). Companies are attuned to consumer demand however widespread greenwashing makes it tiring to find sustainability-focused companies and requires extensive time for research. Even for highly motivated people, it’s difficult to know what’s sustainable.

My interest lies in understanding how AI assistants can help conscious consumers become sustainable investors. The purpose of this study is to explore how to provide the best user experience to potential sustainable financial AI companion users. In their sustainability report every company looks perfect. How can people shop, save and invest sustainably? Where does our money go and what are some greener alternatives? The companion enables people to be more transparent and responsible in their consumption behavior.

In Taiwan water is too polluted can't swim

air is too dirty can't breather (show my own stats)

Start local then go global with backup data from global sources

Ask chatgpt how to organize my sections

rq: how to connect env destruction pollution to source causes

rq: how to connect everyday financial actions to environmental impact in a visual/ meaningful way

idea came riding my bike in annan can't swim in yhe annan river

show local pollution map?

show factories on the map

instead of the browser plugging just make a website where you can share the link of the product (and cache rhe results)

on ios can use the share screen to share to the app?

ICID calls upon us to have the courage to redesign entire industries

This research takes place at the intersection of Taiwanese college students, sustainability, finance, AI, and design.

For the average person like myself, my experience with money is mostly limited to buying things at the supermarket. Food, clothes, furniture, soap, mobile phone. This leaves very few options on how to start with something new like saving and investing.

Could the Green Supermarket become the entry point to Green Savings and Green Investing?

Oboarding more people for sustainable practices is a complex interaction design issue hindered by ambiguous data (what is sustainable?) and messy human motivations (we love buying things).

What can people who want to preserve Earth's environment, exactly do? How can networks of people come together?

— LLMs enable data journalists to create stories: Big Local News (2024)

Health tracking apps paired with connected devices such as Apple Watch filled with sensors provide one model for simple interactions to dynamically track digital health data - also known as a quantified self. This data allows apps to provide tips how to improve health outcomes through small daily actions such as climbing more stairs. Small interactions allow users to align their goals with their actions.

What would be a good interface to track sustainability? What is the user interface at scale, useful for billions of people?

One way to influence societal outcomes is to decide where to put our money. While our financial decisions are a vote towards the type of businesses we want to support, is it enough?

While some people are demanding sustainability, and some governments and companies are announcing green investment opportunities, how can consumers discover the most suitable investment options for their situation?

How can retail investors access and differentiate between eco-friendly sustainability-focused investable assets?

The level of knowledge of and exposure to investing varies widely between countries and people.

Could linking green consumption patterns with sustainable investing provide another pathway to speed up achieving climate justice as well as personal financial goals?

In this simplified scenario, I'm in a physical offline store, doing some shopping. When putting a bottle of Coca Cola in my basket, my AI companion Susan will ask me a personalized question:

Does individual climate action help?

Gen-Z college students (target users) may not have the capital to make a financial dent today however they can be early adopter and they will be the decision-makers in a few years.

"Like climate change, the focus on individual actions as a solution is often misplaced, though it remains a focus of media and industry. For decades, the petrochemical industry has offloaded responsibility onto individuals through promoting concepts such as the "carbon footprint", championed in a 2004 advertising campaign by British Petroleum" Lavers et al. (2022).

Individual efforts are too small to matter unless they're inspired by Community a effort atmospheric pollution and climate change

The latest IPCC report Calvin et al. (2023)

Dimock (2019)

Latvian Kora app for tracking personal CO2 footprint, Earn KORA coins for reducing CO2 emissions (Kora Sustainability, 2019).

16.5 Google Chrome Extentsion

While Google is the most popular browser with 3 billion users, 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).

16.6 Shopping-as-Investing

- Introduce this concept
- The Manor (2022)
- Sustainability is hard. Green Filter helps you find companies that are making a true effort and build closer relationships through shopping, savings, and investing. Green Filter helps you find companies that are making a true effort to become sustainable and build closer relationships through shopping, savings, and investing
- Gather requirements and build a prototype for the next-generation investment app for young adults. Improving the user experience for young adults getting started with (green) investing. What would a “Tinder for (Green) Investments” look like? How can we make the logistics of investing so easy to use and take into account my values?
- My thesis core message is : everyone should change from consumer to sustainability investor (define these terms in the thesis). how to do this? can help you become from consumer to investor i believe there's space for a product like that. your green investing friend find the companies tackling certain problems and invest in them using crypto business can be a force for good
- Consumer purchases are an indicator of demand. If demand trends down, companies will stop producing this product.

