

JRC TECHNICAL REPORTS

Technology Innovation Monitoring (TIM) for mapping emerging photovoltaics and offshore wind energy technologies

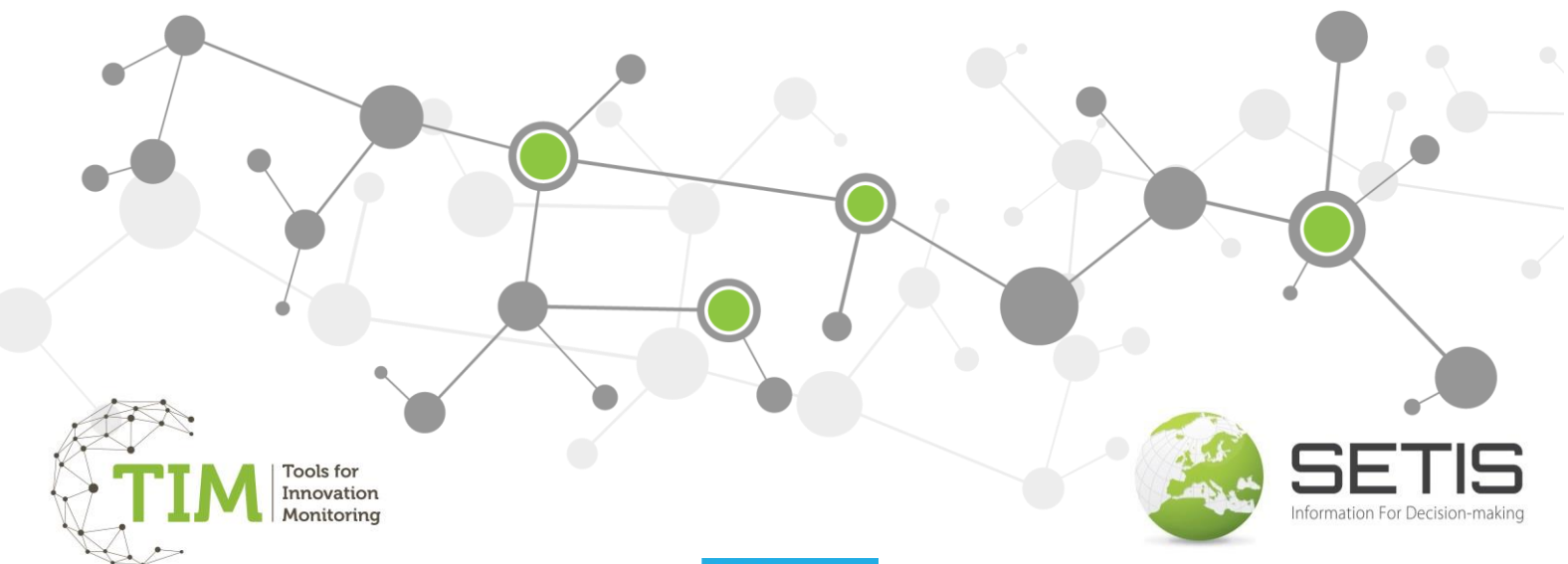
Authors:

Boelman, E. and Telsnig, T.

Contributors:

Joanny, G., Georgakaki, A. and
Bardizza, G.

2016



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JRC Science Hub

<https://ec.europa.eu/jrc>

JRC104449

EUR 28259 EN

Print	ISBN 978-92-79-64022-3	ISSN 1018-5593	doi:10.2760/39001
PDF	ISBN 978-92-79-64023-0	ISSN 1831-9424	doi:10.2760/865392

Luxembourg: Publications Office of the European Union, 2016

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How to cite this report: Boelman E., Telsnig T., Joanny G., Georgakaki A., Bardizza G. 2016, *Technology Innovation Monitoring (TIM) for mapping emerging photovoltaics and offshore wind energy technologies*, EUR 28259 EN, doi:10.2760/865392.

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Abstract

The Joint Research Centre (JRC) is currently developing a monitoring system for tracking the evolution of established and emerging technologies (Tools for Innovation Monitoring, TIM). The editor tool developed is based on semantic analysis, powerful data mining and visualization of complex data sets and holds the promise to complement expert knowledge by identifying emerging trends within a technology. Within this context, this report provides guidance and illustrates possible ways of applying bibliometric analysis to research-for-policy questions on specific energy technologies.

Printed in Luxembourg

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Acknowledgements

Elisa Boelman and Thomas Telsnig produced this report, with substantial contributions from Geraldine Joanny who provided guidance on the use of the TIM tool and supported the design of search strings; from Aliko Georgakaki on setting up and reviewing the first searches on wind energy; and from Giorgio Bardizza who provided expert knowledge on photovoltaic energy.

The authors would like to thank Evangelos Tzimas, Efstathios Peteves, Nigel Taylor and Olivier Eulaerts for their insightful and timely reviews of the report drafts, as well as Natalia Lebedeva and Alberto Moro for their ideas and insights.

The context, guidance and comments contributed by Efstathios Peteves (Knowledge for Energy Union Unit) and Olivier Eulaerts (Text and Data Mining Unit) are gratefully acknowledged.

Executive summary

The Joint Research Centre (JRC) is currently developing TIM, a monitoring system for tracking the evolution of established and emerging technologies (Tools for Innovation Monitoring, www.timanalytics.eu). The TIM tool developed in this context is based on semantic analysis, powerful data mining and visualization of complex data sets; and holds the promise to complement expert knowledge by identifying emerging trends within a technology.

The identification of future trends will become a decisive factor in retaining Europe's leading role in global development and large-scale deployment of renewable energy technologies, which is a key priority of the research, innovation and competitiveness dimension of the Energy Union.

The JRC contributes to the implementation of the research, innovation and competitiveness dimension of the Energy Union through the management and implementation of SETIS¹, the Information System of the integrated Strategic Energy Technology Plan. In particular, SETIS, monitors energy innovation in Europe; contributes to the identification of R&I gaps; and reports on the overall progress in the implementation of the research, innovation and competitiveness dimension of the Energy Union. Thus, SETIS needs to have access and effectively manage large volumes of information. TIM-Energy is among the tools that have the potential to greatly facilitate the work of SETIS.

The use of TIM provides SETIS with a quick indication of trends and facilitates analysis that would otherwise be very time consuming, while at the same time provides useful visual representations. This allows for quick filtering of data offering additional insights to the experts' work.

Within this context, this report provides guidance and illustrates possible ways of applying bibliometric analysis to research-for-policy questions on specific energy technologies. It presents the work done within the JRC on using TIM for bibliometric mapping of emerging photovoltaic and offshore wind energy technologies. Both technologies have seen increasing deployment rates in the last years due to the ambitious energy and climate targets in place and therefore a focus of research has been set on ways to increase their operational efficiency and reduce costs.

Depending on the search formulation, TIM counts activity levels in documents (e.g. scientific publications, patents, EU projects...) and identifies patterns of collaboration. The relationships detected can be visualised by entities, geographical location or topics. The effort and the search direction can vary significantly being highly dependent on how the search strategy and search terms are designed and selected.

Regarding photovoltaics (PV), the search strings presented in Chapter 2 address specific technologies identified by JRC PV-technology experts as being emerging chemistries or manufacturing techniques, such as 'perovskite', 'kesterite', 'roll to roll'... TIM was able to show that Perovskite is a rapidly emerging technology. For offshore wind, besides the use of specific search terms for particular support structure technologies (e.g. monopiles, floating support structures), queries also used filters to identify trends in EU funding and patenting, or the development of networks participating in EU projects over time.

