EURITO

RELEVANT, INCLUSIVE, TRUSTED AND OPEN INDICATORS
FOR RESEARCH AND INNOVATION POLICY

Danmarks Tekniske Universitet DTU

Technological Change Indicators

An application to worldwide bioenergy R&D

Pedro Parraguez*, Agzam Idrissov, Duarte Carmo & Anja Maier

Technical University of Denmark
Engineering Systems Division

Stanko Škec

University of Zagreb
Department of Design, FMENA

EURITO New Data for R&I Policy Workshop
25 September 2018, Brussels

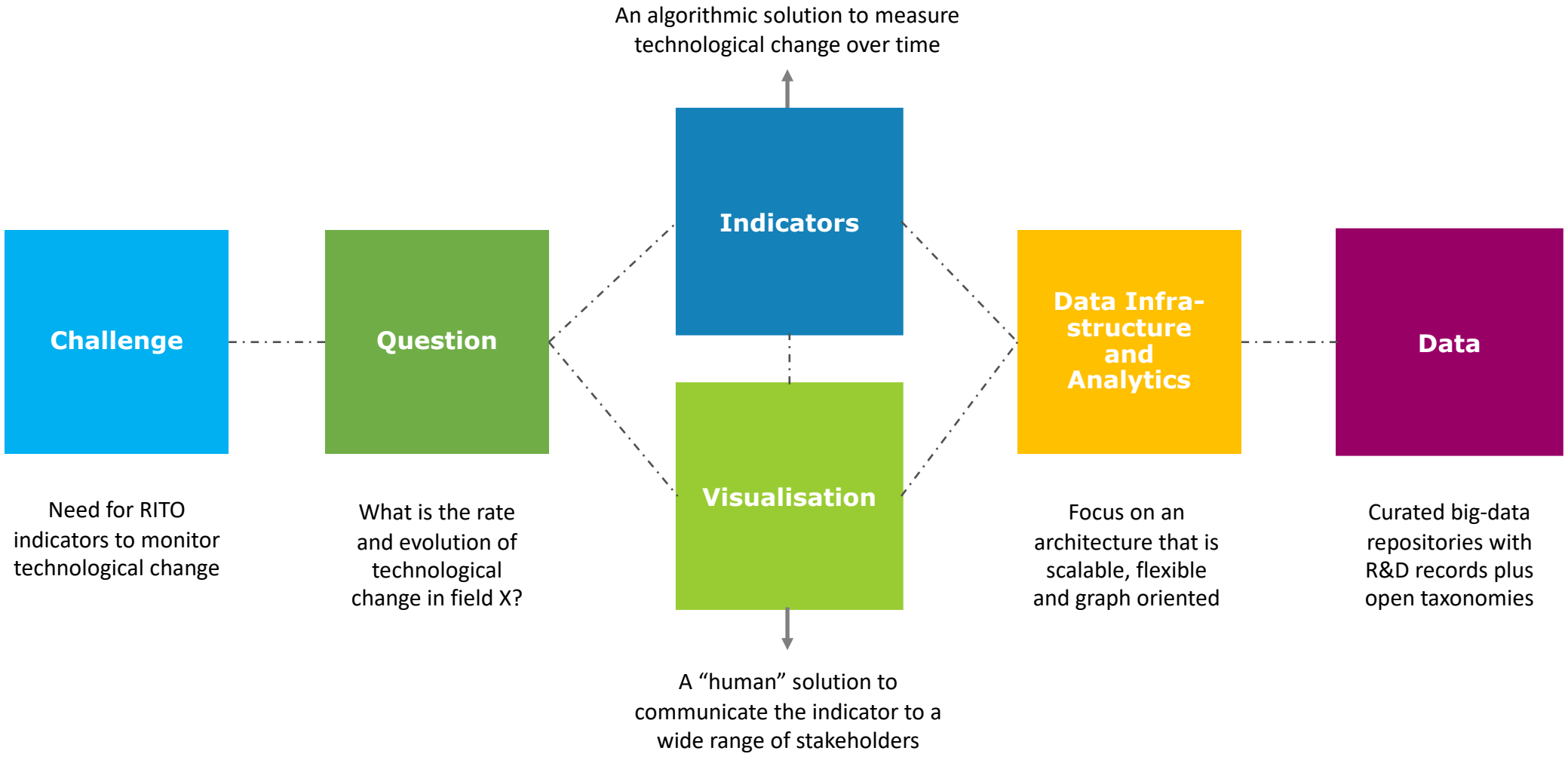
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 770420 – EURITO.

@EuritoH2020 #EURITO

Web: www.eurito.eu

EURITO PILOT # 3: Technological Change Indicators

An application to worldwide bioenergy R&D



Challenge

Need for RITO indicators to monitor technological change

- **Changes in products, devices, processes and practices, i.e. <u>technological changes</u>, largely determine** the **development** and consequences of industrial society.

  Advancing technological knowledge is the most important single factor that contributes to long-term productivity and economic growth [e.g. 1,2]

- **Technological change is a process** → However, the focus of currently adopted indicators is on input (e.g. expenditure) and output (e.g. # patents)

- **No** cross-domain R&I **indicator for technological change has been adopted** in "mainstream" policy making circles

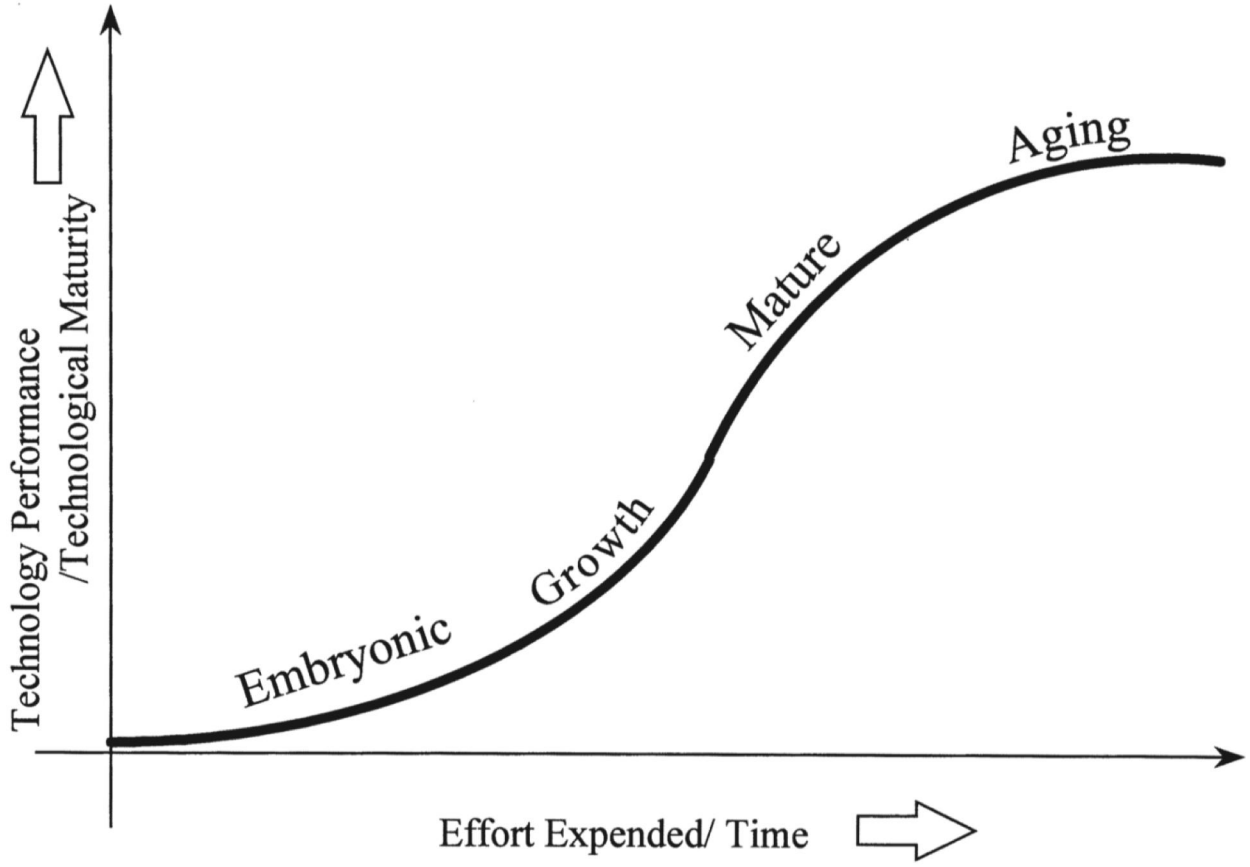
1. Grübler, Arnulf. 2000. *Modeling Technological Change: Implications for the Global Environment*. Laxenburg Austria: International Institute for Applied Systems Analysis.
2. Organisation for Economic Co-operation and Development. 2015. *The Future of Productivity*. Paris: Organization for Economic Cooperation & Development.

Challenge

Current approaches to answer questions related to technology change

1) Changes in the characteristics (**cost/performance/ impact**) of technology-related entities

e.g. Moore, Gordon E. 1998. "Cramming More Components onto Integrated Circuits." *Proceedings of the IEEE* 86 (1): 82–85. https://doi.org/10.1109/JPROC.1998.658762



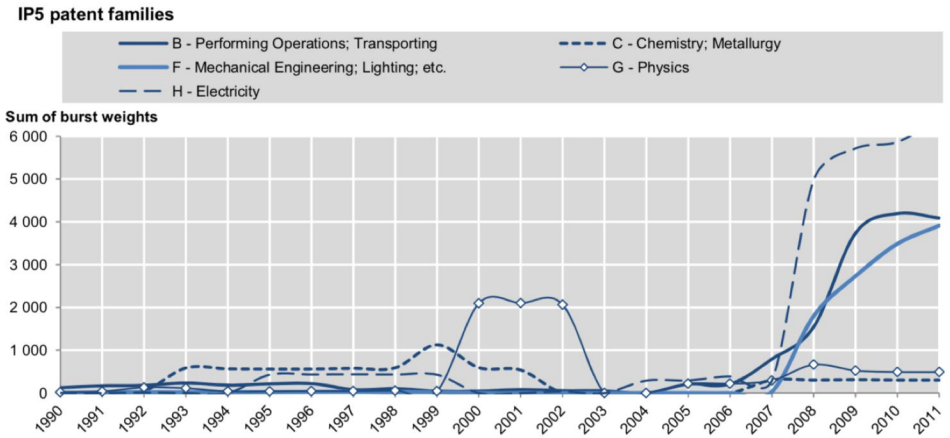
Nieto, Mariano, Francisco Lopéz, and Fernando Cruz. 1998. "Performance Analysis of Technology Using the S Curve Model: The Case of Digital Signal Processing (DSP) Technologies." *Technovation* 18 (6–7): 439–57.

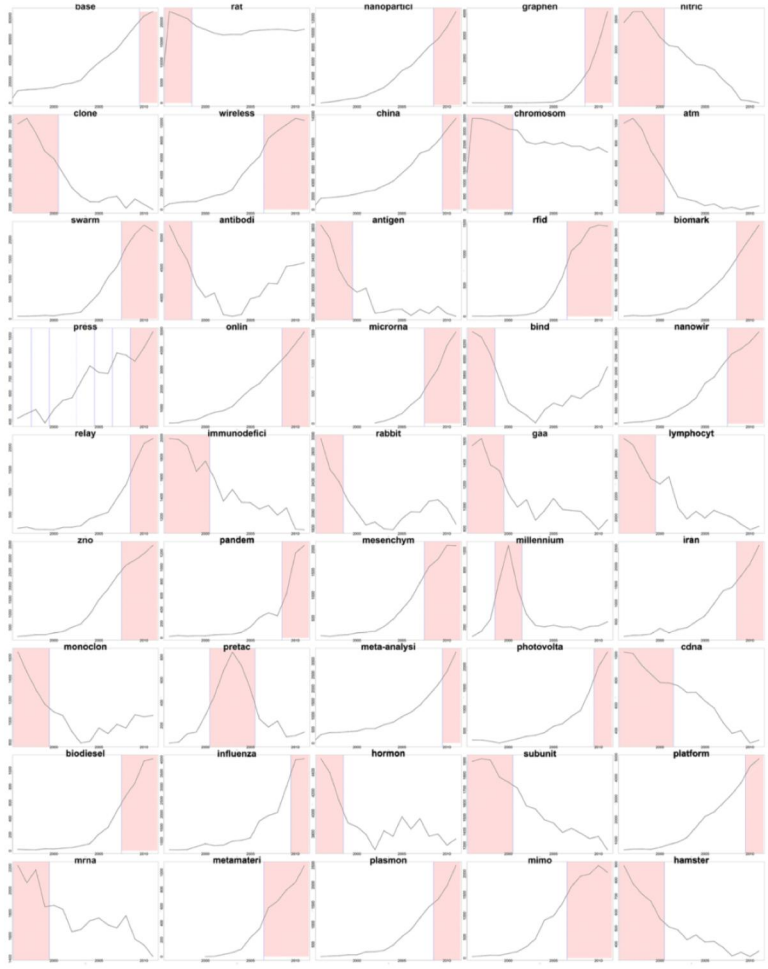
Challenge

Current approaches to answer questions related to technology change

2) Changes in the **volume** of technology-related entities (**terms, categories, keywords…**)

e.g. Dernis, Hélène, Mariagrazia Squicciarini, and Roberto de Pinho. 2015. "Detecting the Emergence of Technologies and the Evolution and Co-Development Trajectories in Science (DETECTS): A 'Burst' Analysis-Based Approach." *The Journal of Technology Transfer*, October





Challenge

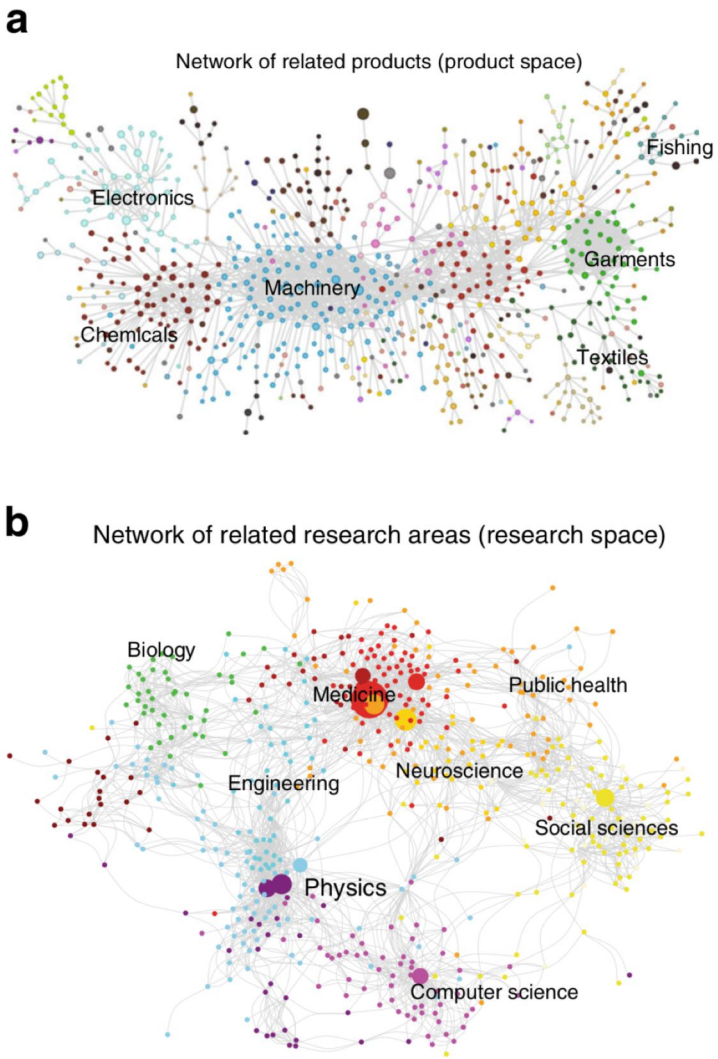
Current approaches to answer questions related to technology change

3) Methods capturing **structural changes** of technology-related **networks**

-Terms
-Categories
-Explicit document links

--> Measuring technological changes in the form of the evolution of the space of **combinatorial possibilities** of a given technological field

e.g. Alshamsi, Aamena, Flávio L. Pinheiro, and Cesar A. Hidalgo. 2018. "Optimal Diversification Strategies in the Networks of Related Products and of Related Research Areas." *Nature Communications* 9 (1).