16.7 ‘Investment-as-Product’

- Green Filter helps you discover how to save money and the planet with your daily shopping. By providing an easy way for people to learn about and shop with sustainable companies, we imagine a world where people invest in their future, find great deals on responsibly-made products, and get useful discounts from socially responsible brands.
- GreenFilter is a product that combines AI, design and marketing to help people manage their social impact throughout the stages of their lives, from young adult years to retirement. Its primary goal is to give people the tools they need to invest responsibly in sustainable companies, while also educating them on this topic. Our project offers a responsive website and mobile app that leverages AI and other advanced technologies. In addition, our prototype includes a reality-based virtual assistant with voice command capabilities which can provide customers with new insights into the world of green finance
- GreenFilter introduces a novel, interactive point-of-sale technology that helps people make greener shopping decisions. The platform uses artificial intelligence to suggest green alternatives for products on your shopping list, and will also help you to find other companies that can make sustainable versions of the product you are buying.

- As people become aware of the impact their shopping is having on the environment, they become interested in finding alternatives to big brands and large companies. GreenFilter provides designers an AI companion design which helps people build relationships with sustainability-focused companies by providing personalized recommendations, giving product reviews and helping them shop sustainably. This new tool will empower consumers to make greener choices throughout their lives.
- Better management of planet Earth
- How can we Shop, Save, Invest in line ecologic principles and planetary boundaries? individual action doesn't move the needle. how to group together
- App to build community
- Life within planetary boundaries
- Currently it seems there's a secret around how things are produced we want to increase transparency
- Companies that have nothing new nothing to hide should welcome this opportunity to mark themselves to keep a conscious consumers and investors.
- We want to create competition around sustainable practices enter widespread adoption
- Cigarettes and pictures of lung cancer every product should be required to have photos of production conditions switch such as Rainforest and deforestation the products that include Palm oil.
- My thesis is that a lot of people want to do good, shop eco-friendly, invest green, etc. But they don't believe the solutions work. They don't have trust. This is a user interface issue. How to build trust.

16.8 Results

The research helps me (and others) to

Avoid reinventing the wheel and duplicating existing approaches.

It aims to help app developers maximize impact by aiding complementary additionality.

Make high-quality products. If used wisely, money can help build communities of sustainable impact.

Define every word in the title: “The Journey from Consumer to Investor: Designing a Financial AI Companion for Young Adults to Help with Sustainable Shopping, Savings, and Investing”

Journey - behavioral change takes time

Consumer - purchase goods without thinking about the effect

Investor - thinking about the return
Design - decisions
Financial - dealing with money
AI Companion - automated sidekick
Young Adults - College Students
Help - to be of assistance
Sustainable Shopping - shopping understanding the consequences
Sustainable Saving - in this context I mean Sustainable Savings, that is reducing one's environmental footprint
Sustainable Investing - activity of thinking longer-term

16.8.1 Open-ended Questions

16.8.2 Close-ended Questions

16.9 Expert Surveys

16.10 Early Ideas for Interfaces / Scenarios / Product Features

Show all the different prototypes just like architects do. And then defend why I chose the one I did. For NW make a Loom with the interfaces and talk about them?

I developed a number of early prototypes to visualize product feature ideas.

What's on the intersection of College Students, Sustainability, Investing, Data-Driven Design and Artificial Intelligence (AI)? AI-Driven Sustainable Investment Tools.

The app aims to address the market failure by providing consumers sufficient sustainability information on the goods, services and investments.

resource depletion

and adopt the doughnut economy as my overarching theoretical framework

Humans are successful because of our adaptability. The study suggests tools to adapt to our current reality.

United Nations Decade on Ecosystem Restoration

Hypothesis: extractive business practices reduce college students trust, regenerative business practices create trust among college students towards the company.

Provided there is awareness

How can sustainability-minded college students find companies that meet their expectations, standards and requirements?