Chapter 3 shows illustrative results of tailor-made searches defined for photovoltaics and offshore wind. For photovoltaic energy, this pilot exercise focuses on the mapping in four different areas. First, for each of the individual emerging photovoltaic technologies a visual mapping of collaboration networks is performed to infer their level of maturity. This is followed by a visual mapping of the keywords (called 'keywordgram') used for the years 2000 and 2015 with the aim to show their development over time. TIM's capabilities to export data are used in performing a frequency analysis of keywords in

¹ <https://setis.ec.europa.eu/>

order to analyse the rapidly evolving field of perovskite solar cells between 2013 and 2015. A mapping of the countries involved in 'roll to roll' manufacturing, to visualise the inter-linkages worldwide and within the EU, completes the results on photovoltaics.

With regard to offshore wind, results derived from TIM visualise the activity of entities and countries involved in EU projects and patenting. The development in EU project participation is mapped on country level to identify the main actors over time and to spot the formation of different networks. Moreover, data exports from TIM are used to identify entities which are engaged in both EU projects and patenting. In a second set of TIM-based searches, existing and emerging offshore wind support structure concepts are mapped to visualise the publication activity and to identify the top patenting entities within each concept.

1. Introduction

Capacity-building in fields such as bibliometrics and network analysis, including the development and use of an own in-house tool, can facilitate knowledge-management and help address policy questions and issues related to the positioning of the EU in the global science, technology and innovation landscape, at granularity levels ranging from global to sub-national and organisational.

From energy and innovation policy perspectives, low-carbon technologies such as photovoltaics and wind power are key to reduce greenhouse gas emissions and improve the sustainability of the energy system. The uptake of new energy technologies can also decrease reliance on external suppliers of fossil fuels, as well as spur job creation and economic growth [1].

From a data-driven economy perspective [2], many EU policy domains are faced with the challenge of extracting accurate, targeted and timely information from an increasing volume of textual data. In this context, policy makers need text mining and analysis solutions to access the right information, in the proper format for the decision making process in a variety of contexts.

1.1 Objectives, scope and structure of this report

This report aims at illustrating how the TIM tool can be used by energy technology experts to analyse innovation trends in specific energy technologies addressed by the SET-plan.

The European Commission's Directorate General Joint Research Centre (JRC) coordinates knowledge and competence activities to process science-based evidence to inform policy-makers and to provide tools and services for all EU policy areas.

In the field of energy, SETIS, the SET-Plan Information System, offers an integrated approach to the exchange of data and information on low-carbon energy technologies and innovation across Member States and energy sectors. This information is used to support the effective strategic planning, monitoring, and assessment of the progress of implementation of the SET-Plan, one of the instruments of implementation of the research, innovation and competitiveness dimension of the Energy Union.

The JRC also has strong competences in text mining (automatic extraction of information from text), which offers policy makers timely access to important information that would otherwise be practically impossible to extract manually. The new JRC Text Mining and Analysis Competence Centre will support the Commission and other EU institutions in activities requiring mining and analysis of textual data. For example, it is developing a novel text mining tool for monitoring innovation and technological development, TIM (Tools for Innovation Monitoring).

This report is one of the first concrete results of collaboration between JRC teams from the Directorates for energy transport & climate, knowledge management and competences.

This report describes work done within the JRC on using the TIM tool for bibliometric mapping of emerging photovoltaic and offshore wind energy technologies. It is organised as follows:

- This introduction briefly outlines the context, policy relevance and present status of these technologies, including a brief note on the scope of TIM-based mapping for these two technologies.
- Chapter 2 presents the main search strings and briefly discusses the process of designing these strings.
- Chapter 3 presents and discusses the results and presents several visual examples of network maps produced by TIM. This chapter is the most relevant for policymakers interested in energy-technology innovation.
- The conclusion summarises and reflects on the main elements of the report.

1.2 Policy context and relevance

1.2.1 Technology monitoring and information retrieval

Information on scientific and patent production can complement expert knowledge by providing quantitative evidence to underpin policies that are subject to an increasing integration between R&D and technology innovation. Expanded databases and enhanced computing power now allow combining bibliometric analysis (counting activity levels and identifying patterns in R&D bibliographic records, plus patent analyses) with text mining from complex databases to identify, select and visualize information on emerging technologies. This allows constructing maps of keywords and R&D actors based on co-publication and co-patenting, as a valuable evidence base to compare the advancement of knowledge among different technologies in the course of time and across different geographical regions.

The Joint Research Centre (JRC) has developed the TIM software which allows among other things tracking the evolution of established and emerging technologies using text mining and semantic analysis to visualize complex data sets [3]. TIM counts activity levels (based on R&D bibliography, patents and news) and identifies patterns of collaboration and technological evolution, potentially tracking the progression of keywords in time and by domain. TIM uses network analysis to detect events related to technology change, by identifying, clustering and visualizing complex relationships and connections by topics, institutions and countries or regions [4].

This allows for example to analyse different cases of technological change by monitoring the evolution of collaboration patterns between research organisations, the emergence of new keywords and/or subject categories in articles, as well as changes in patent or publication counts.

TIM's capabilities include monitoring technological development trends, e.g. by identifying relevant keywords and lead players by country, region and sector, and by comparing them with other players and other technologies. Such analysis can be valuable to researchers and research managers who need to better understand opportunities and challenges in the research landscape [5] [6] [7] [8].

TIM uses a search string to retrieve data pertaining to e.g. scientific publications, patents, conference proceedings and EU projects.

Visualisations from TIM are very effective in conveying a quick first impression of the 'big picture' at high aggregation levels, although they may appear somewhat ambiguous upon more detailed scrutiny.

TIM works on a combination of nodes (bubbles) and edges (lines). The node size is based on the number of publications/documents retrieved by a semantic search/query. An edge between 2 nodes (countries, organisations, keywords...) means co-occurrence of documents between these nodes; it exists between two nodes when these nodes have documents in common (co-filed patent, co-publication). An edge means they appear together in articles, patents, reviews...

1.2.2 Policy relevance of energy technology R&D

The EU is stepping up efforts to increase resource productivity, sustainably reindustrialise the EU economy, secure access to raw materials whilst reducing environmental impacts, increase energy efficiency and reduce greenhouse gas emissions [9] and lead the global transition to renewables [10].

Driven by climate and energy targets, the share of renewable energy in the EU has increased from 8.5% in 2005 to 15.3% in 2014 (26% in electricity). This has enabled Europe to lead the global development and large-scale installation of renewable energy technologies [11]. European renewable energy businesses have a combined annual turnover of €129bn and employ over a million people. EU companies have a share of

40% of all patents for renewable technologies. The challenge is to retain Europe's leading role in global investment in renewable energy [12].

The implementation of the Paris Agreement (i.e., avoiding climate change by limiting global warming below a 2 degree Celsius rise in global temperatures) will mean significant investment in low carbon technologies, renewables and energy efficiency, representing tremendous opportunities in both our domestic European markets and globally [10].

The European Commission is proposing eight pieces of legislation in the 'Clean Energy for All Europeans' package, covering energy efficiency, renewable energy, the design of the electricity market, security of electricity supply and governance rules for the Energy Union strategy, adopted in February 2015. These measures aim at putting the European Union at the forefront of the clean energy transition, incentivising investment in grids, in smart, innovative and efficient technologies, and enabling more renewable energy to flow through our energy systems.

The Energy Union dedicates one of its five dimensions to research, innovation and competitiveness. Within this context, the European Strategic Energy Technology Plan (SET-Plan) aims to accelerate the development and deployment of low-carbon technologies. It seeks to improve new technologies and bring down costs by co-ordinating research and helping to finance projects. The EU's SET-Plan Information System (SETIS) provides information on the state of low-carbon technologies, assesses the impact of energy technology policies, reviews the costs and benefits of various technological options, and estimates implementation costs.