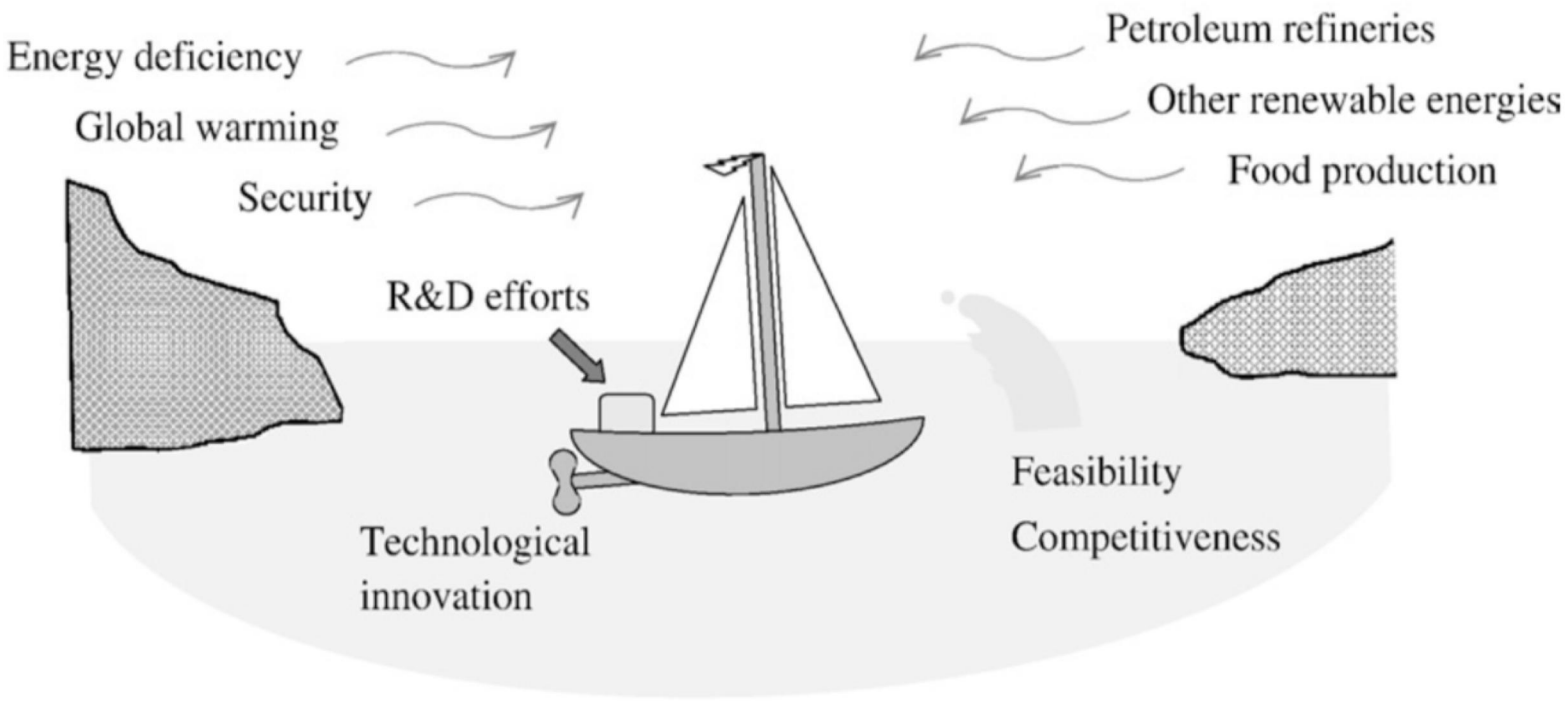
A combinatorial perspective of technological change

Technological innovation emanates from **recombining and synthesizing components** in a novel manner (Carnabuci and Bruggeman, 2009; Fleming, 2001) or for a **new application** (Henderson and Clark, 1990; Yayavaram and Ahuja, 2008).

Novel combinations can be considered as **principal sources of technology development and progress** which dominate innovative activity (Youn et al., 2015)

Challenge

Applied to the context of bioenergy and biofuels

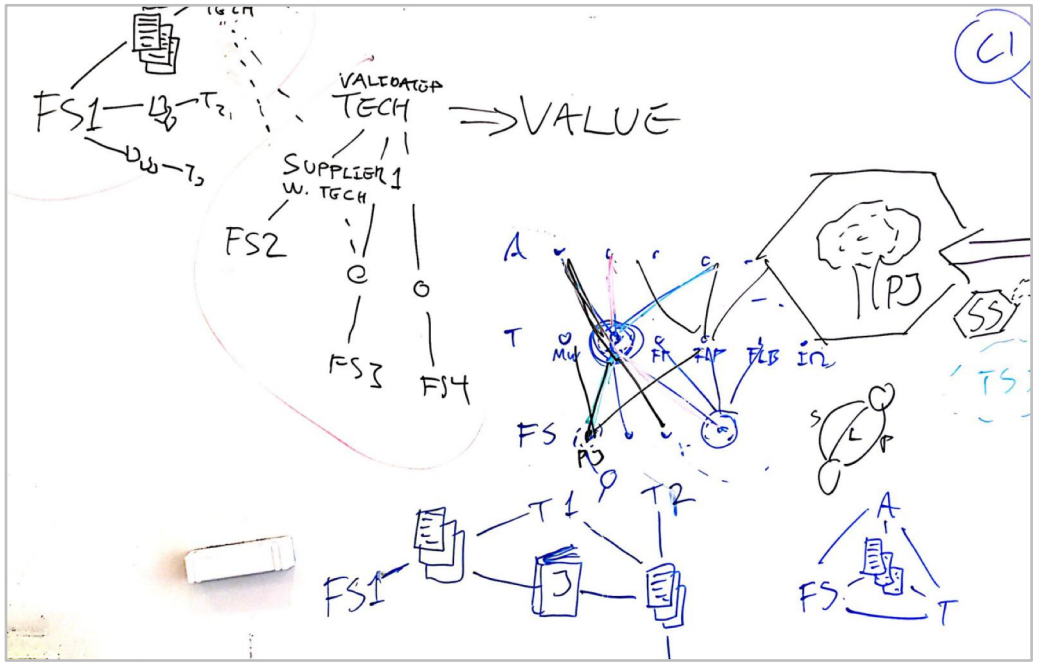


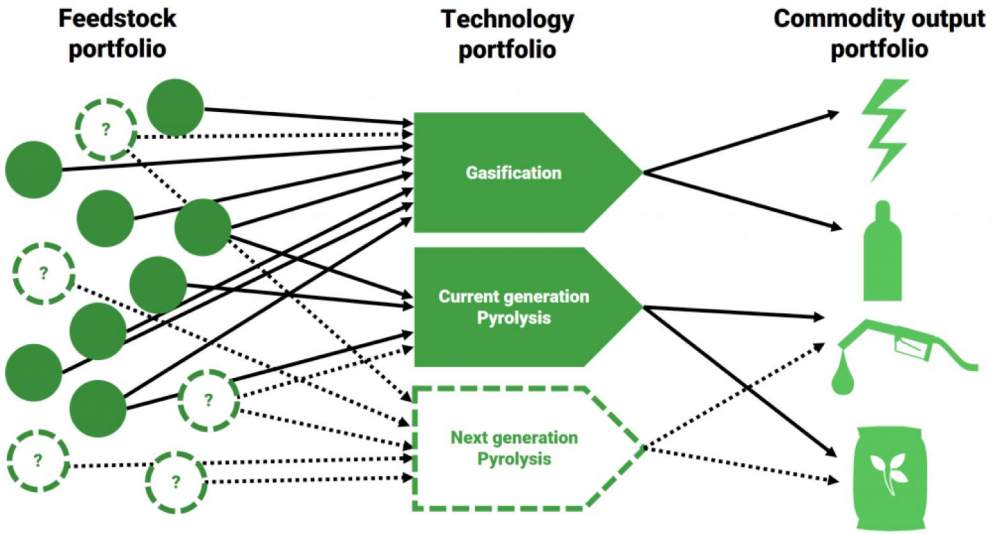
Kajikawa Y, Takeda Y. Structure of research on biomass and bio-fuels: A citation-based approach. Technol Forecast Soc Change [Internet]. 2008;75(9):1349–59. Available from: http://dx.doi.org/10.1016/j.techfore.2008.04.007

EURITO

Challenge

Applied to the context of bioenergy and biofuels





Source: MASH Biotech and AMICa-Pathfinder Project

Challenge

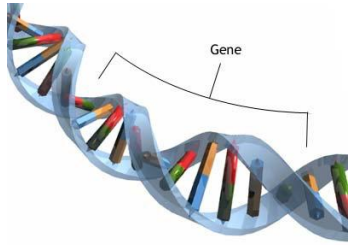
A qualitative picture of technological change - Biofuels

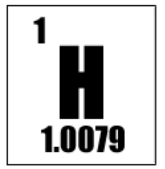
First Generation

Second Generation

Third Generation

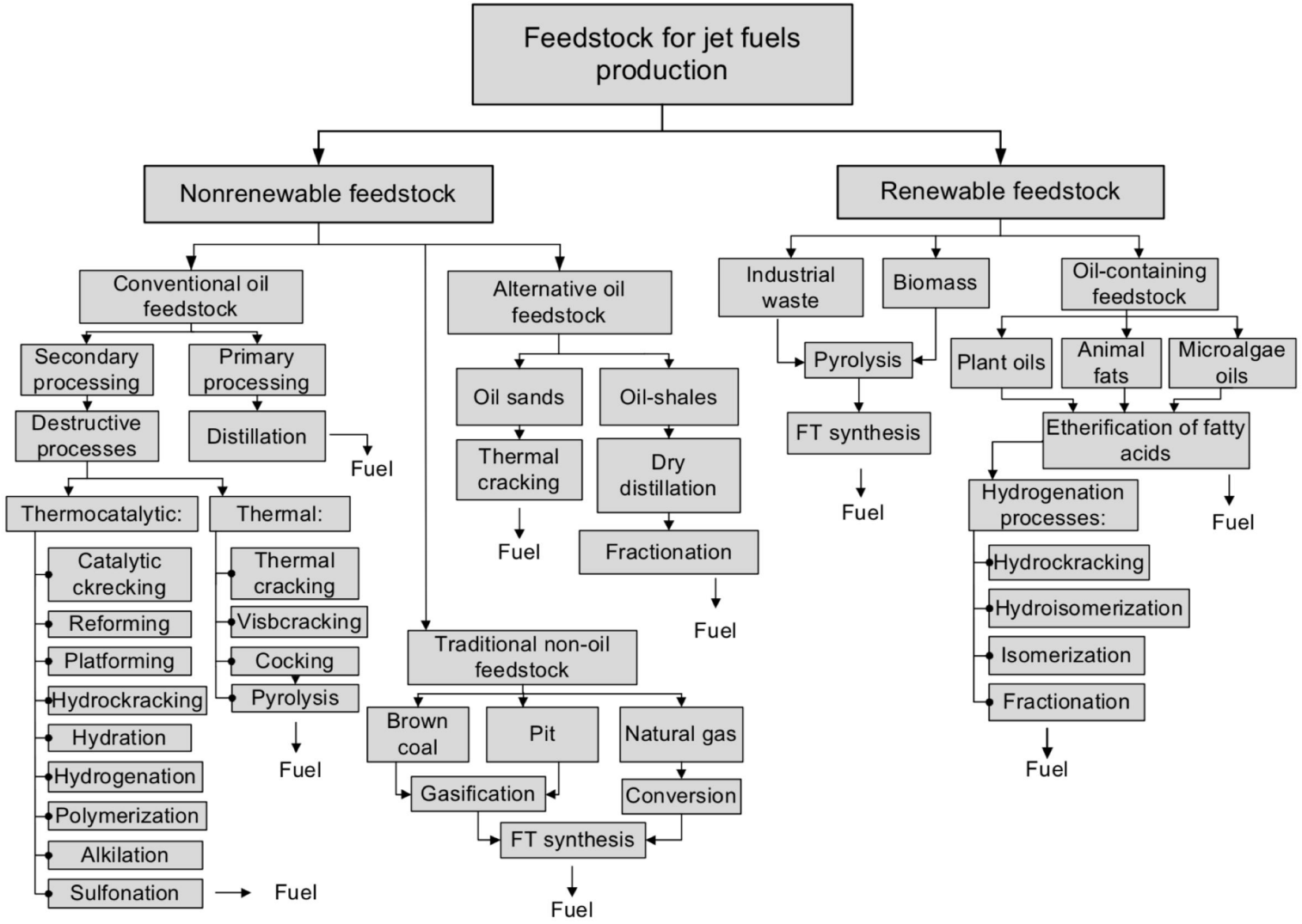
Fourth Generation





Challenge

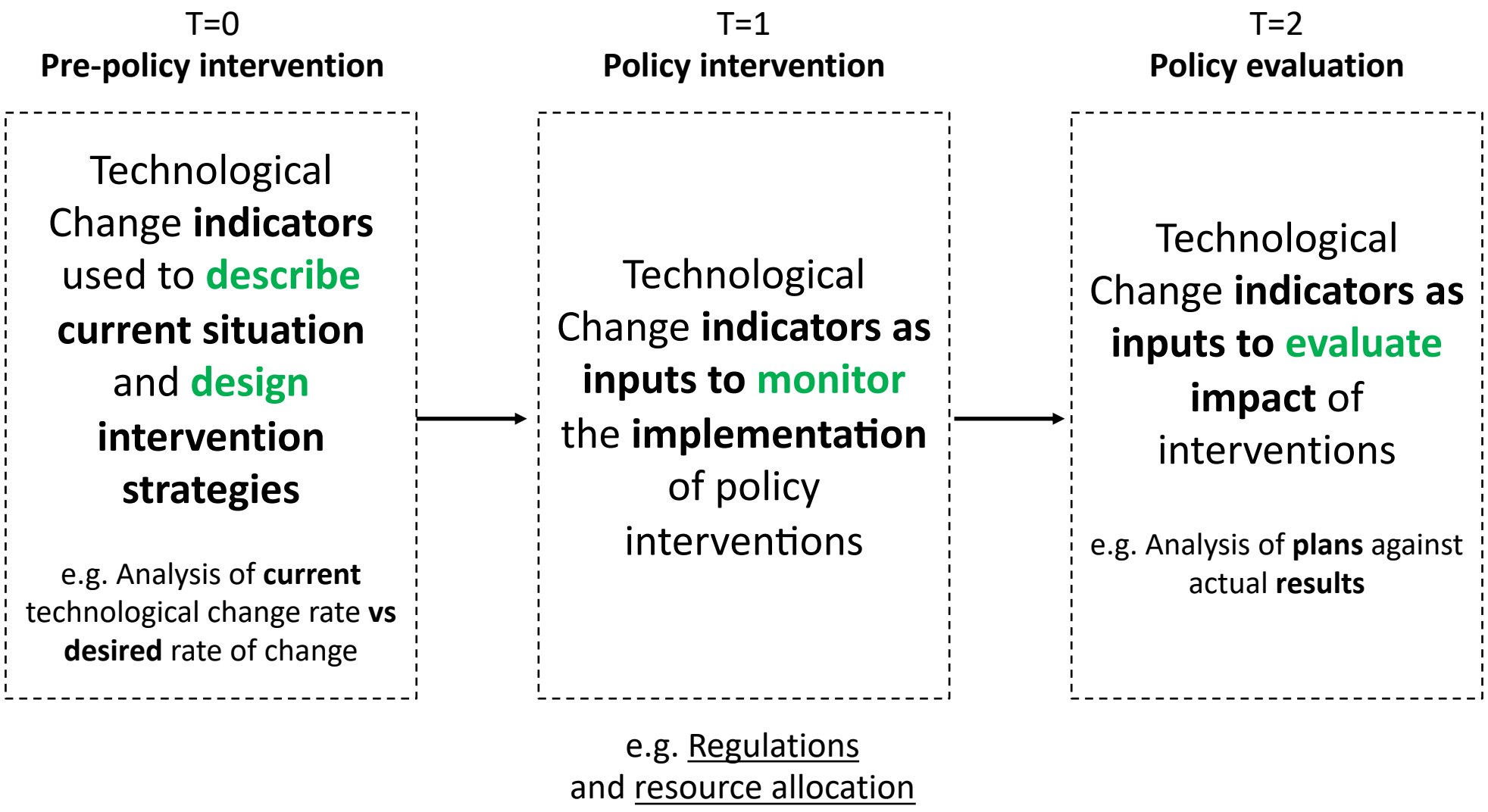
A qualitative picture of technological change - Biofuels



Boichenko, Sergii, Oksana Vovk, and Anna Iakovlieva. 2013. "Overview of Innovative Technologies for Aviation Fuels Production." *Chemistry and Chemical Technology* 7 (3): 305–12.