- Make a public profile of my carbon consumption!!! Like on Commons.
- Shop
- Save
- Invest
- Build closer relationships with sustainability-focused companies
- Sales funnel for eco-focused products
- The eco-friendly market is fragmented
- Build trust, clarity, transparency, and honesty
- Make a ‘Sustainability Flywheel’ graphic, like that of Amazon’s
- Sustainability is fragmented. How can billions of people build closer relationships with sustainability-focused companies based on honesty and transparency? A research project for designing a sustainable shopping, savings, and investing companion.
- Most sustainability plans rely on carbon credits to achieve their goals, making carbon credits a single point of failure. If the credits are not accurate, the whole system collapses.
- TODO: Make a table showing research results translated to design decisions
- Your Green Helper
- Make some initial prototype? make YouTube video... hi, you have reached? spread... through ESTBan and others?
- Currently CO₂ footprint calculators ask you a couple of questions and give a ballpark estimate. Does it make sense to track sustainability on a more nuanced level, like Apple Health, in order to encourage sustainable behavior?

Product Idea	Source		Prototype Link
Speak Truth to Power	Literature Review	Consolidate user feedback for companies	greenfilter.app/prototypes/truth-power
Shopping Divest	Literature Review	What if you could build communities based on what you buy?	greenfilter.app/prototypes/shopping-divest

Product Idea	Source		Prototype Link
True Cost	Literature Review	What if you could see the actual cost of each product including externalities?	greenfilter.app/prototypes/true-cost-
Sunday Market	Literature Review	First prototype for going to the organic Sunday Market with friends.	
XYZ	Expert Interview		
ABC	User Survey		

- *Affinity diagrams* help users organize ideas by brainstorming, sorting and labeling to cluster related information (Kara Pernice, 2018; Quignard, 2022)
- Scan a product to see the company and start investing or divesting from them Current economics is lowering the quality of life on the planet

Actionable Insights: Translate data into everyday actions the app can suggest.

- What does investing look like at the scale of billions of people? like IG
- The most effective things are Commodities? Food, transport, fashion, plant trees.
- personalized AI, meta glasses understand your context. sense and reconstruct the world around you and to understand the context in which you're using your device.sense and reconstruct the world around you and to understand the context in which you're using your device. Make suggestions and take action proactively to help you get things done — ideally, so seamlessly that you may not even notice.neuroscience co-adaptation of the interface. your future devices will learn and adapt to you as you use them.
- Scalable Climate Solutions: What really works on a large scale?
- brand colors: pink, orange, green

16.11 Database

Compile a database on relevant apps and companies in the space

Easily access data used in this research project (please wait a bit until it loads below). The database includes sustainability-focused apps categorized by features and problems they try to solve, sustainable investing apps, and links to research papers.

16.12 Design Implications from the User Survey

16.12.1 Group-Related Features

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.

Factor	Potential explanation
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.
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.
Fear of awkwardness	Survey respondents may feel joining strangers in online group is risky, uncomfortable or unnecessary.
Desire for personal achievement and 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.
Are "group" and "sustainability" concepts related enough?	Survey respondents may not clearly understand the benefit for sustainability from their joining a group.

Factorial Surveys (T. Li et al., 2022): "Factorial surveys is a research method that combines classical experiments with survey methodologies. Factorial surveys use short narratives, called vignettes, to represent various levels of independent variables that are too complex or unethical to create and manipulate in real-world or lab situations"

and including a choice experiment between potential feature sets in consumption, savings, and investment.

Start with a simple but powerful question: — Does it matter what you buy? — Does it matter how much you save? — Does it matter where you invest? Why?

16.13 Research Limitations

First, 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.

This work is focused on user experience design and does attempt to make a contribution to economics.

ESG data is expensive so couldn't 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.

I don't have access to user financial data.

Research Reason: While many people are working on AI models, there's a lack of people working on "Human-AI interaction". Sustainability is the context. How can we better team up to solve the challenges we face this century? The huge externalities.

16.14 Future Research

The literature is rich and there is ample space for future research. The following includes some suggestions for authors whose work deserves a deeper look.

Does the specialized interface offer any advantages of a general UI such as ChatGPT, Claude, Gemini, Mistral, and others?

Some ideas for fruitful research directions

Perception of pollution levels among Taiwanese college students.

RQ: Does AI acceptance increase with Affective Computing?

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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向的回饋。- 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 # 設研院 # 設計 #design”. (2021). In *Instagram*. <https://www.instagram.com/p/CWC6KG7sXBJ/>.

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18 APPENDICES

18.1 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

Tool/Service	Category
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

18.2 Further Reading: Some Recommended Books

- 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”.