1.3 Emerging photovoltaic technologies

The International Energy Agency (IEA) estimates that the full implementation of climate pledges will require the energy sector to invest USD 13.5 trillion in energy efficiency and low-carbon technologies from 2015 to 2030. More than 60% of total investment in power generation capacity is projected to be for renewable capacity, at USD 4.0 trillion, with one-third of this being for wind power, almost 30% for solar power (mainly solar photovoltaics) and around one-quarter for hydropower [13].

The PV market is dominated by crystalline silicon (Si) technologies. Solar cell prices have decreased by a factor of 8 since 2008 and the installed PV system capacity increased by a factor of 50 over the last decade, while PV electricity costs have been going down to EUR 80 /MWh [10] [14] [15].

Thermodynamic considerations limit PV efficiency to a fundamental limit of approximately 30% for conventional (single-junction) solar cells, due to a great extent to heat dissipation [16] resulting from inefficiencies in how light particles (photons) are captured by and transported inside the solar cell.

The development of new, disruptive PV technologies based on novel advanced materials could create a new industry, which must be competitive with current technologies in efficiency, cost, and reliability; use readily available materials; and be compatible with low-cost expenditure production processes to ensure rapid industry growth after initial commercialization.

Over the past decade, considerable research effort has addressed alternative approaches to increasing efficiency and/or reducing production costs.

A few examples of products or prototypes close to commercialisation are already available for organic PV (OPV) and dye sensitized solar cells (DSSC). Indeed by companies such as Heliatek, Belectric OPV and Glass2Energy, which are already installing OPV and DSSC systems for commercial applications. Recently hybrid organic/inorganic compounds known as perovskites have emerged as a new class of

photovoltaic materials. There is no example of full-scale perovskite module² yet, but there are already examples of perovskite mini-modules (up to 10% efficiency approximately) demonstrated in literature [17] [18].

1.3.1 Use of TIM to map emerging PV technologies

Within the JRC, work is on-going on bibliometric analysis using TIM as a complement to expert-intelligence for detection and monitoring of emerging technologies. This report outlines the approach to and results of a pilot exercise using TIM to map emerging PV technologies³.

This pilot mapping exercise uses TIM to explore possibilities of retrieving, visualising and analysing bibliometric data from the SCOPUS database of peer-reviewed scientific journals. The analysis focuses primarily on:

- **visual mapping of collaboration networks** to infer the maturity level of eight emerging PV technologies identified by JRC PV experts. These maps (called 'sociograms') were made for each of the individual technologies.
- **visual mapping of keywords** as two 'snapshots' for the years 2000 and 2015, for the same eight technologies, to infer how these technologies evolved over time at an aggregate level. These maps (called 'keywordgrams') were made for the ensemble of all eight technologies.
- **frequency analysis of keywords** for Perovskite solar cells, in order to spot the emergence of new keywords from 2013 to 2015 in this rapidly emerging field. A so-called frequency-rank chart was made using data exported from a TIM keywordgram for perovskites.
- **county-level collaboration mapping** for roll to roll manufacturing technologies, to visualise the intensity of publication activity and inter-linkages worldwide and within the EU. These maps were made for a single technology.

JRC PV experts identified emerging PV technologies in the frame of the low carbon energy observatory (LCEO) project of the Joint Research Centre. A more comprehensive analysis of emerging low carbon energy supply technologies is on-going in the LCEO project. The LCEO is an in-house project by the European Commission providing data, analysis and intelligence on developments in low carbon energy supply technologies [19].

² Commercial PV modules typically have an area of about 1.5 m² and comprise many interconnected cells as well as a weather-resistant packaging to maintain performance in the field over 20 years or more. So-called mini-modules have an area of several cm², and are used to demonstrate the performance of multiple cell interconnections and the prototype packaging systems.

³ The JRC's European Solar Test Installation is also investigating experimental methods for accurately assessing the electrical performance of perovskites.

1.4 Offshore Wind Energy Technologies

The wind energy sector has shown significant deployment rates in EU Member States and will therefore significantly contribute to reach the EU's ambitious energy and climate targets towards a decarbonised economy [20]. Starting from 8 % in 2014 a steady growth resulted in 10 % of the European electricity demand being met by wind energy in 2015. With yearly deployment rates between 10-15 GW, wind energy will cover at least 15 % of the European electricity demand by 2020 [21]. Although having reached already a low electricity production cost level, there is still cost reduction potential to be unlocked. With increasing size and number of projects, it is expected that especially costs of offshore wind energy will be driven down, despite the fact that projects are moving farther away from the coastline and to deeper waters. Developments that focus on innovative designs of foundations, new construction vessels or new operation and maintenance concepts will increase the competitiveness of offshore wind.

1.4.1 Use of TIM to map offshore wind technologies

Within this context TIM was used for two case studies. In the first case study TIM was used to perform specific searches on actors, EU funding and patenting activity in the area of offshore wind. The aim of this analysis is to:

- identify possible relationships between entities participating in offshore wind EU projects and patenting
- identify and visualise the interlinks between actors and to detect emerging networks and their evolution over time.

In a second case study the capabilities of TIM are tested by performing a search on specific technology concepts in offshore wind. Therefore, different types of offshore wind support structures are investigated as they were identified as critical component for future offshore wind deployments at deeper seabeds and locations farther away from shore.

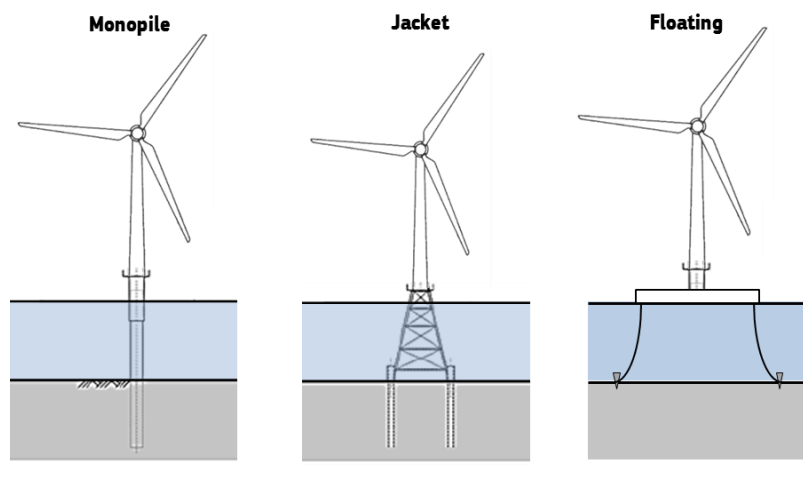


Figure 1 Selected types of offshore wind support structures investigated applying the TIM tool

We assessed three support structure concepts which are currently at a various stages of technological maturity, namely:

- **Monopiles** – Large dimension steel tubes (4 – 7 m diameter, 50 – 90 m length, up to 1000 t weight) [22] [23]. Monopiles are the most widely deployed foundation type, particularly used for shallow and intermediate-depth waters (20 – 30 m)
- **Jacket structures** – Lattice truss templates installed on the seabed are suitable for medium water depths. Offshore wind projects which are currently under construction indicate that jacket structures will likely play a more prominent role in the future, especially for intermediate water depths (20 – 45 m)

- **Floating concepts** – Prototypes using spar-buoys or platforms anchored to the seabed. Applicable for near shore deep water areas (water depths range from 40 – 200 m)

The aim of the TIM-based searches performed on support structures is to identify emerging technology concepts in offshore wind and to track their evolution. Furthermore the leading actors for each concept are identified.

2. Search string design

This chapter presents and discusses examples of how to conceive and design Boolean search strings in order to retrieve targeted outputs from queries with TIM.

The purpose of this chapter is to conceptually illustrate possible ways of defining a research question and/or a specific field to search upon. The query examples presented below are not meant as normative guidelines but rather as examples of how to design a TIM-based query.