Question

What is the rate and evolution of technological change in field X?



Question

What is the rate and evolution of technological change in field X?

Some organisations sharing the same question:

Measuring technological change
RITO Requirements

- **Relevant**:
  Should tell us something important –
  e.g. capture recombinant nature of technological processes not just volume

- **Inclusive**:
  Broad coverage of R&I activities –
  e.g. cross domain and data-source agnostic

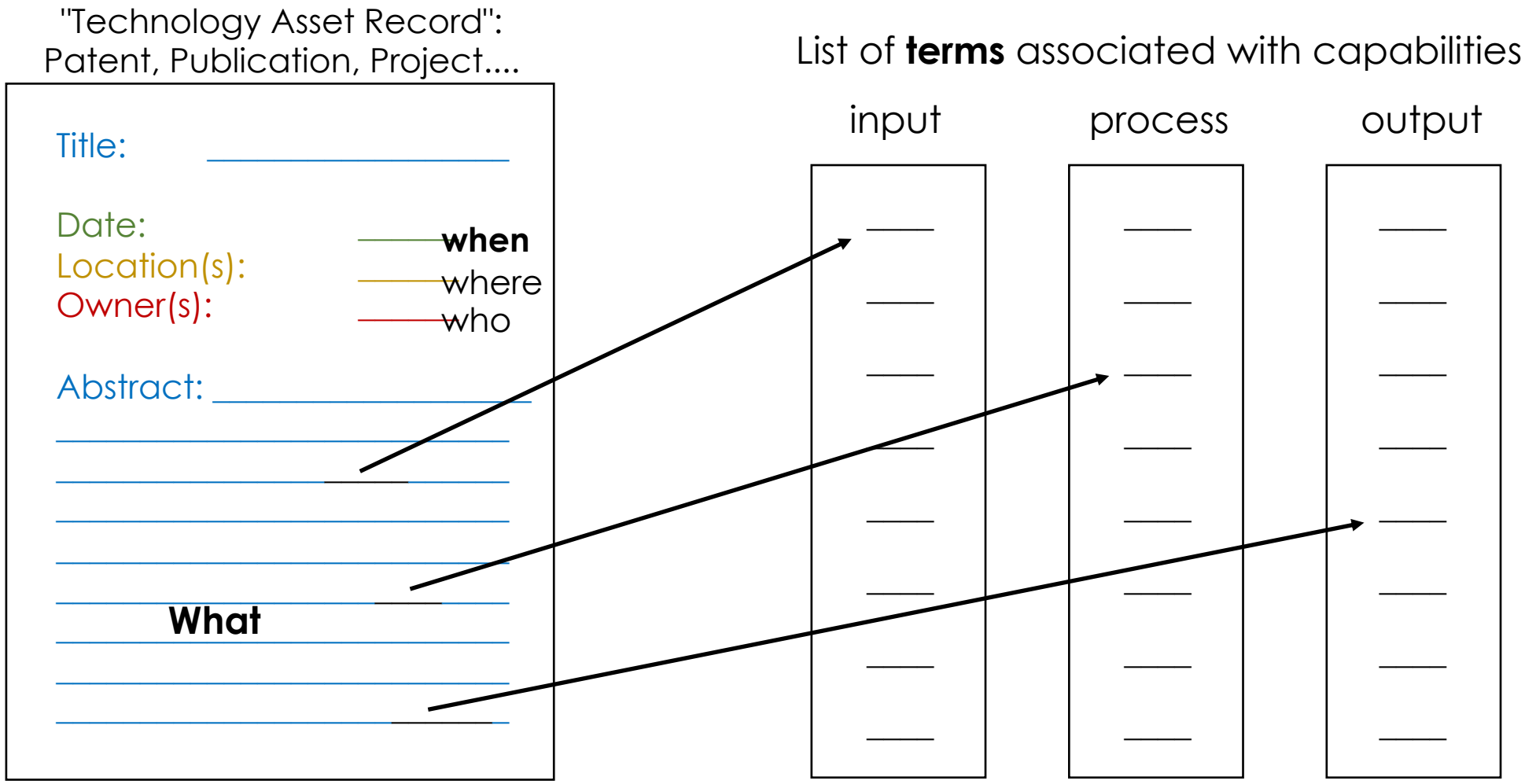
In fact,
volume independent

- **Trusted**:
  Transparency and intuitiveness –
  e.g. simple but possible to drill-down

- **Timely**:
  Minimum lag and
  robust to changes over time

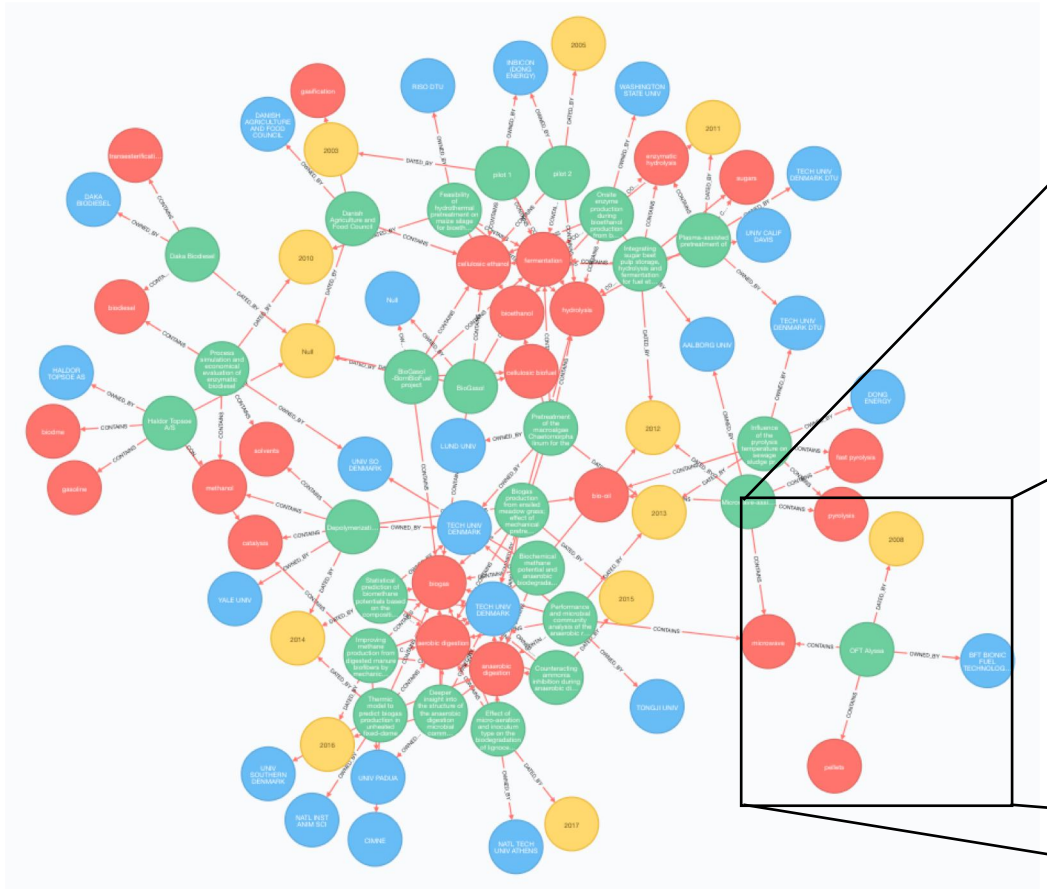
- **Open**:
  Should use open algorithms and
  widely available data

A model to quantify technological capabilities



A model to quantify technological capabilities

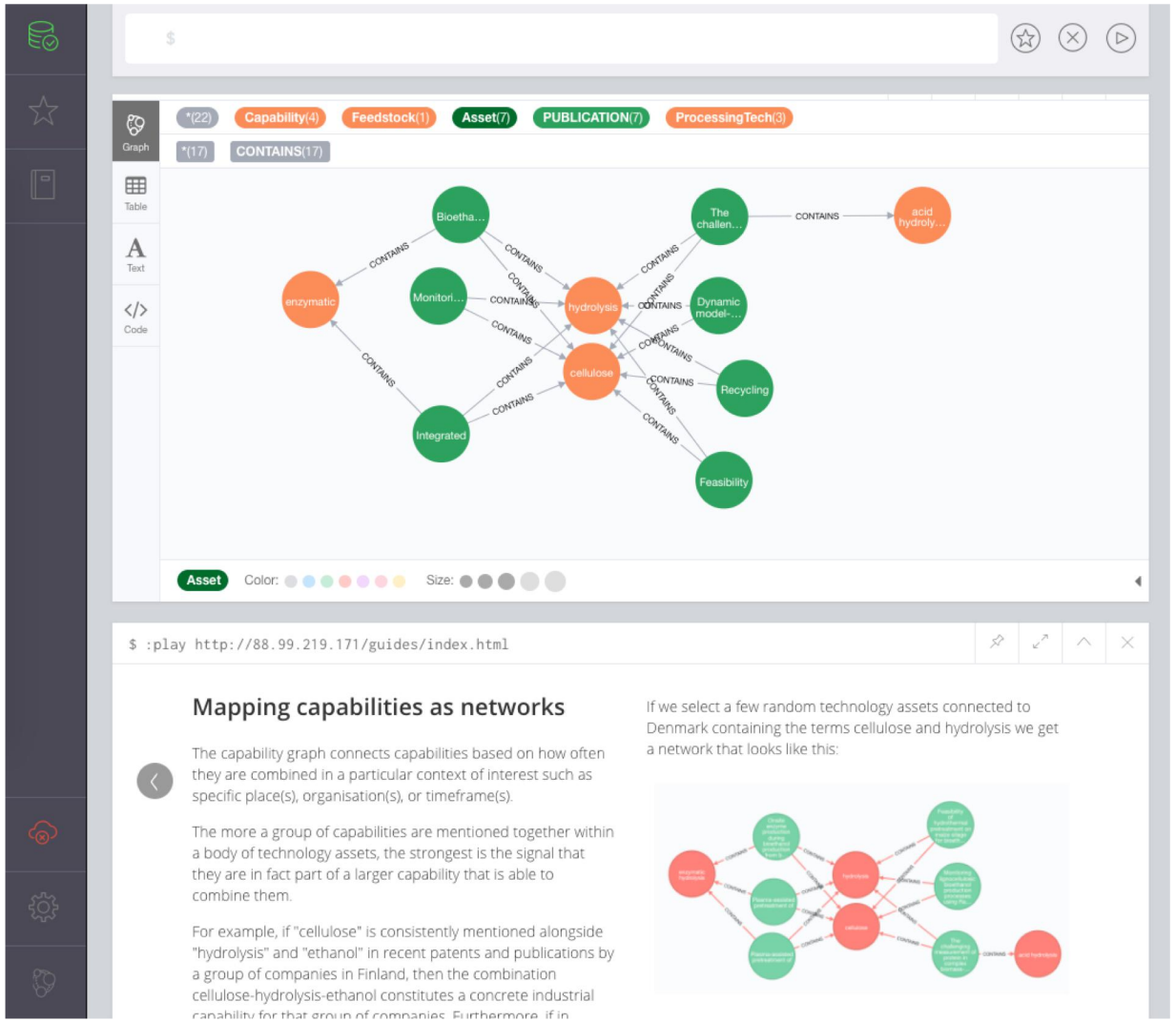
Year(12) ProcessingTech(12) Capability(23) Asset(26) ORGANIZATION(3) Output(11) PUBLICATION(18) FACILITY(5)




```
MATCH (a1:Asset)-[:LOCATED_IN]->(country:Country {name:"Denmark"})MATCH (a1:Asset)-[:DATED_BY]-
>(year:Year)MATCH (a1:Asset)-[:OWNED_BY]->(Owner:Owner)MATCH p=(proc:ProcessingTech)<-[:CONTAINS]-
(a1:Asset)-[:CONTAINS]->(out:Output)WITH proc.term AS Processing_Technology, out.term AS Output, p, a1.title
AS title, year, Owner//WHERE out.term = "butanol"//RETURN distinct Processing_Technology, count(p) AS Count,
Output//RETURN distinct Processing_Technology, Output, count(p) AS Count, collect(distinct(title))RETURN
*//ORDER BY Count DESCLIMIT 100
```

A model to quantify technological capabilities

The first challenge is to model, understand and quantify technological capabilities and explore how intuitive the results are