The queries discussed in this report have the same build-up and syntax as the dataset definitions inserted in TIM. In order to maximise retrieval of relevant records (bibliometric recall) while minimising retrieval of irrelevant records (thereby increasing bibliometric precision), queries and their search terms need to be iterated and fine-tuned, often in close collaboration with technology experts.

A separate 'Search strategy help' is available directly from TIM⁴ with specific guidance on the syntax of fields, terms and operators.

2.1 Mapping emerging photovoltaic (PV) technologies

For emerging photovoltaics, the two main query 'families' consist of:

- a. eight search strings each addressing a specific technology identified as 'emerging' by JRC PV technology experts and;
- b. one 'overview string' combining terms for all these eight technologies.

For a search string addressing a specific emerging technology, the dataset definition consists of one part attributing search terms to characterize a specific technology, such as 'perovskite', 'kesterite' or 'roll to roll' in the examples below, plus a few search terms chosen to delineate PV technology as a research field. These two parts are connected by 'AND', as shown in the two boxes below. The search strings also have filters allowing to select only a given class of documents ('articles' in the examples below) and years.

Search string 1: Query for journal articles on perovskite solar cells between 1996 and 2015. Search terms are highlighted in bold letters.

```
Dataset definition = ti_abs_key: (perovskite AND (photovoltaic OR "solar cell" OR "solar PV" OR "solar power") ) AND (class:("article")) AND emm_year:[1996 TO 2015]
```

In the example above for perovskites, the initial search runs included the term 'PV' among the search terms delineating PV technology. After several trial runs, however, the search term 'PV' was omitted from the final search string because it was causing retrieval of articles irrelevant to photovoltaics, thereby reducing the bibliometric precision. This happened because the acronym 'PV' is also used by some authors to designate perovskites, which in turn lead to retrieval of articles related to astronomy and/or geology with no photovoltaic relevance. For the sake of consistency, the acronym 'PV' was removed from all search strings. The term 'solar PV' does not seem to reduce bibliometric precision and therefore remained in the final search string.

Search string 2: Query for journal articles on kesterite solar cells between 1996 and 2015. Kesterite-related search terms are highlighted in bold letters.

```
Dataset definition = ti_abs_key: ((kesterite OR CZTS OR "copper-zinc-tin-sulfide") AND ( photovoltaic OR "solar cell" OR "solar PV" OR "solar power" ) ) AND (class:("article")) AND emm_year:[1996 TO 2015]
```

⁴ The 'Search Strategy for TIM Technology' guidelines are available on <http://www.technologymonitoring.eu/>

In the example above for kesterites, the acronym 'CZTS' was included at the upon suggestion from a PV technology expert. Since it is relatively unusual and does not seem to reduce bibliometric precision, it was not removed during the subsequent iterative search string design process.

In general, use of acronyms on search strings is discouraged because many acronyms can have different meanings and therefore reduce bibliometric precision.

Search string 3: Query for journal articles on 'roll to roll' solar-cell manufacturing technology, between 1996 and 2015.

Dataset definition = ti_abs_key: ("**roll to roll**" AND (photovoltaic OR "solar cell" OR "solar PV" OR "solar power")) AND (class:"article")) AND emm_year:[1996 TO 2015]

Search strings such as the three examples above were constructed for each of the emerging PV technologies analysed in this report (see items 3.1.1. 3.1.3. and 3.1.4 below).

After several runs using strings for each of the individual technologies, a search string grouping all eight emerging technologies was also designed in order to produce overview maps (see item 3.1.2). The term 'nano' in the example below could be replaced by more specific terms (nanostructure OR nanowire OR carbon nanotube OR nanocomposite OR nanorod OR nanocrystal OR nanomaterial) to increase bibliometric precision.

Search string 4: Query for journal articles on the eight emerging solar PV technologies identified by JRC experts (1996 to 2015). Search terms used to designate these 8 techs are highlighted in bold letters.

Dataset definition = ti_abs_key: ((**organic** OR "dye sensitised" OR "**dye sensitized**" OR DSSC OR **kesterite** OR CZTS OR "copper-zinc-tin-sulfide" OR **nano** OR **perovskite** OR "**roll to roll**") AND (photovoltaic OR "solar cell" OR "solar PV" OR "solar power")) AND (class:"article")) AND emm_year:[2000 TO 2000]

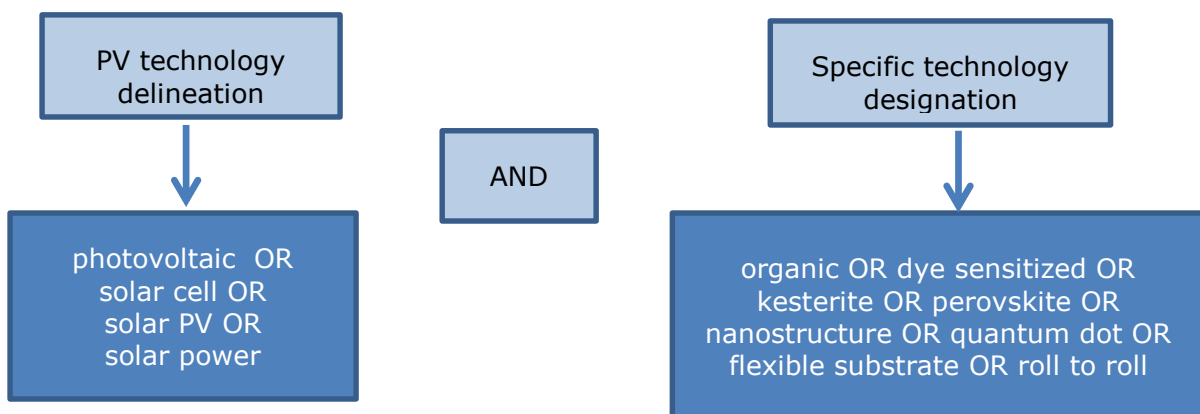


Figure 2 Technology domain delineation and specific technology designation through a Boolean search string

2.2. Mapping offshore wind technologies

On the basis of two different queries, the user is herein introduced into the basic approach of constructing search strings in TIM.

In the case of offshore wind the aim of the performed TIM-based searches is to identify:

- a. if EU funding promotes patenting of entities involved in the area of offshore wind.
- b. the development of new emerging support structure technologies.

2.2.1 Search strings on EU funding and patenting

To address the topic on the link between EU funding and patenting a set of searches have been performed within the TIM tool. For both funding and patenting, queries on the top entities and their affiliation are made. Moreover, search strings with different time frames are implemented to identify the development of clusters or the occurrence of new entrants. The stepwise approach in creating search strings is presented below by highlighting the main functionalities of each query.

The first search aims to identify all EU projects which have been granted between 1996 and 2015 in the area of offshore wind. Search string 5 is composed of three different search filters addressing the topic in question, the time period and the type of document searched for.

The filter "topic" searches in the fields "title", "abstract" and "author keywords" and "automatic keywords" of documents indexed in TIM [24]. The filter "emm_year" limits the query to a time period in which the documents are published. The last term in the search string "class" defines the type of document that should be displayed. Search filters are linked by the use of standard logical operators ("AND", "OR", "NOT").

As it will be shown in the next chapter, a set of different visualisations and conclusions can be drawn from this query without changing the search string itself. Search string 5 was used to generate sociograms and countrygrams to identify entities and countries participating in EU projects, respectively.

Search string 5: Query for EU projects between 1996 and 2015 in the area of offshore wind. Search filters are highlighted in bold letters.

```
Dataset definition = topic("offshore wind")AND emm_year:[1996 TO 2015]  
AND ( class("euproject" ) )
```

In a second step, the development of offshore wind EU projects over time is assessed to identify the building of clusters and leading countries within the community. For this purpose, additional filters on different time periods are added stepwise to Search string 5, which covers the entire period between 1996 and 2015. Alternatively, an entire new search could be performed with the respective time period in the first search string.