DTU | AMICa
Advanced Mapping of Industrial Capabilities for Climate

Supported by: eit Climate-KIC

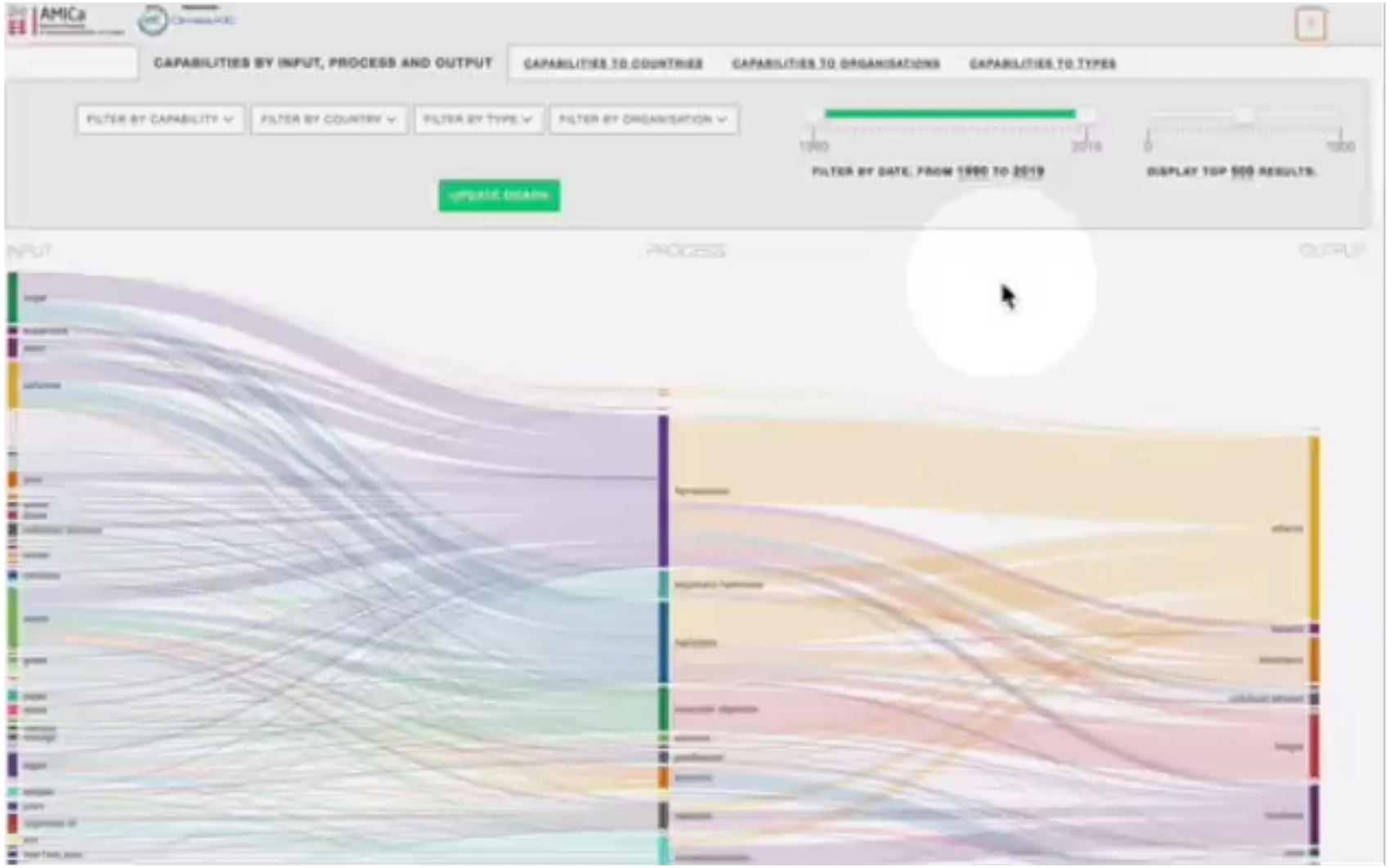
EURITO

Indicators

A visual exploration of technological capabilities

DTU AMICa Advanced Mapping of Industrial Capabilities for Climate

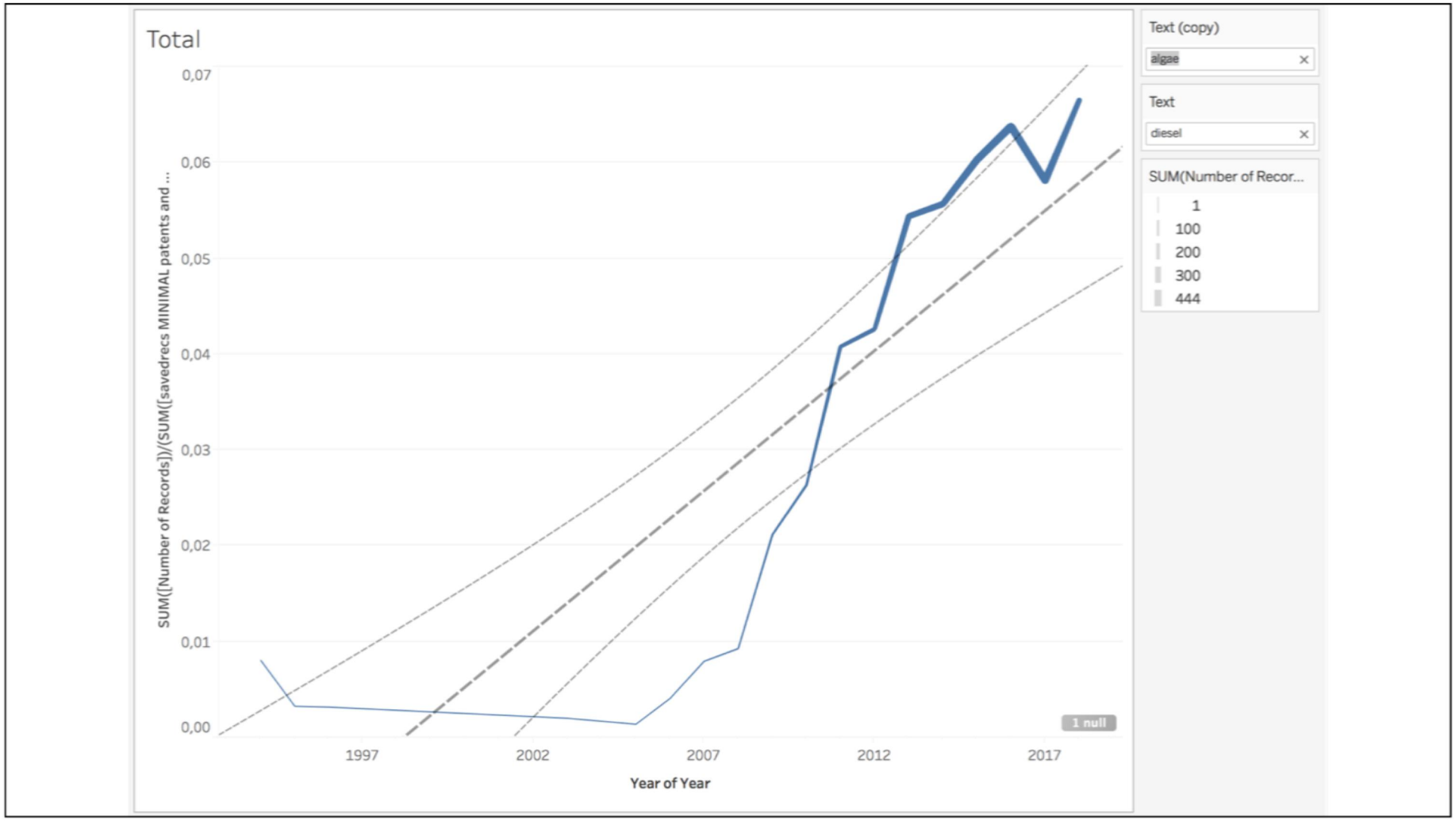
Supported by: eit Climate-KIC



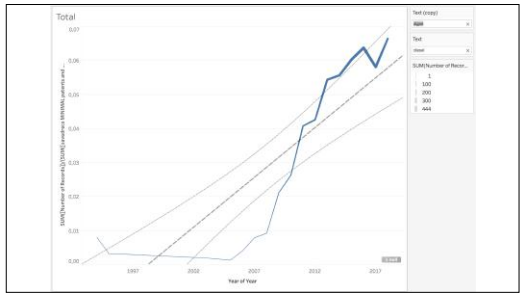
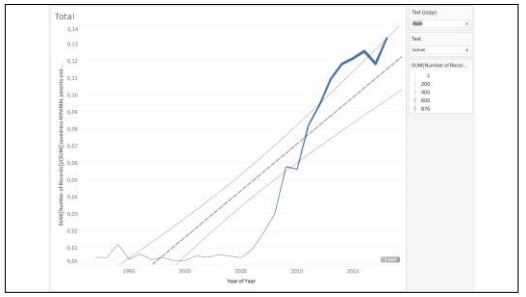
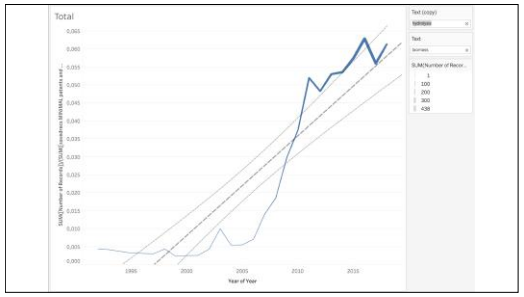
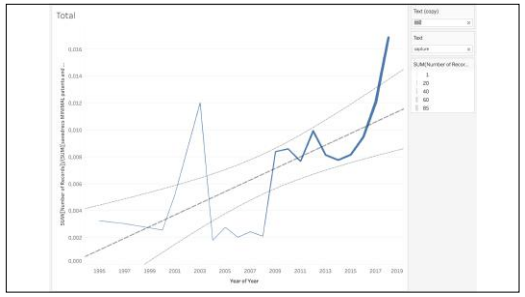
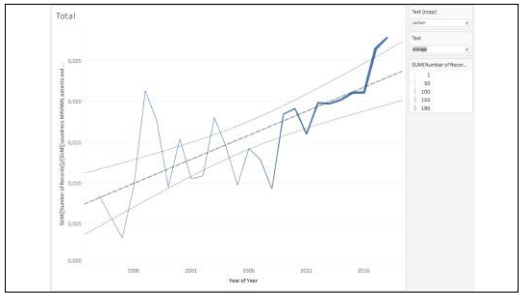
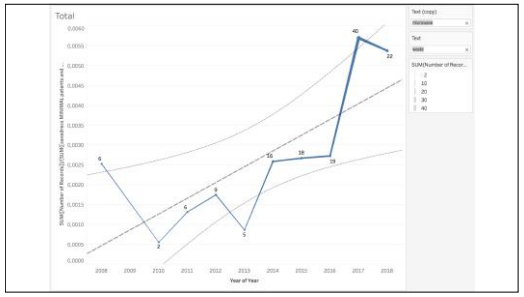
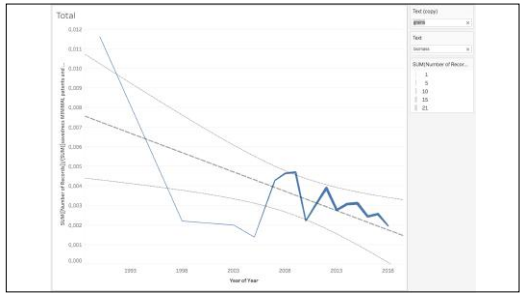
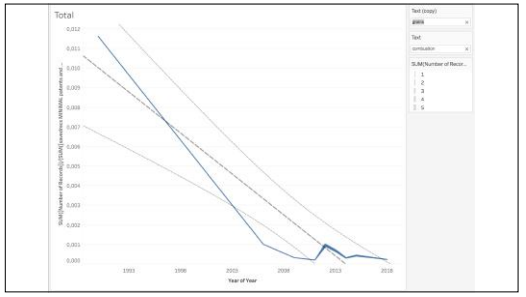
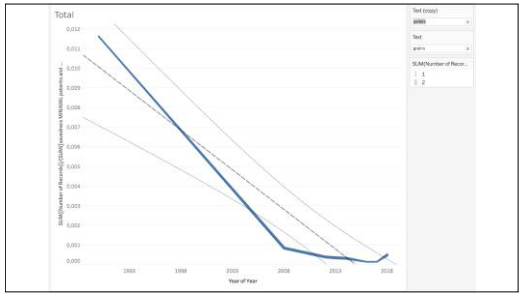
www.amica-pathfinder.net

EURITO

Problem: How to create an indicator for overall technological changes, not just single patterns?



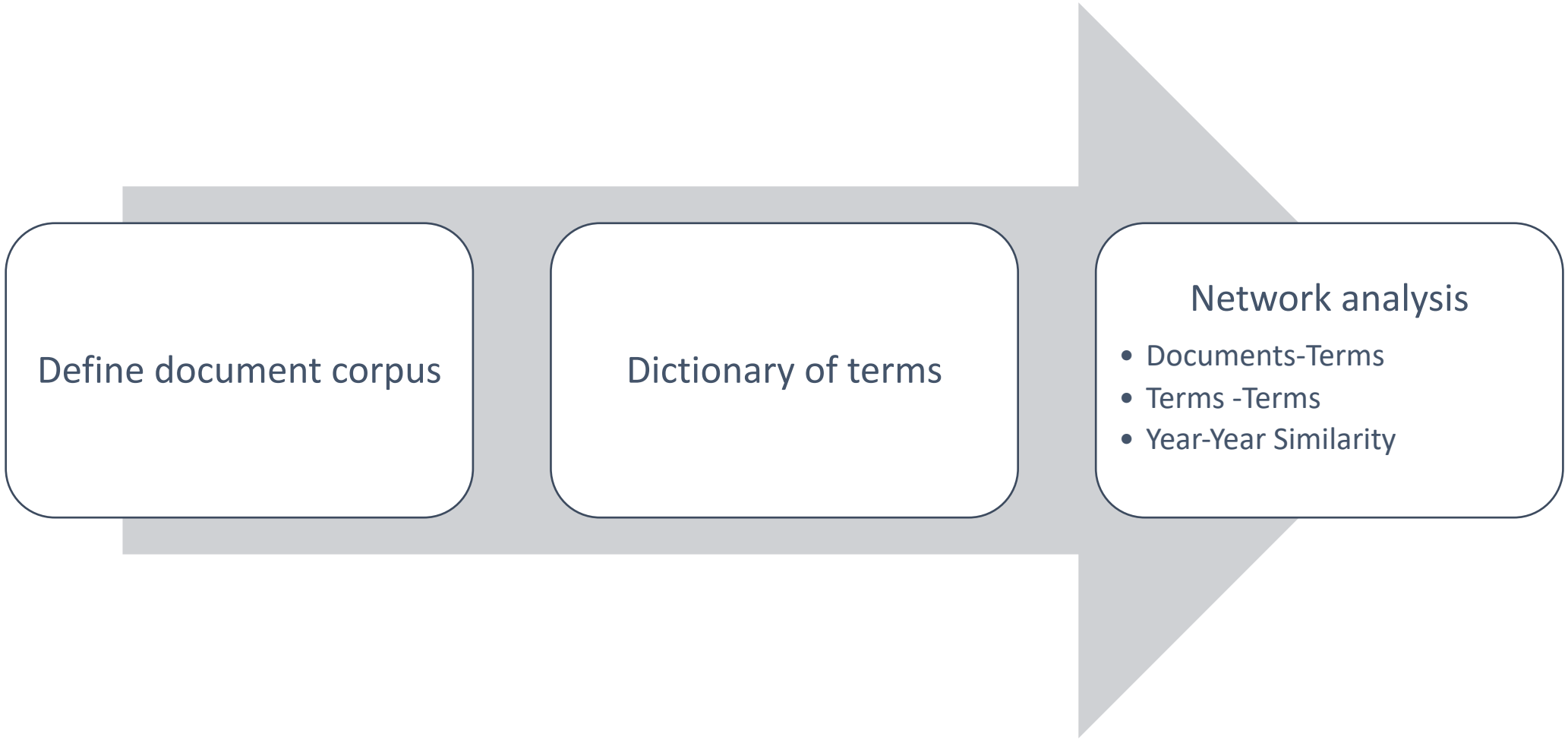
Problem: How to create an indicator for overall technological changes, not just single patterns?

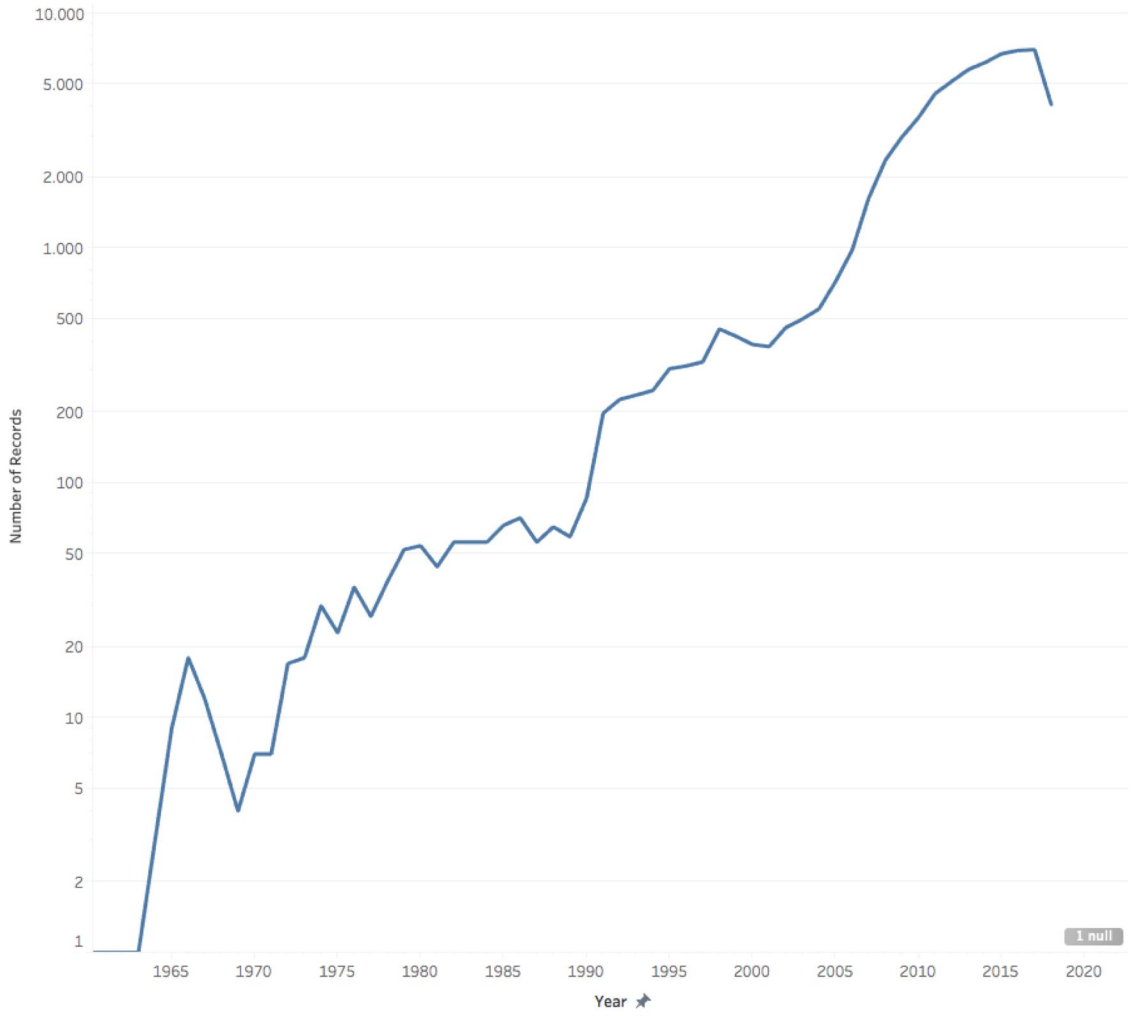
Problem: How to create an indicator for overall technological changes, not just single patterns?

An algorithmic solution to measure technological change over time

Overall Methodology



Technological change in bioenergy R&D – Document Corpus



- **Patents** (Derwent Innovations Index): 6.570 documents
- **Scientific publications** (WoS): 58.239 documents
- **EU project descriptions** (Cordis database): 692 documents
- **Industry Databases** Bioenergy2020+, ETIP Bioenergy, Biofuel Digest and Genscape databases: 1.647 documents

Volume of R&D-related documents within the bioenergy field (logarithmic scale)
Filter: [“biofuel* OR bio-fuel* OR "bio fuel*" OR bioenerg* OR "bio energ*" OR bio-energ*”]

Technological change in bioenergy R&D – Dictionary of terms

Taxonomies mined include:

- Reegle's "Renewable Energy Glossary"
- "NREL - The Biofuels Atlas"
- The "Advanced Biofuels & Biobased materials Project Database"
- The "Bioenergy Feedstock Library Idaho National Laboratory".

Once we extracted and removed duplicated terms, we consolidated a **list of 208 terms**
→ 21.528 unique term-pairs

Feedstock examples:
"corn", "algae" and "bagasse".

Processing technology examples:
"transesterification", "pyrolysis" and "enzymatic hydrolysis".

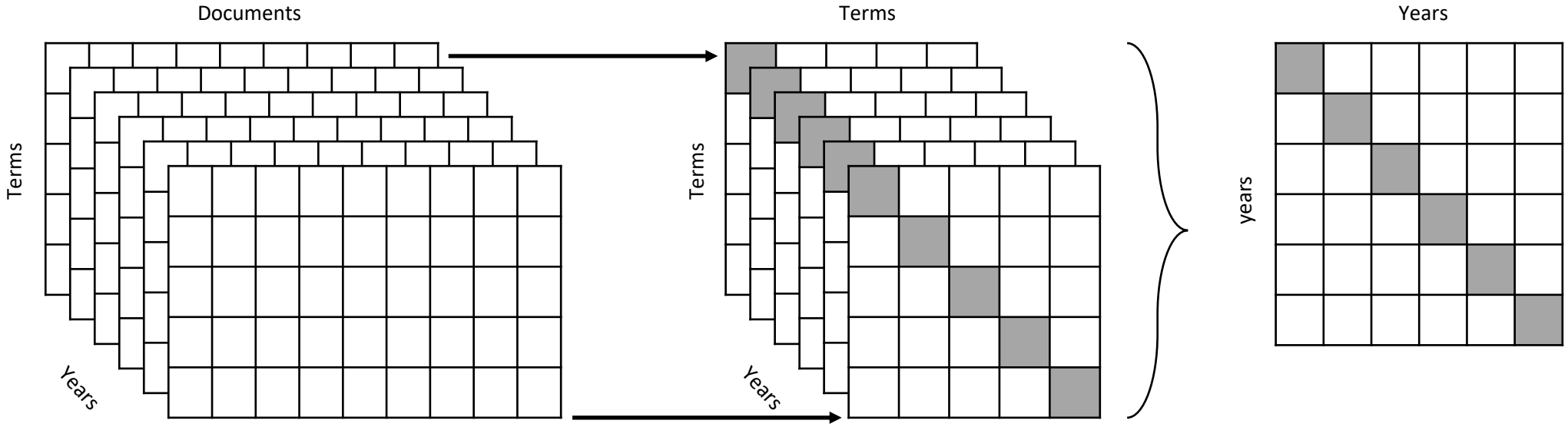
Outputs examples:
"biobutanol", "biodiesel" and "methanol".

An algorithmic solution to measure technological change over time – Network analysis in three parts

MATRIX A: Documents - Terms

MATRIX B: Terms - Terms

MATRIX C: Years - Years



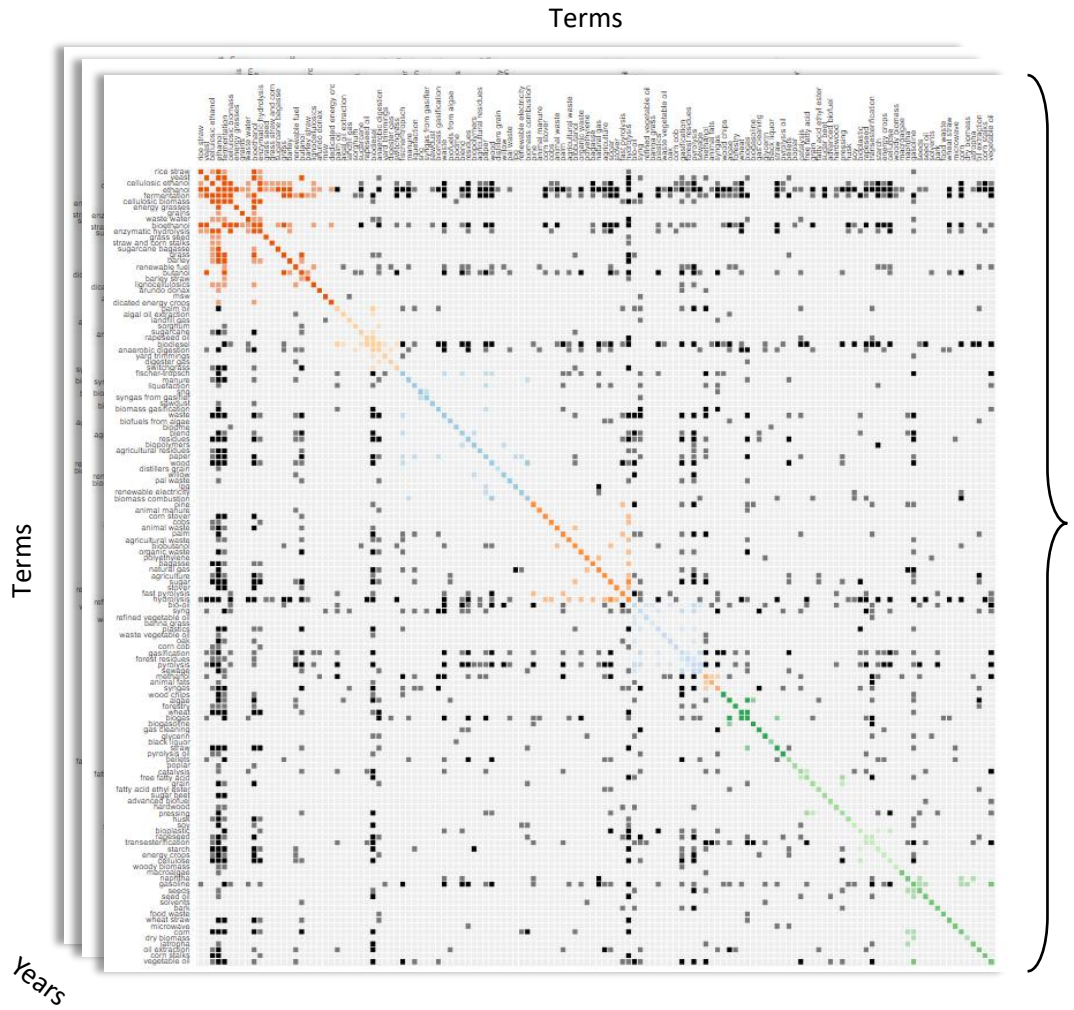
Bi-adjacency matrix of term occurrences in documents

Adjacency matrix of term co-occurrences

Year-year similarity matrix using RV-coefficient

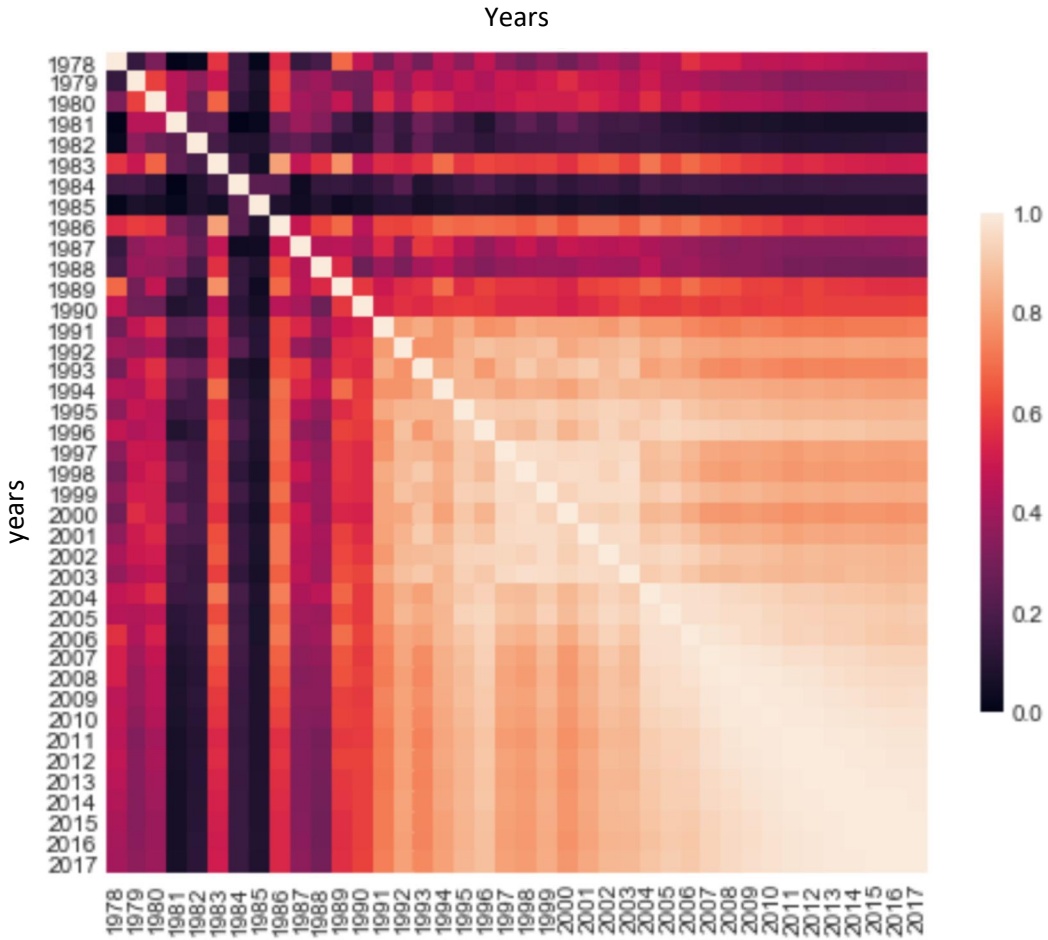
An algorithmic solution to measure technological change over time
RESULTS

MATRIX B: Terms – Terms (2008)