Search string 6: Query for EU projects in the area of wind energy between certain periods. Different search filters for time periods are highlighted in bold letters.

```
Dataset definition = topic("offshore wind")AND emm_year:[1996 TO 2015] AND (  
class:( "euproject" ) )  
Filter : emm_year:[1996 TO 2000]  
Filter : emm_year:[1996 TO 2005]  
Filter : emm_year:[1996 TO 2010]
```

The third search string addresses patenting activities in the area of offshore wind in the European Economic Area (EEA) aiming to identify the entities active in patenting. The query consists of the following three main parts: The first part is a filter ("emm_classificationCPC") that narrows the search for patents on specific CPC (Cooperative Patent Classification) patent classes which relate to wind energy. This is done to avoid a too extensive search result which occurs if a more general filter on patents ("class:patent") is applied together with the search term "offshore wind".

Moreover, patents not directly related to wind energy can be excluded by applying the search on specific patent classes. Analogously to the previous search strings, the second part of the query includes filters for the topic and the time period in question. Finally the last part of the search string filters the search according to the geographical location ("emm_affiliation_country"). The countries selected are based on the results of Search string 5, i.e. EU countries participating in EU funded offshore wind projects (see also results in item 3.2.2) to find a possible correlation between EU project funding and patenting. Additionally, countries from EEA (CH, NO) were added to the search string as they are often the base of companies which have patenting subsidiaries in EU Member States (e.g. ABB).

Search string 7: Query for patenting in the area of wind energy between 1996 and 2015. Search filters for patent classes and geographical location are highlighted in bold letters.

```
Dataset definition = ((emm_classificationCPC("Y02E 10/70" OR "Y02E 10/72" OR "Y02E 10/721" OR "Y02E 10/722" OR "Y02E 10/723" OR "Y02E 10/725" OR "Y02E 10/726" OR "Y02E 10/727" OR "Y02E 10/728" OR "Y02E 10/74" OR "Y02E 10/76" OR "Y02E 10/763" OR "Y02E 10/766")) AND (topic("offshore wind")))) AND emm_year:[1996 TO 2015] AND ( emm_affiliation__country:("Germany" OR "Spain" OR "France" OR "Switzerland" OR "Denmark" OR "Sweden" OR "Austria" OR "Poland" OR "Norway" OR "Netherlands" OR "Finland" OR "United Kingdom" ) ))
```

These three search strings were used in TIM to generate sociograms and countrygrams as it is shown in section 3.2 of this report. To identify a possible correlation between patenting and participation in EU projects TIM offers the possibility to export the data to MS Excel (see button icon "Export"), which is depicted in the visualisations.

2.2.2 Search strings on support structure concepts

The second search exercise aims to identify the development of new support structure concepts in offshore wind. Indicators for emerging offshore wind concepts are the number of patents issued and articles published.

For the concepts investigated, the specific keywords "monopile", "jacket structure" and "floating" are used in the queries. Search string 8 shows the structure of the query for floating wind foundations. Queries for concepts on monopiles and jacket structures are formulated analogously by replacing the respective keyword. Again the first part of the search string filters the CPC patent classes for the support structure concept in question. The second part of the string identifies all articles that mention the search words "floating" and "offshore" in their title, abstract or author keywords (using the filter "ti_abs_key"). In addition to that, the last part of Search string 8 filters all patents which mention "floating" and "offshore wind" together in the title, abstract or author keywords.

Search string 8: Query for patents and articles in the area of floating offshore wind concepts between 1996 and 2016. Search filters to identify articles that include the search words "floating" and "offshore wind" are highlighted in bold letters.

```
Dataset definition = ((emm_classificationCPC("Y02E 10/70" OR "Y02E 10/72" OR "Y02E 10/721" OR "Y02E 10/722" OR "Y02E 10/723" OR "Y02E 10/725" OR "Y02E 10/726" OR "Y02E 10/727" OR "Y02E 10/728" OR "Y02E 10/74" OR "Y02E 10/76" OR "Y02E 10/763" OR "Y02E 10/766")) AND (topic("floating")))OR (class:(article) AND ti_abs_key:("floating") AND ti_abs_key:("offshore wind")))OR(class:(patent) AND ti_abs_key:("floating") AND ti_abs_key:("offshore wind")))) AND emm_year:[1996 TO 2016]
```

During testing TIM in this query it has been observed that the filters "topic:" and "ti_abs_key:" are interchangeable and lead to the same search result. Possibly this happens because the additional feature of the filter "topic", which adds the automatic keywords to searches, does not lead to additional information if a narrow query is

formulated. The search performed allows identifying, if a certain concept shows an emerging trend in patenting or publications over the investigated time period.

Filtering certain results out of a search string can be achieved in two different ways. Either an entire new dataset is created or the filter is applied on a result afterwards. These two cases are exemplified via the presented Search string 8 above on which a filter for patents is applied. In the first case a new dataset would be created which excludes the highlighted search filters in Search string 4, whereas in the second case a the filter is applied directly on the visualised result of Search string 8 by using the button icon "Class Filter" in TIM (see Search string 9).

Search string 9: Query for patents and articles in the area of floating offshore wind concepts between 1996 and 2016. Change in search string after applying a filter in TIM directly on the result generated from Search string 4. Additional filter is highlighted in bold letters.

```
Dataset definition = ((emm_classificationCPC:("Y02E 10/70" OR "Y02E 10/72" OR "Y02E 10/721" OR "Y02E 10/722" OR "Y02E 10/723" OR "Y02E 10/725" OR "Y02E 10/726" OR "Y02E 10/727" OR "Y02E 10/728" OR "Y02E 10/74" OR "Y02E 10/76" OR "Y02E 10/763" OR "Y02E 10/766") AND (topic:("floating"))))OR (class:(article) AND ti_abs_key:("floating") AND ti_abs_key:("offshore wind"))OR(class:(patent) AND ti_abs_key:("floating") AND ti_abs_key:("offshore wind"))) AND emm_year:[1996 TO 2016] AND ( class:( "patent" ) )
```


3. Results

This chapter presents and discusses results for collaboration networks, including participation in EU projects, keyword occurrence and patenting. Section 3.1 focuses on emerging photovoltaic technologies and section 3.2 on offshore wind.

3.1 Mapping emerging photovoltaic (PV) technologies

The search strings described in section 2.1 above are used as inputs for TIM to produce sociograms for eight emerging PV technologies (Figure 3), clean keywordgrams for these eight emerging PV technologies (Figures 4, 5 and 6) as well as a countrygram and a Europegram for roll to roll PV manufacturing technology (Figure 8). TIM-generated data were also exported: from yeargrams to produce the time series in Figure 3 and; from clean keywordgrams to obtain the rank-frequency plot for the rapidly-emerging perovskite PV of Figure 7.

3.1.1 Visualisation of collaboration networks

As exemplified in section 2.1 for perovskites, kesterites and roll to roll manufacturing, eight search strings were designed and input to TIM to retrieve publications on emerging PV technologies identified by JRC PV experts. Figure 3 shows the resulting bibliometric maps (sociograms) made with TIM. Among the emerging PV technologies dye sensitized solar cells (DSSC) and organic PV (OPV), in the upper left part of the figure, are relatively more established. This can be seen by the denser sociograms [25] and by the larger number of journal publications per year (time series) in Figure 3.