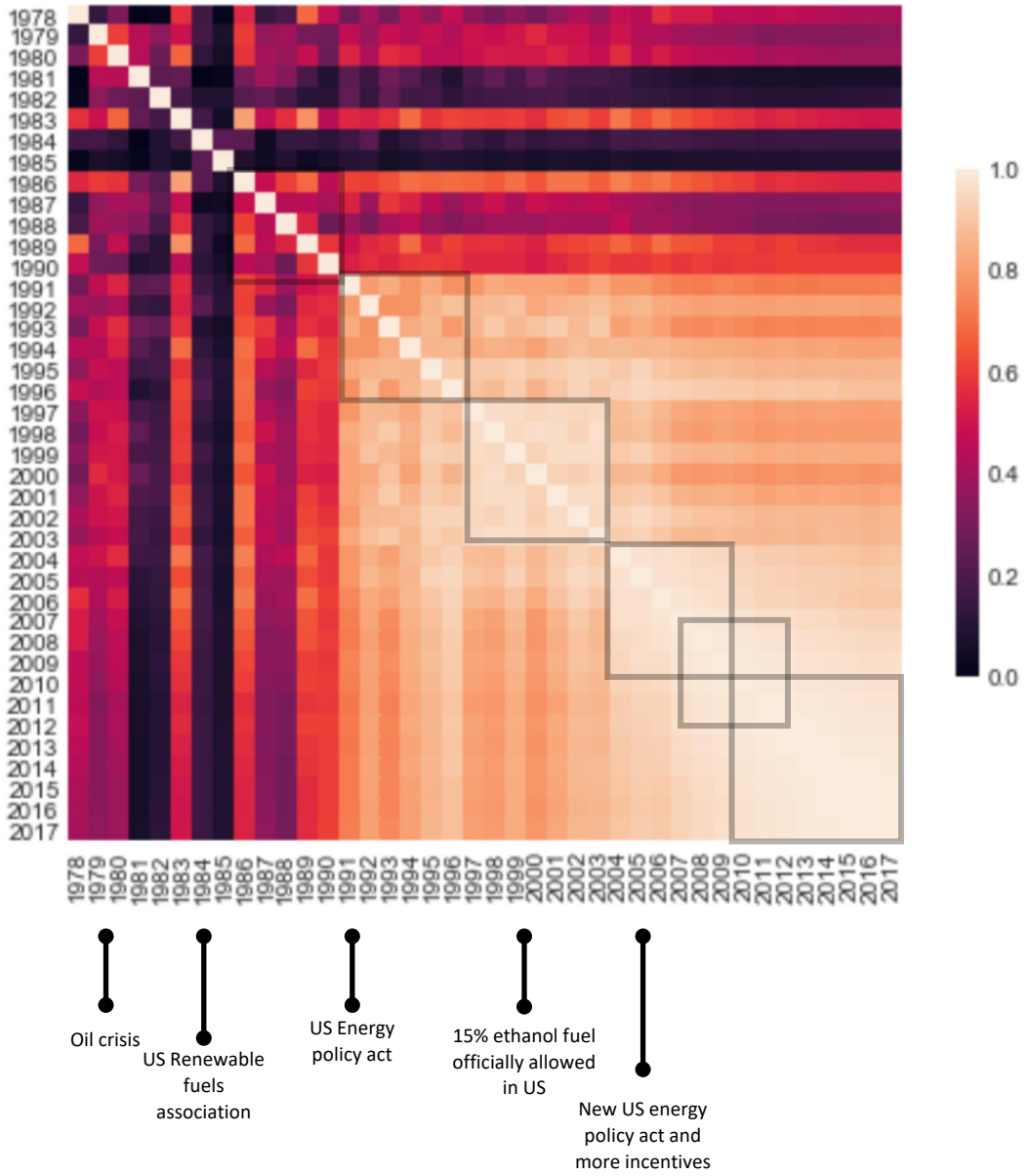
Adjacency matrix of
term co-occurrences

MATRIX C: Years - Years

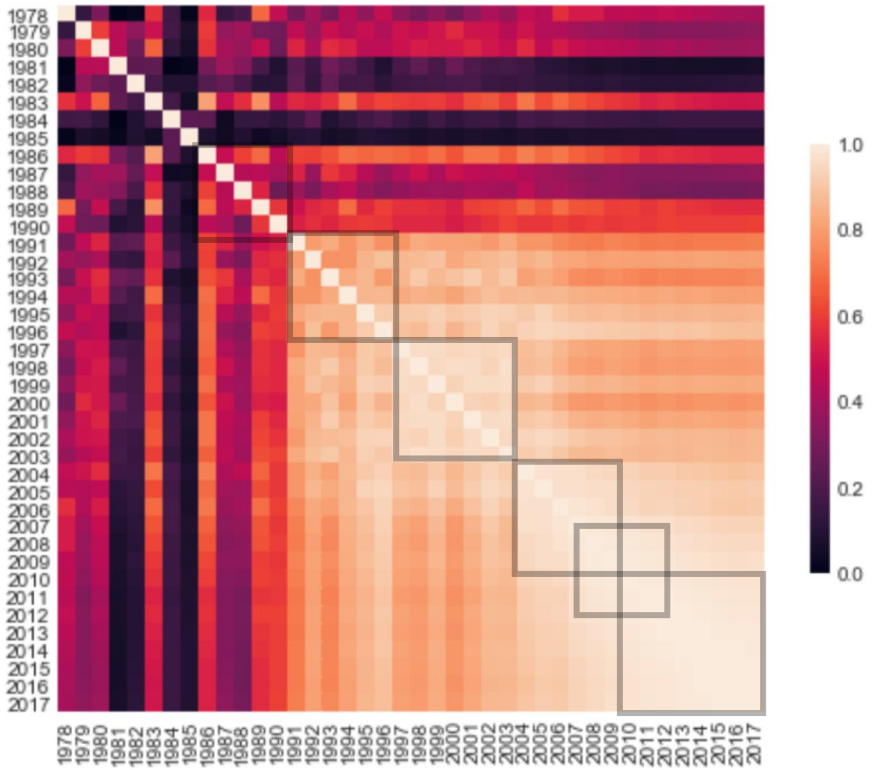


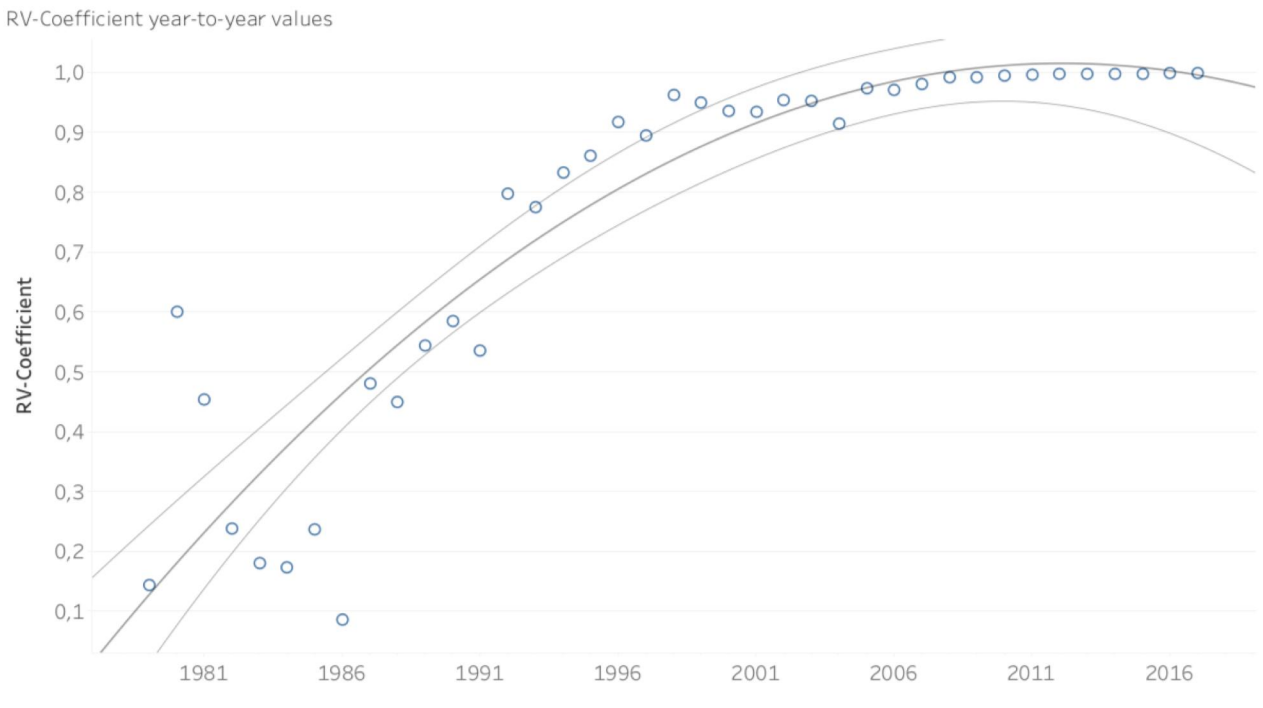
Year-year similarity matrix
using RV-coefficient

Technological Change – Spatial representation of year-to-year similarity

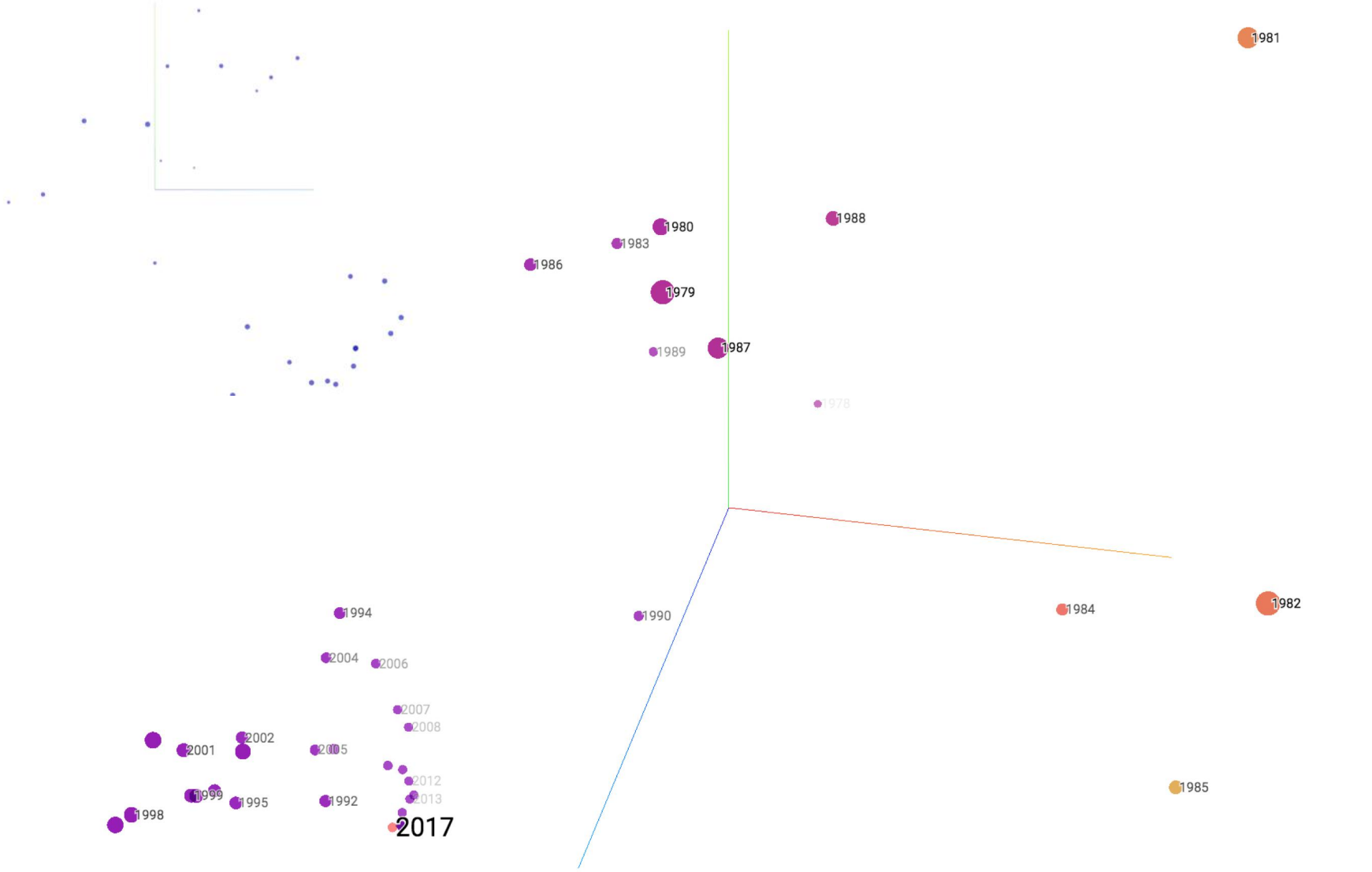


Technological Change – Spatial representation of year-to-year similarity





Technological Change – spatial representation of year-to-year similarity



Nearest points in the original space:

2016	0.000
2015	0.000
2014	0.000
2013	0.000
2011	0.000
2012	0.000
2010	0.000
2009	0.001
2008	0.001
2007	0.002
2005	0.003
1996	0.004
2006	0.004
2004	0.006
1995	0.007
1992	0.007
2002	0.008
2003	0.008
1999	0.010
1994	0.011
1997	0.012
2001	0.012
1998	0.015
2000	0.016
1991	0.018
1993	0.019
1990	0.024
1989	0.045
1986	0.050
1983	0.058
1978	0.085
1980	0.092
1987	0.112
1979	0.114
1988	0.134
1984	0.332
1982	0.392
1981	0.447
1985	0.576

PCA with 3 components - Total variance described: 99.2% - Reference year: 2017

Collective "tagging" of technological change – Four biofuel generations

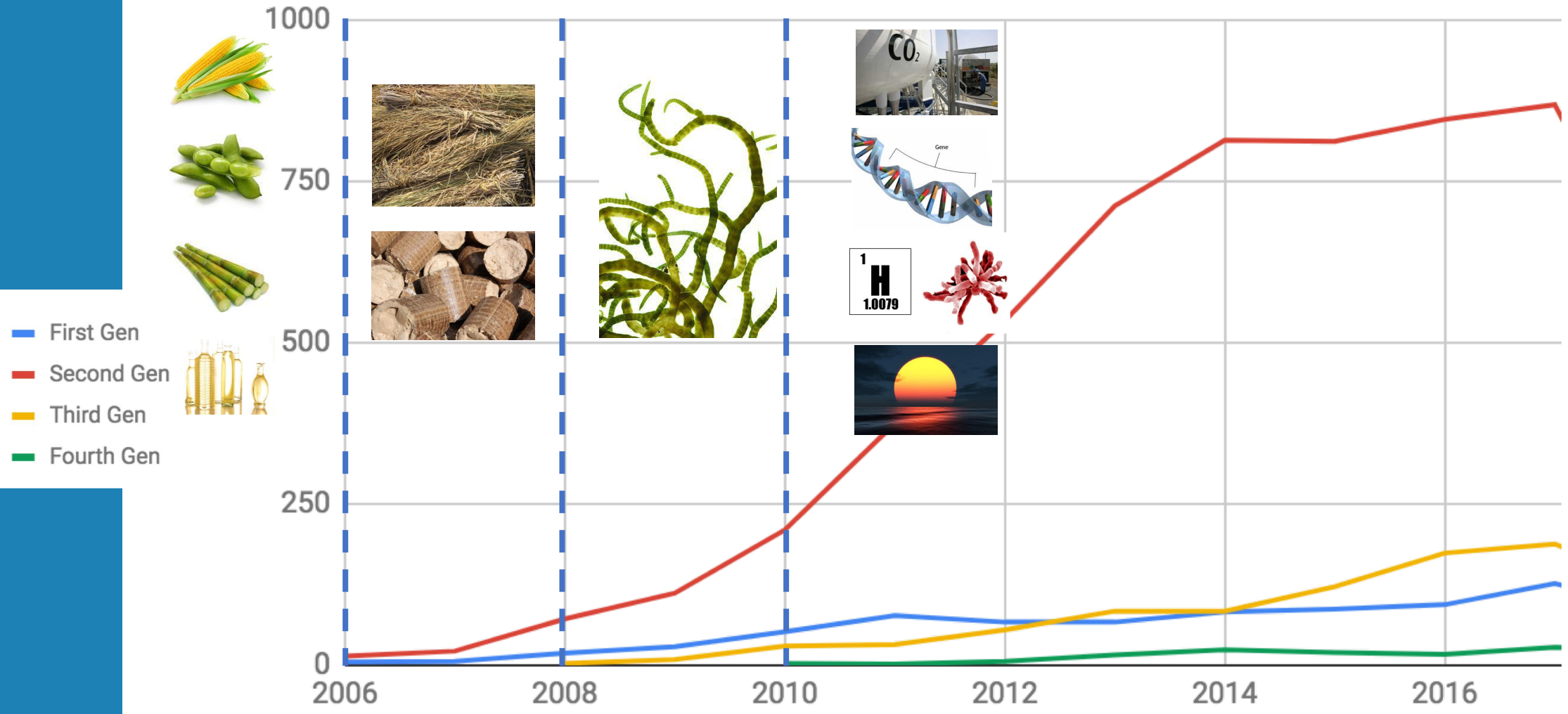
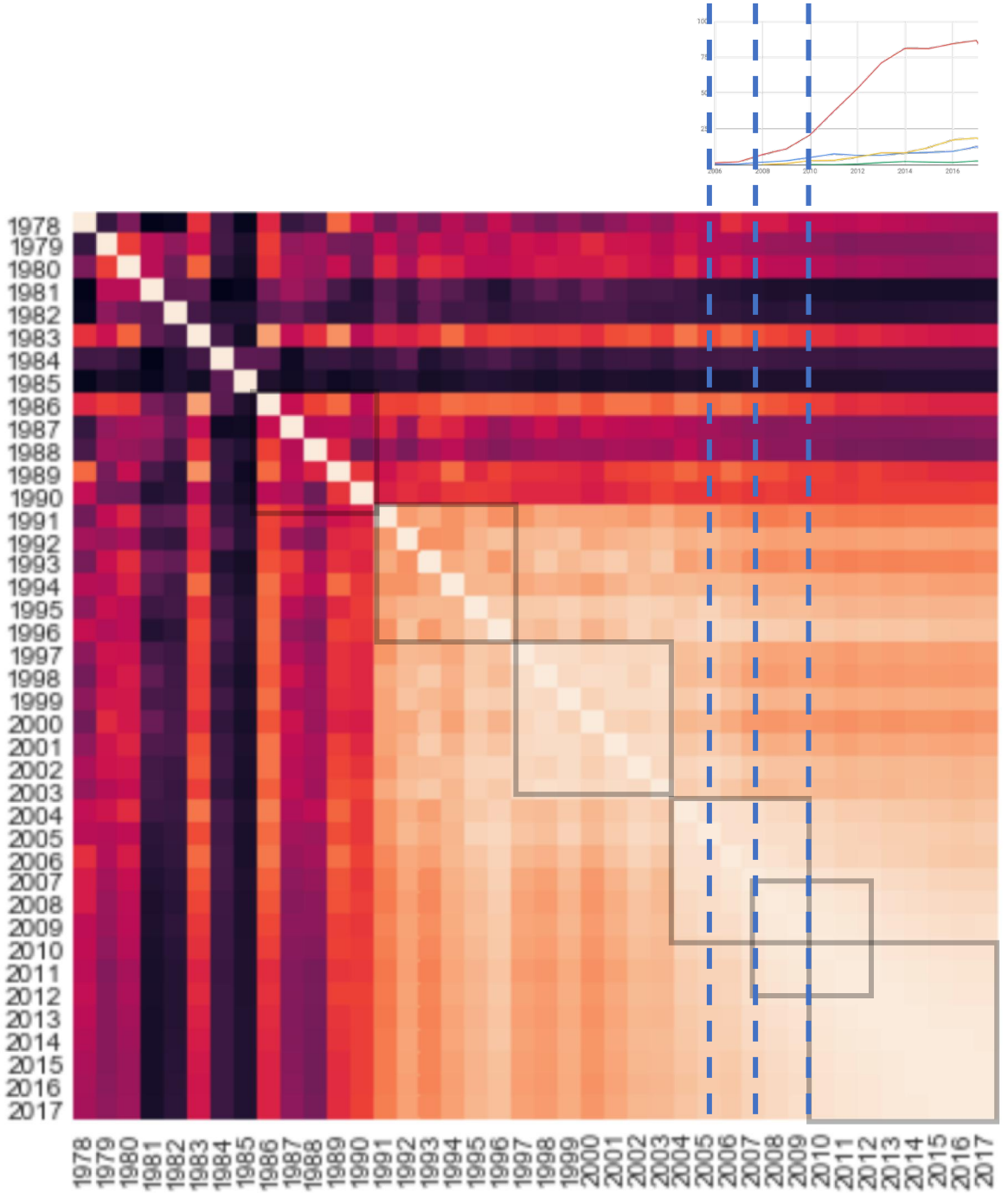