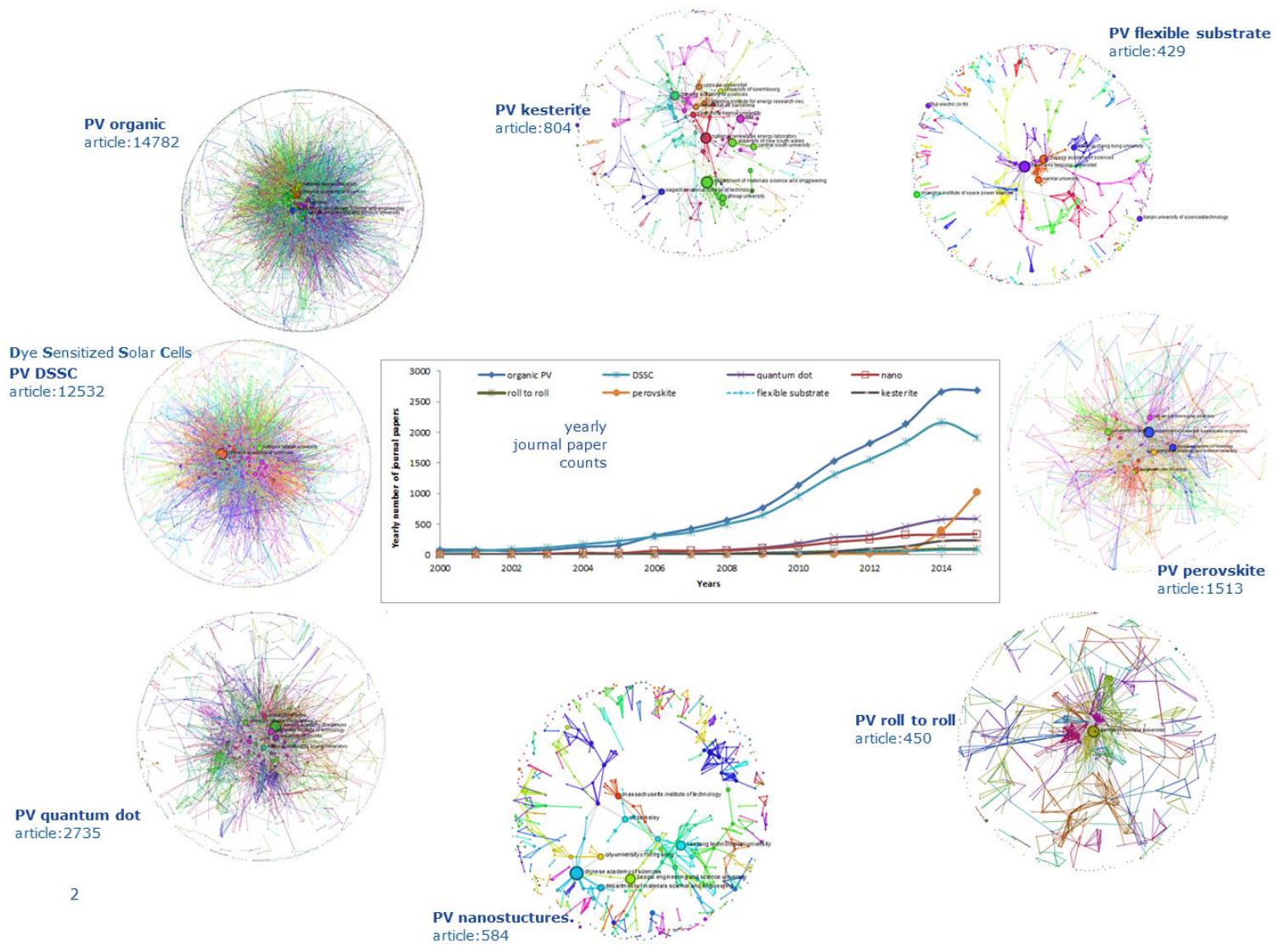


Figure 3 Sociograms and time series for eight emerging PV technologies (indicative counts of journal articles 1996-2015)

Particularly noteworthy emerging PV technologies are kesterites and perovskites solar cells. The latter have reached cell (area of the order of mm²) efficiencies above 20% in just a few years of research and development. Both systems must overcome significant hurdles before they will become commercial (e.g. performance, stability and also toxicity from lead, used in the case of perovskite solar cells) [16]. The TIM-based sociograms in Figure 3 show a less dense (more dispersed) pattern for kesterites and perovskites solar cells, as well as for technologies more related to manufacturing such as flexible substrates (potentially allowing PV to be applied in curved or irregularly shaped surfaces) and roll to roll (potentially allowing very low-cost manufacturing).

3.1.2 Keyword mapping

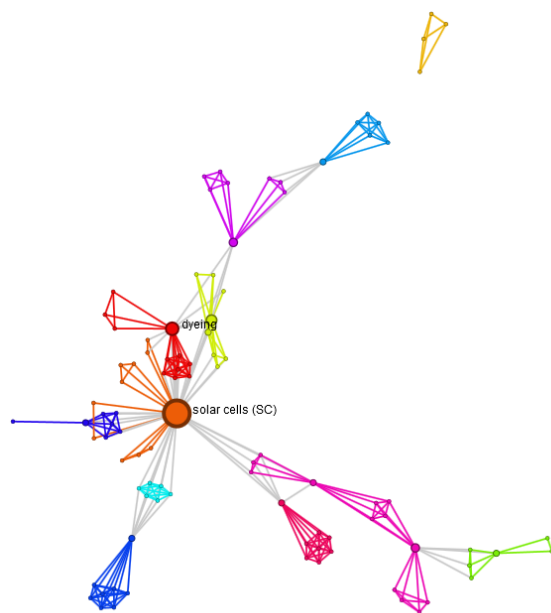
In addition to co-occurrence patterns, TIM also provides information on the frequency whereby certain terms (e.g. keywords, countries...) occur in a given dataset. The bigger the node (bubble) referring to a term in a graph, the more often the term occurs in that dataset. The size of a node is relative to the size of other nodes within the same dataset, but node sizes in TIM-based visual network maps are not comparable among different datasets. This is because node sizes in such visual network maps do not provide absolute indications of the frequencies of occurrence which these node sizes are based on.

TIM has a data export functionality which allows exporting frequency-of-occurrence data in tabular form (e.g. into an Excel file). These data can be rank-ordered in (decreasing) order of frequency of occurrence, whereby the most frequently occurring keyword (e.g. 'solar cell' or 'wind turbine') appears first. Typically, the frequency of occurrence tends to decrease rather rapidly, i.e., the second most frequently occurring keyword appears half as often as the first one, and so forth. This can be seen in the keyword rank-frequency chart for Perovskite solar cells in Figure 7, which is based on clean keywords exported from TIM. When done for different years, keyword frequency analysis can provide valuable indications of evolution patterns for a given technology.

For journal publications, use of clean-keywords is advised for TIM-based keyword frequency analysis. This is because the 'native' keywords input by authors contain many ambiguities (e.g. in spelling, capitalisation, hyphenation...) which are cleaned by TIM. What TIM usually cannot do (unless provided with tailor-made dictionaries) is to discern between conceptually similar or equivalent terms which might be used interchangeably, such as 'organic' and 'polymer' solar cells. The clean keyword lists generated by TIM therefore need expert judgement to be meaningfully interpreted.

Figures 3, 4 and 5 show year-snapshots of bibliometric keyword maps for the eight selected emerging PV technologies, for the years 2000 and 2015.