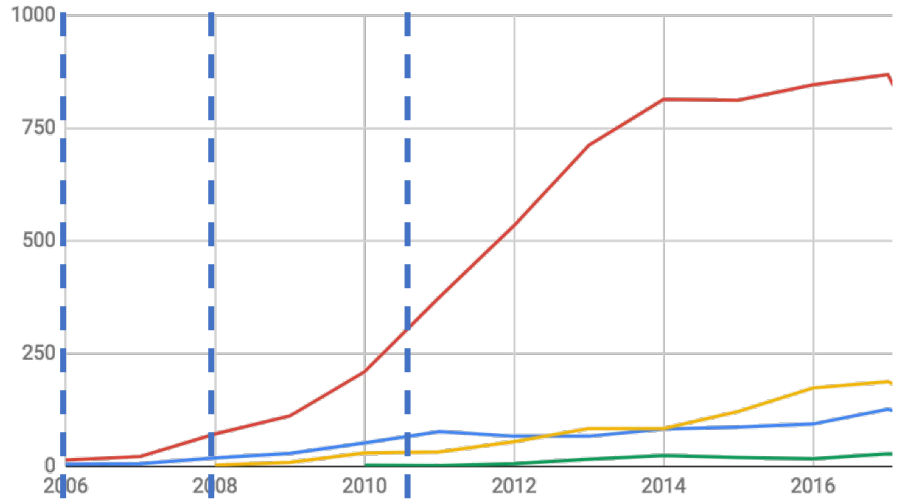
Figure: Number of literature mentions for each generation

Interpretation of our findings

Collective tagging is a slow process and requires “strong signals”



Interpretation of our findings - Four biofuel generations



First Gen
Second Gen
Third Gen
Fourth Gen

Zoom in 1991 – 2017

	A	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
15	1991	1	0,796965	0,832698	0,780667	0,82592	0,770519	0,782529	0,834885	0,816669	0,819192	0,814106	0,791673	0,830805	0,782469	0,782676	0,752845	0,733671	0,724036	0,742451	0,73173	0,717999	0,720565	0,717213	0,724288	0,725869	0,722695	0,73188
16	1992	0,796965	1	0,774273	0,781003	0,857638	0,888532	0,869765	0,87528	0,892682	0,83154	0,855258	0,869738	0,855681	0,846628	0,86338	0,83054	0,821254	0,807291	0,813097	0,808634	0,807439	0,814586	0,811868	0,81767	0,814351	0,806069	0,810566
17	1993	0,832698	0,774273	1	0,83267	0,864676	0,79407	0,863188	0,913881	0,870829	0,892742	0,915595	0,871105	0,90977	0,851529	0,839341	0,806581	0,761976	0,753314	0,768054	0,751683	0,737521	0,746849	0,740058	0,749368	0,748688	0,745775	0,755805
18	1994	0,780667	0,781003	0,83267	1	0,860545	0,86644	0,829304	0,85124	0,842525	0,815081	0,859266	0,853412	0,863417	0,874598	0,859831	0,864312	0,84445	0,841966	0,836811	0,831401	0,820998	0,829518	0,819251	0,820506	0,810669	0,807735	0,810768
19	1995	0,82592	0,857638	0,864676	0,860545	1	0,917248	0,909283	0,910755	0,926022	0,905636	0,919856	0,936285	0,928737	0,907358	0,934316	0,899226	0,882954	0,87846	0,882695	0,869177	0,857523	0,860702	0,859326	0,861179	0,858314	0,854564	0,861763
20	1996	0,770519	0,888532	0,79407	0,86644	0,917248	1	0,894018	0,877218	0,921221	0,855777	0,896782	0,938061	0,906606	0,930742	0,945895	0,934192	0,926507	0,920648	0,911299	0,906703	0,896494	0,903248	0,897764	0,898453	0,890232	0,885507	0,88671
21	1997	0,782529	0,869765	0,863188	0,829304	0,909283	0,894018	1	0,962263	0,959138	0,942606	0,953035	0,947211	0,95213	0,879652	0,894595	0,865485	0,829526	0,819147	0,822119	0,813248	0,800138	0,812699	0,805362	0,812926	0,808473	0,802532	0,809654
22	1998	0,834885	0,87528	0,913881	0,851242	0,910755	0,877218	0,962263	1	0,949677	0,961991	0,958405	0,933841	0,966489	0,876264	0,885965	0,847836	0,809025	0,800361	0,812552	0,800912	0,788473	0,798765	0,791525	0,799177	0,796425	0,789542	0,798321
23	1999	0,816669	0,892682	0,870829	0,842525	0,926022	0,921221	0,959138	0,949677	1	0,935217	0,958434	0,960801	0,962622	0,910169	0,92994	0,890749	0,869201	0,853773	0,861224	0,847261	0,832174	0,842699	0,835704	0,842608	0,836929	0,832229	0,839033
24	2000	0,819192	0,83154	0,892742	0,815081	0,905636	0,855777	0,942606	0,961991	0,935217	1	0,933785	0,923174	0,948199	0,863472	0,878402	0,832877	0,79063	0,787273	0,798723	0,786059	0,771161	0,781481	0,775614	0,781703	0,781566	0,774624	0,786068
25	2001	0,814106	0,855258	0,915595	0,859266	0,919856	0,896782	0,953035	0,958405	0,958434	0,933785	1	0,954041	0,959339	0,903243	0,916771	0,891943	0,853421	0,840612	0,847025	0,834125	0,815645	0,82824	0,821167	0,82838	0,823755	0,817198	0,824763
26	2002	0,791673	0,869738	0,878105	0,883412	0,936285	0,938061	0,947211	0,933841	0,960801	0,923174	0,954041	1	0,951591	0,937975	0,952932	0,935144	0,908748	0,892831	0,891187	0,879354	0,864309	0,874538	0,866464	0,869856	0,863832	0,858214	0,864799
27	2003	0,830805	0,855681	0,90977	0,863417	0,928737	0,906606	0,95213	0,966489	0,962622	0,948199	0,959339	0,951591	1	0,914263	0,935895	0,905653	0,870032	0,858412	0,862175	0,871038	0,859831	0,870829	0,863267	0,868353	0,868353	0,862147	0,869839
28	2004	0,782469	0,846628	0,851529	0,874598	0,90738	0,930742	0,879652	0,876264	0,910169	0,863472	0,903243	0,937975	0,914263	1	0,972871	0,97179	0,965877	0,951058	0,947521	0,936768	0,915979	0,919422	0,909182	0,904406	0,895152	0,890169	0,896751
29	2005	0,782676	0,86338	0,839341	0,859831	0,934316	0,945895	0,894595	0,885965	0,92994	0,878402	0,916771	0,952932	0,935895	0,972871	1	0,970759	0,969206	0,961212	0,961472	0,947641	0,933834	0,93328	0,925031	0,925224	0,917165	0,9107	0,918102
30	2006	0,752845	0,83054	0,806581	0,864312	0,899226	0,934192	0,865485	0,847836	0,890749	0,832877	0,891943	0,935144	0,905653	0,97179	0,970759	1	0,980707	0,973516	0,962175	0,95273	0,935577	0,939697	0,92895	0,923616	0,913119	0,905807	0,909824
31	2007	0,733671	0,821254	0,761976	0,84445	0,882954	0,926507	0,829526	0,809025	0,869201	0,79063	0,853421	0,908748	0,874552	0,965877	0,969206	0,980707	1	0,991404	0,984934	0,978889	0,967033	0,965607	0,956238	0,950265	0,940149	0,935835	0,937264
32	2008	0,724036	0,807291	0,753314	0,841966	0,87846	0,920648	0,819147	0,800361	0,853773	0,787273	0,840612	0,892831	0,870032	0,951058	0,961212	0,973516	0,991404	1	0,992429	0,990821	0,981237	0,979274	0,969797	0,963985	0,954589	0,950037	0,950889
33	2009	0,742451	0,813097	0,768054	0,836811	0,882695	0,911299	0,822119	0,812552	0,861224	0,798723	0,847025	0,891187	0,879203	0,947521	0,961472	0,962175	0,984934	0,992429	1	0,994747	0,989054	0,985146	0,979425	0,974656	0,967999	0,963862	0,965578
34	2010	0,731736	0,808634	0,751683	0,831401	0,869177	0,906703	0,813248	0,800912	0,847262	0,786059	0,834129	0,879354	0,871038	0,936768	0,947641	0,952731	0,978889	0,990827	0,994747	1	0,99572	0,993734	0,988186	0,984128	0,977675	0,974166	0,973895
35	2011	0,717999	0,807439	0,737521	0,820998	0,857523	0,896494	0,800138	0,788473	0,832174	0,771161	0,815645	0,864309	0,860495	0,915979	0,933834	0,935577	0,967033	0,981237	0,989054	0,99572	1	0,997156	0,994841	0,991746	0,987083	0,983633	0,982671
36	2012	0,720565	0,814586	0,746849	0,829518	0,860702	0,903248	0,812699	0,798765	0,842699	0,781481	0,82824	0,874538	0,87032	0,919422	0,93328	0,939697	0,965607	0,979274	0,985146	0,993734	0,997156	1	0,996953	0,995213	0,991031	0,988198	0,987006
37	2013	0,717213	0,811868	0,740058	0,819251	0,859326	0,897764	0,805362	0,791525	0,835704	0,775614	0,821167	0,866464	0,863267	0,909182	0,925031	0,92895	0,956238	0,969797	0,979425	0,988186	0,994841	0,996953	1	0,998041	0,996015	0,993949	0,992458
38	2014	0,724288	0,81767	0,749368	0,820506	0,861179	0,898453	0,812926	0,799177	0,842608	0,781703	0,82838	0,869856	0,871429	0,904406	0,925224	0,923616	0,950265	0,963985	0,974656	0,984128	0,991746	0,995213	0,998041	1	0,99805	0,996532	0,99526
39	2015	0,725869	0,814351	0,748688	0,810669	0,858314	0,890232	0,808473	0,796425	0,836929	0,781566	0,823755	0,863832	0,868353	0,895152	0,917165	0,913119	0,940149	0,954589	0,967999	0,977675	0,987083	0,991031	0,996015	0,99805	1	0,998589	0,99798
40	2016	0,722695	0,806069	0,745775	0,807735	0,854564	0,885507	0,802532	0,789542	0,832229	0,774624	0,817198	0,858214	0,862147	0,890169	0,9107	0,905807	0,935835	0,950037	0,963862	0,974166	0,983633	0,988198	0,993949	0,996532	0,998589	1	0,998443
41	2017	0,73188	0,810566	0,755805	0,810768	0,861763	0,88671	0,809654	0,798321	0,839033	0,786068	0,824763	0,864799	0,869839	0,896751	0,918102	0,909824	0,937264	0,950889	0,965578	0,973895	0,982671	0,987006	0,992458	0,99526	0,99798	0,998443	1

Interpretation of our findings

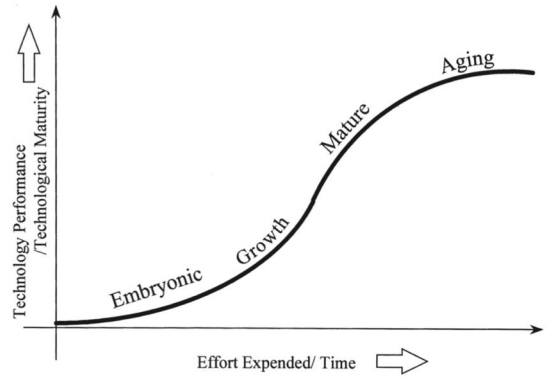
- In general, when the time between two years increases their similarity decreases → **Cumulative nature of technological changes**

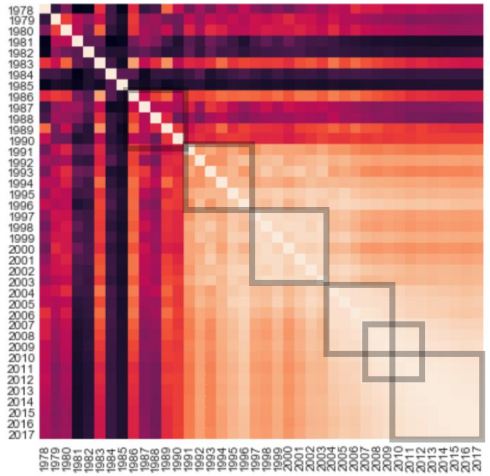
- In earlier periods, year-to-year similarity measures are lower

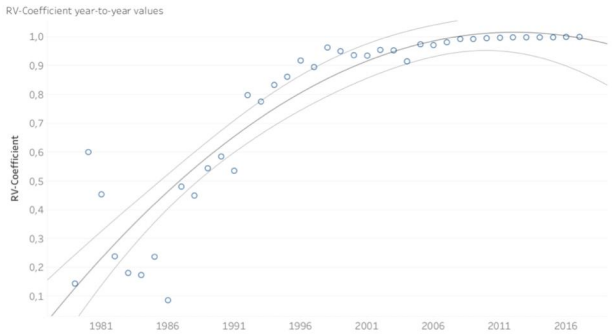
  - In the beginning year-to-year configurational changes are of larger magnitude and more frequent → "**Burstiness**"

  - As the time passes, year-to-year changes become smaller → Sign of **maturity** and of settling into more stable configurations

- It is possible to identify blocks of years (clusters) with higher and more stable year-to-year similarity which are interrupted by often a single year until a new block emerges → **incremental VS radical changes**

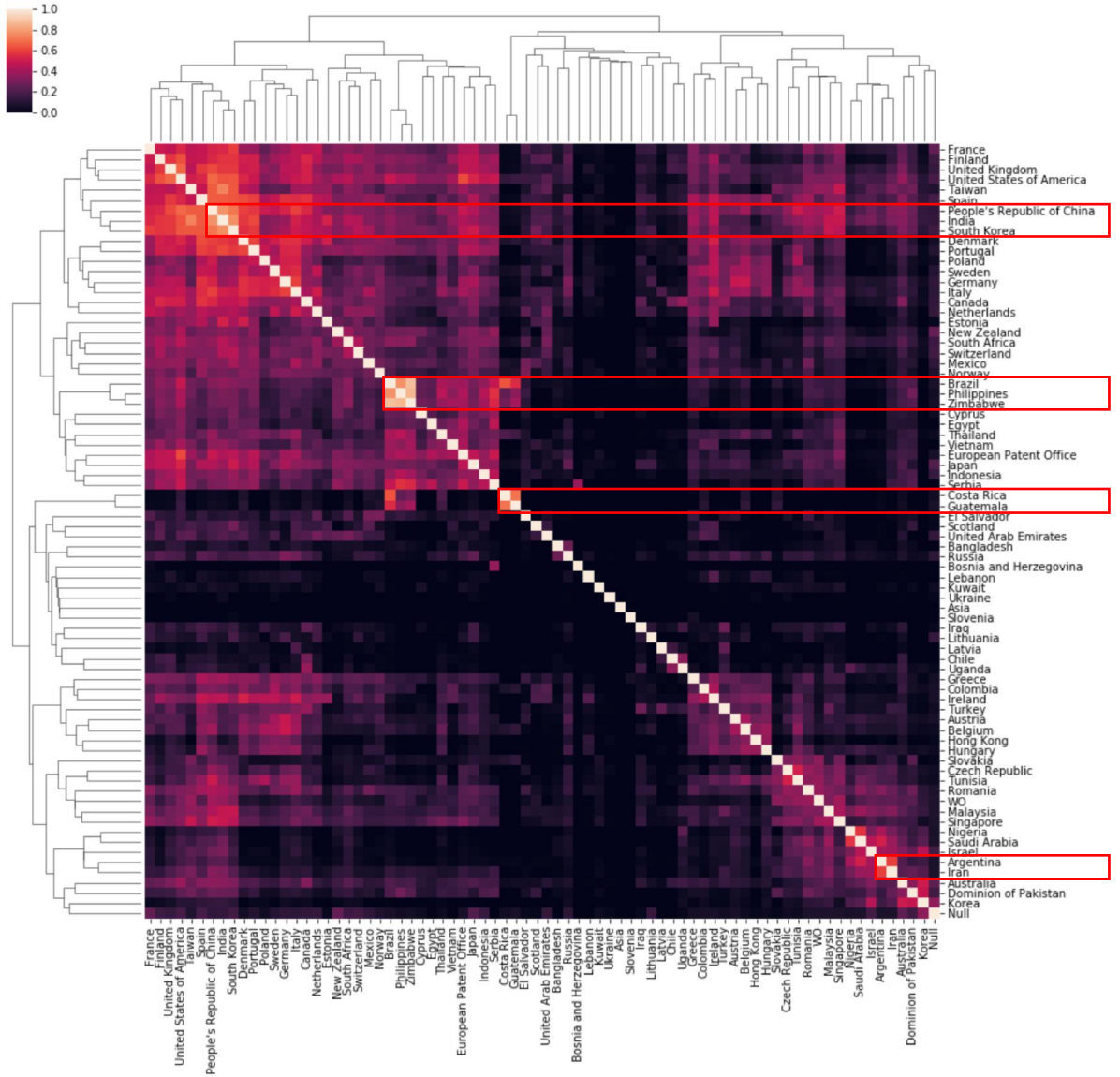




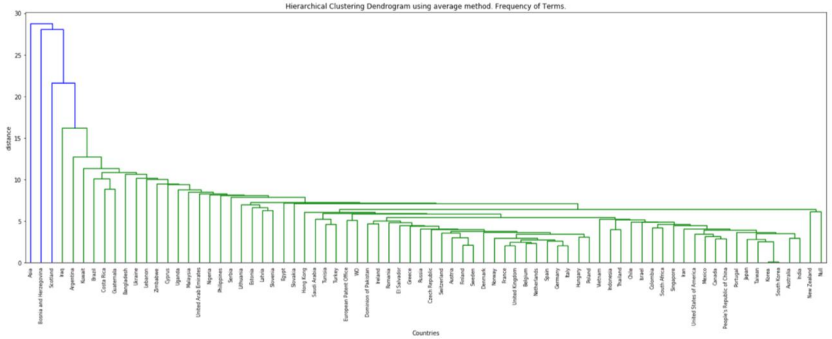


Interpretation of our findings – Does it make any sense?

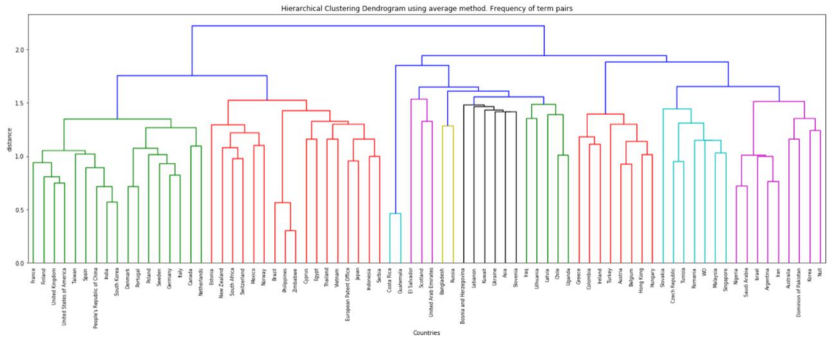
An ecosystem approach where diversity matters



Clustering of countries based only on individual term count



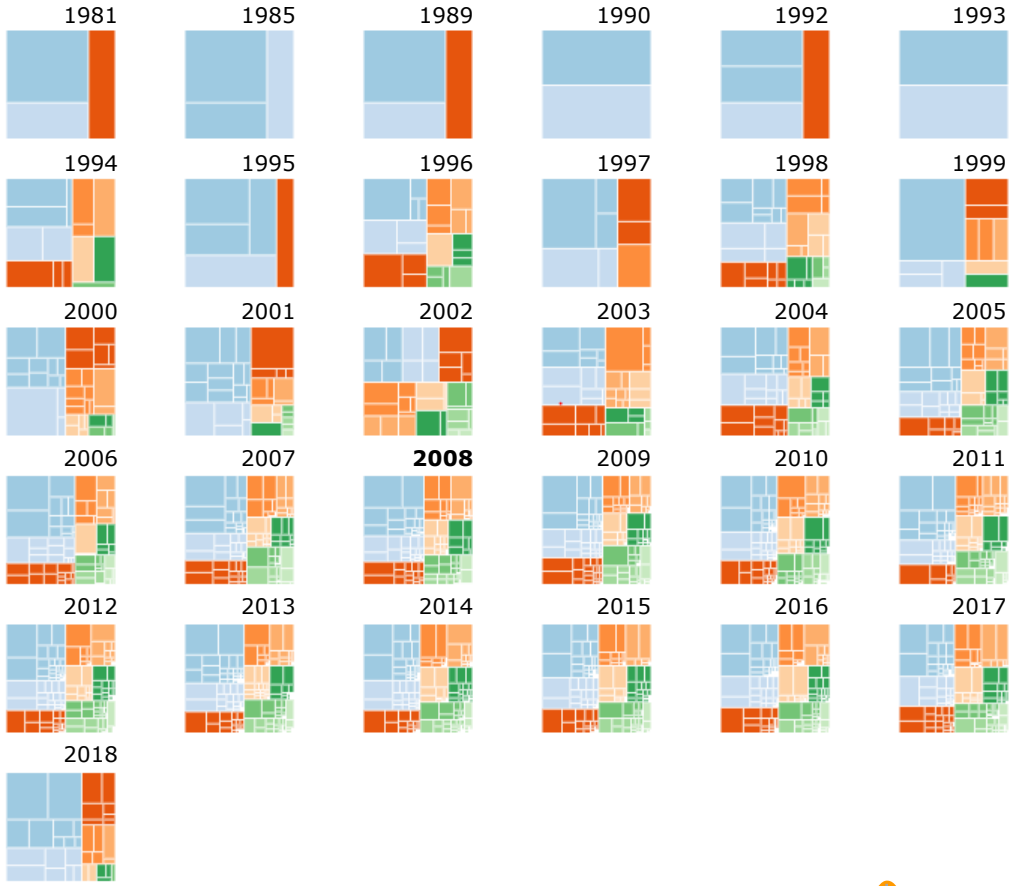
Clustering of countries using the network of inputs, technologies and outputs

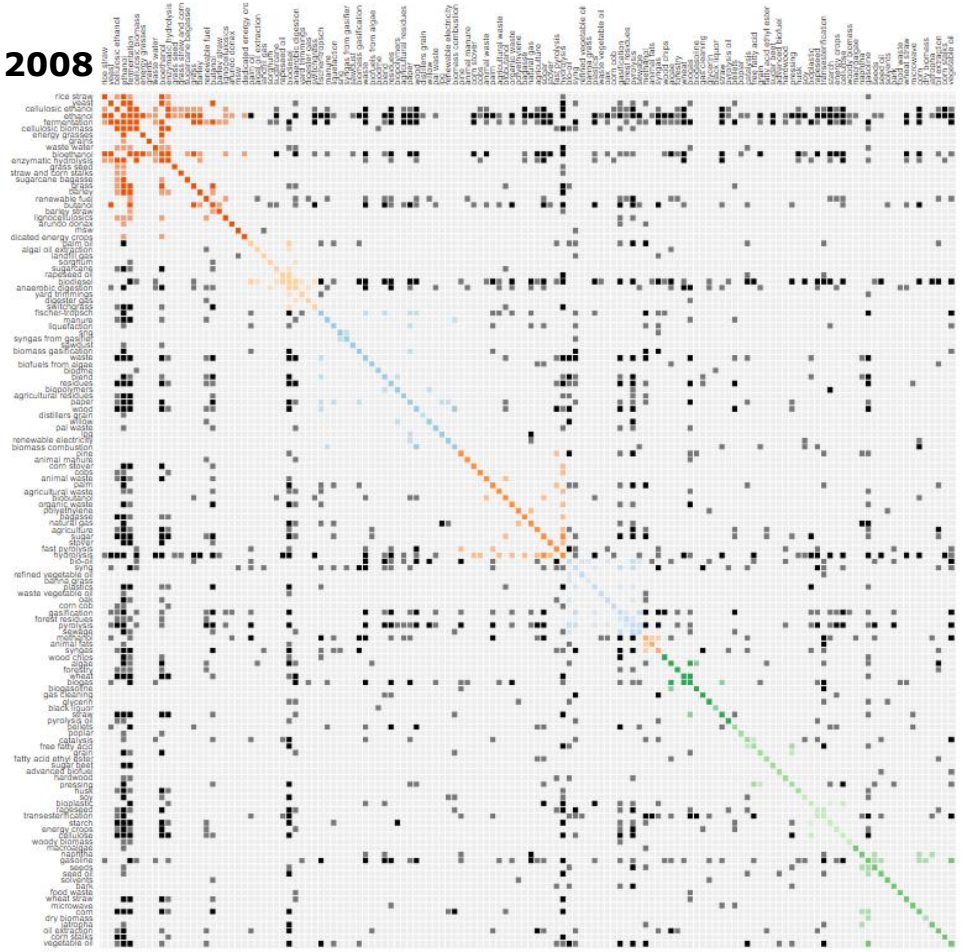


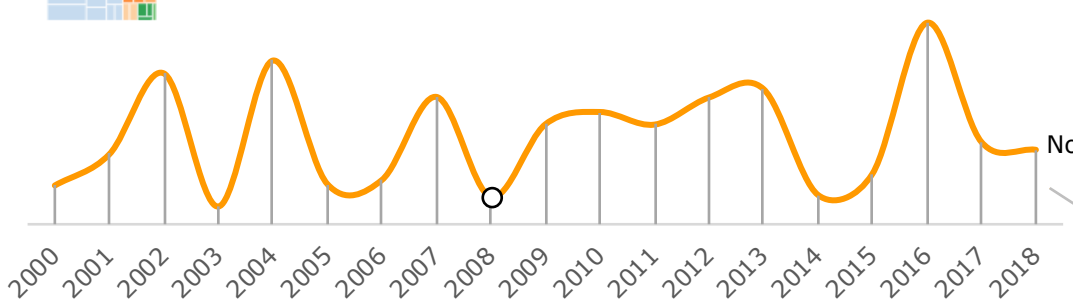
Reference: Duarte Carmo Thesis - https://duarteoc.gitbook.io/technological-capabilities/

Visualisa-
tion

A dynamic multi-view representation of technological change – early prototype







Node/Edge/Cluster Activity

shows where major changes in the network occur

EURITO

Data

Curated big-data repositories with R&D records plus open taxonomies

RESEARCH PROJECTS*

CORDIS

PATENTS*

The OECD REGPAT Database

PUBLICATIONS*

Crossref

INDUSTRY FACILITIES AND ORGANISATIONS

ETIP Bioenergy
European Technology and Innovation Platform

GENSCAPE BIOFUELS
Biofuel Producer Industry Database

NREL The Biofuels Atlas

bioenergy2020+

BIOENERGY KNOWLEDGE DISCOVERY FRAMEWORK
KDF U.S. DEPARTMENT OF ENERGY

BiofuelsDigest
The world's most widely read biofuels daily

reegle

IEA Bioenergy

climatetagger API

CLIMATE SMART THESAURUS

SEMANTIC KNOWLEDGE GRAPH AND DATA RECONCILIATION SERVICES

GRID
Global Research Identifier Database
Cataloging the world's research organisations

DBpedia

RISIS
Research infrastructure for research and innovation policy studies
http://risis.eu

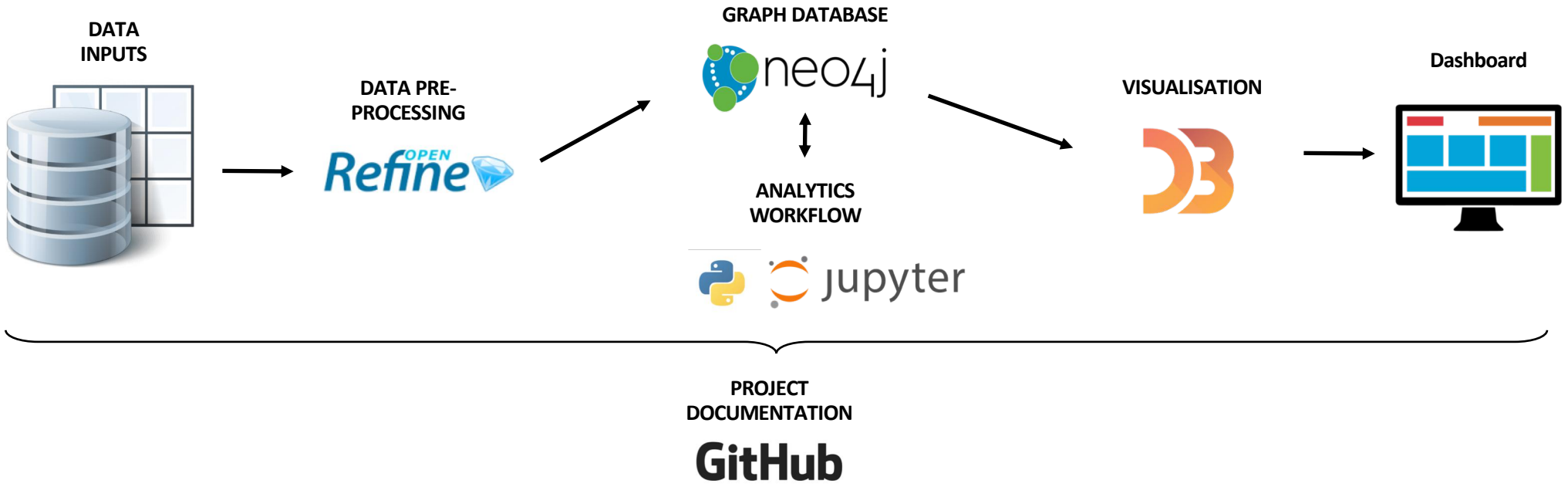
WIKIDATA

*Mostly abstracts

EURITO

Data Infra-structure and Analytics

Focus on an architecture that is scalable, flexible and graph oriented



EURITO

Road ahead

Further steps

- We will keep working on **data visualisations** and **validation** of our findings
- Expand the generic **dictionary of terms** with open taxonomies and NLP expansion
- Connect the **technological change** perspective with **technology emergence**

Limitations

- Developed measure does not capture impact, performance, cost, etc. Focus is on **early stage R&D**
- The **interpretation of terms co-occurrence** is valid only on aggregate
- Relation between **volume of document records** and opportunity to explore **space of combinatorial possibilities** requires additional work to avoid misinterpretations

EURITO

EURITO

RELEVANT, INCLUSIVE, TRUSTED AND OPEN INDICATORS FOR RESEARCH AND INNOVATION POLICY

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 770420 – EURITO.

http://www.eurito.eu/

EuritoH2020
@EuritoH2020 #Eurito
Eurito

Thank you.

Please send us any feedback or comments at:
info@eurito.eu

The EURITO Consortium

nesta

Technical University of Denmark

DTU

COTEC FUNDACIÓN COTEC PARA LA INNOVACIÓN

Fraunhofer FOKUS