Keywordgram



Detail

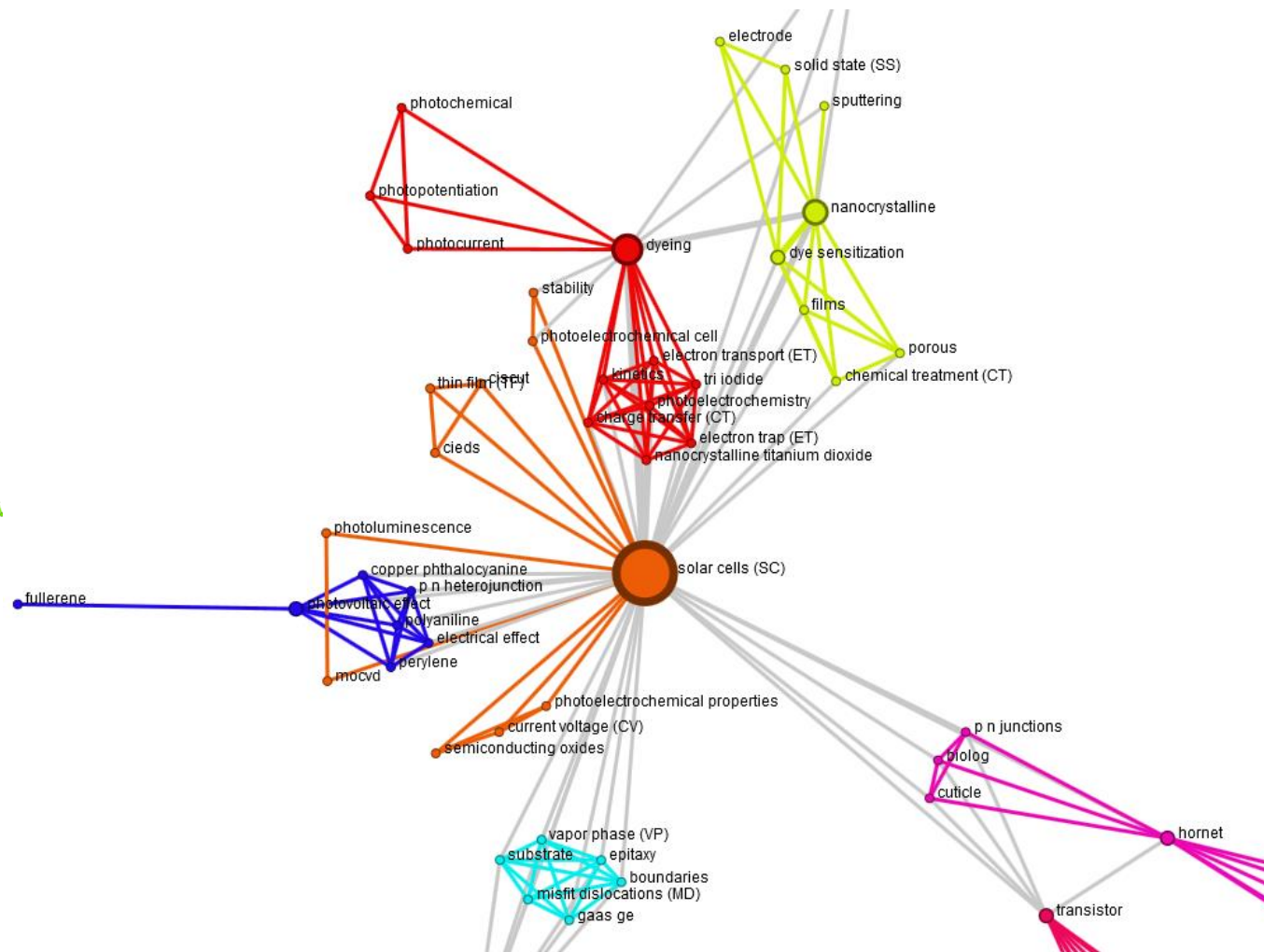


Figure 4 Author keywordgram snapshot for 8 emerging PV technologies, year 2000. Partial detailed view on the right

For the year 2000 (Figure 4), the TIM-based keywordgram shows the eight selected technologies to be at an emerging state, with arising keywords related to dye-sensitization, nanostructures, stability, thin-films...

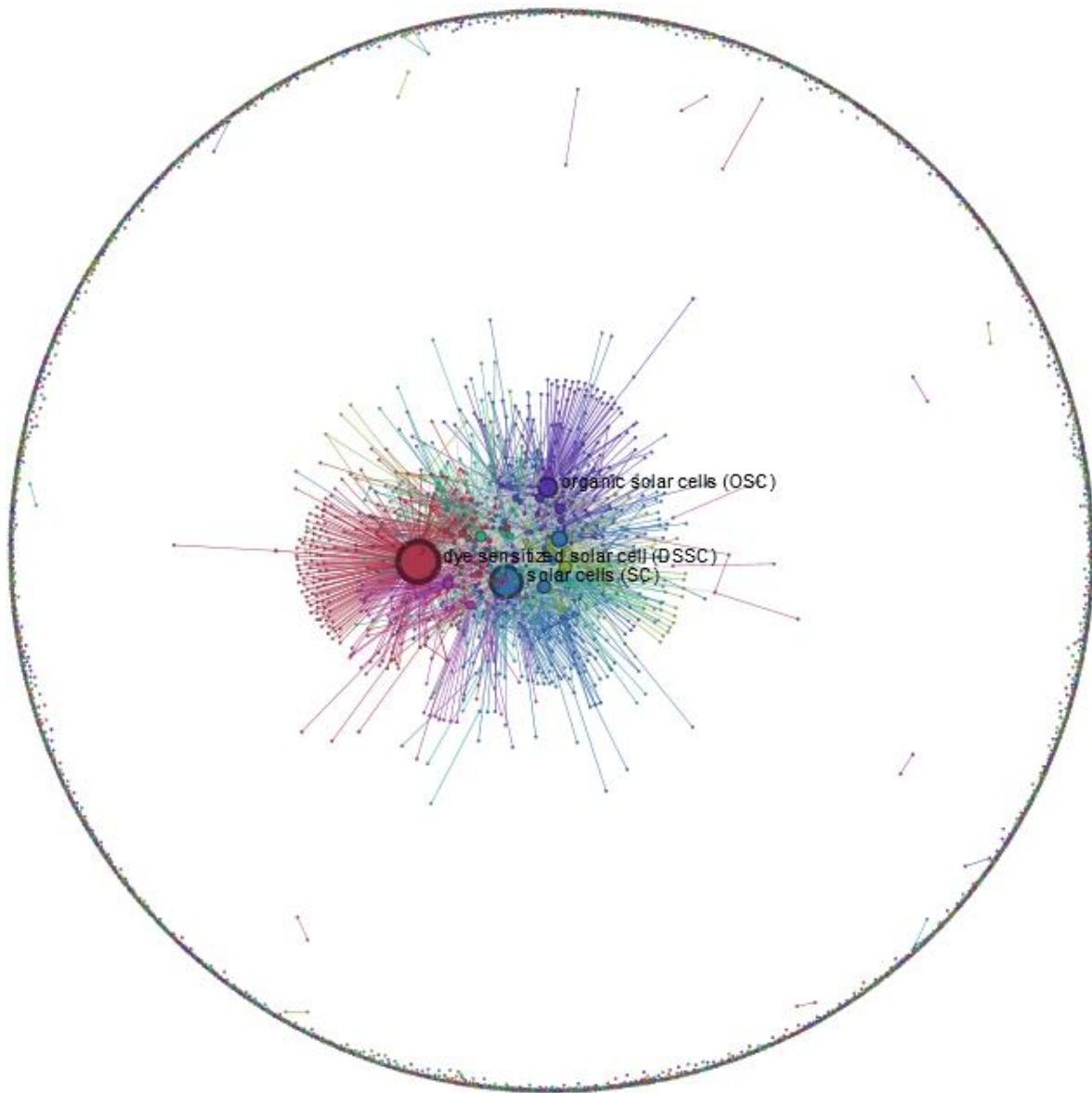


Figure 5 Author keywordgram snapshot for 8 emerging PV technologies, year 2015

The keywordgram for 2015 in Figure 5 above shows pronounced keyword clusters in the centre, which could be a sign that research, development and innovation activity in these topics is rapidly converging and therefore maturing [25]. The zoomed-in keywordgram for 2015 in Figure 6 below indicates the highly salient presence of focus areas such as organic solar cells (OSC) and dye-sensitized solar cells (DSSC), as well as thin films, perovskites and energy conversion. The zoomed-in keywordgram in Figure 6 below was generated by using the 'vis' functionality in TIM to minimise edge complexity, so that only nodes would be visible. This was done because of the sheer number of edges that would have been detrimental to readability.

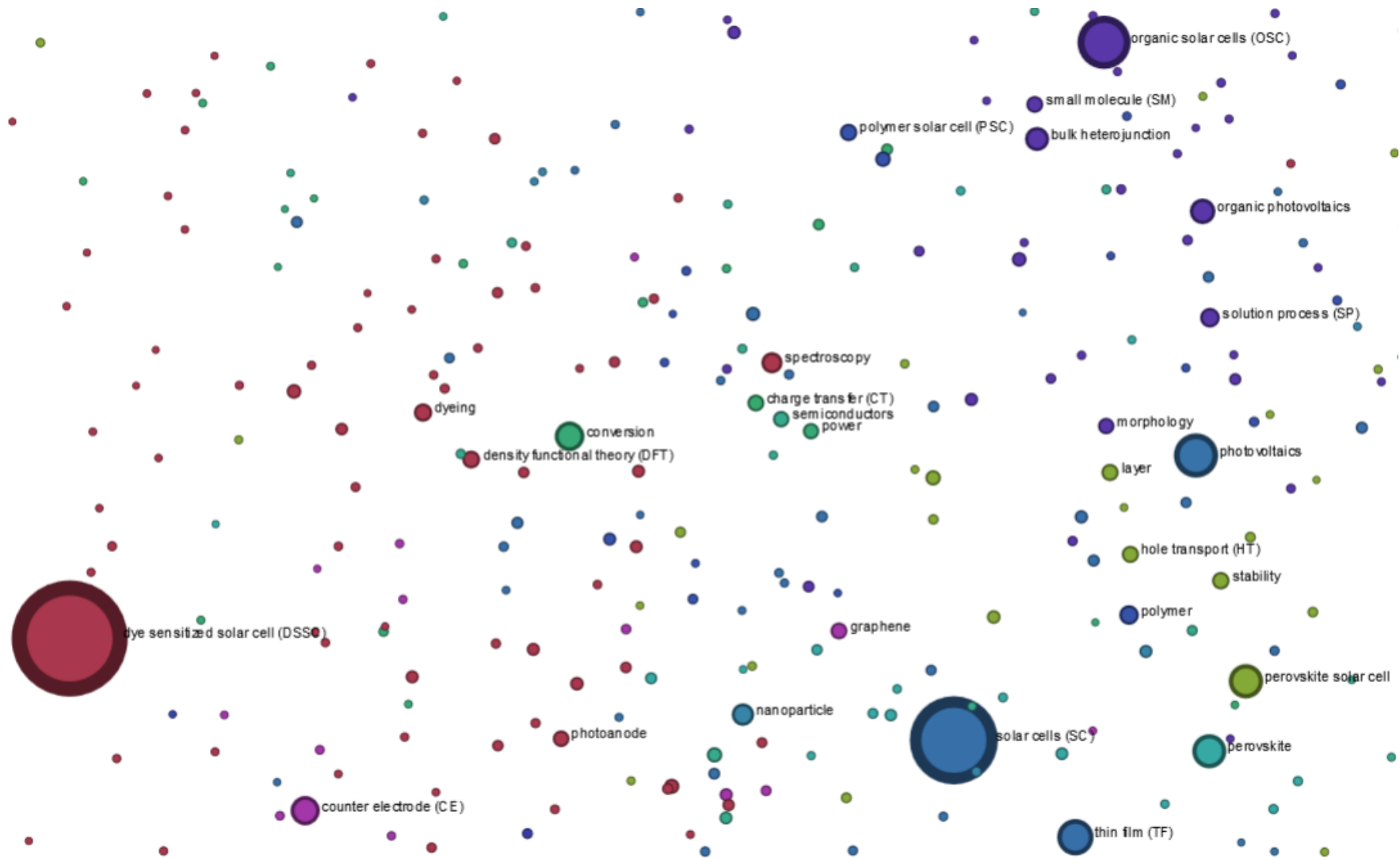


Figure 6 Zoom-in of the 2015 author-keywordgram snapshot for 8 emerging PV technologies

3.1.3 Keyword frequency analysis – example for rapidly emerging for perovskite photovoltaic technology

TIM allows easily exporting and counting semantically cleaned keywords. Keyword frequency analysis can help to get an idea on the direction of technology development [26] [27] [28].

As indicated by the steep surge in the number of yearly publication counts in the bibliometric time-series graph (Figure 3), perovskite-based solar cells have been developing rapidly in recent years. As recently as 2009, the first peer-reviewed journal publication of a perovskite sensitized solar cell reported 3.5% efficiency [29]. The first efficient solid-state perovskite cells were reported in mid-2012; and certified efficiency of 17.9% was reported in early 2014 [30] [31] at laboratory scale and for small area cells (approximately 1 cm²). Such rapid progress was possible because many research groups working in the field of organic PV (OPV) and dye-sensitized solar cells (DSSC) simply and rapidly moved to perovskite solar cells (PSC), capitalising on knowledge they had already built over 20 years on OPV and DSSC [31].

Perovskite solar cells merge the two main advantageous properties of standard Si PV technology (low and wide optical band gap, enabling sunlight absorption over a broad spectral range, including the lower-energy infrared range) and emerging organic PV technologies (thin films with high absorption coefficients and possibility to be manufactured with simpler wet chemistry techniques in a traditional lab environment, resulting in an easy-scalable and low-cost production process). Perovskite compounds allow for solar cells having very thin active layers (less than 500 nm) absorbing large part of the solar spectrum (from 300 nm up to 1100 nm).

Perovskite solar cells may offer the potential for an earth-abundant and low-energy-production solution to truly large-scale manufacturing of photovoltaic (PV) modules [32], although present perovskite devices are still very unstable due to the interaction with water and oxygen in the air. Other open issues and potential pitfalls include toxicity due to lead use, reliable performance measurement and use of chloride ions [30].

Figure 7 shows plots of keywords retrieved by TIM-based bibliometrics for perovskite solar cells for the years 2013 and 2015, rank-ordered by frequency of occurrence. It is noteworthy that the search retrieved 200 occurrences of the term 'perovskite solar cell' for 2015 but none for 2013. The term 'conversation' (likely a truncation related to energy conversion) was retrieved 19 times for 2015 (at rank 10) but none for 2013. The term 'stability' (at rank 6 in 2015, with 26 occurrences) was also not retrieved for 2013 by the search performed. The term 'dye sensitized solar cell (DSSC)', on the other hand, dropped from rank 3 (5 occurrences) in 2013 to rank 27 in 2015 (albeit with an increase to 11 occurrences, amid an increased number of publications on perovskite solar cells). Other keywords among the top-ten retrieved include 'thin film' (a broader category of PV to which perovskite solar cells belong), hysteresis (charge history dependence, which can make it difficult to accurately determine the real photoconversion efficiency of a given perovskite solar cell [33]) and 'halide' (absorber materials are mainly based on methylammonium lead halide perovskites [32]). Among the top-ten keywords retrieved by the TIM-based search, five were recognized by a JRC PV-technology expert as 'reasonably making sense': "stability", "conversion", "thin film", "hysteresis", "halide".

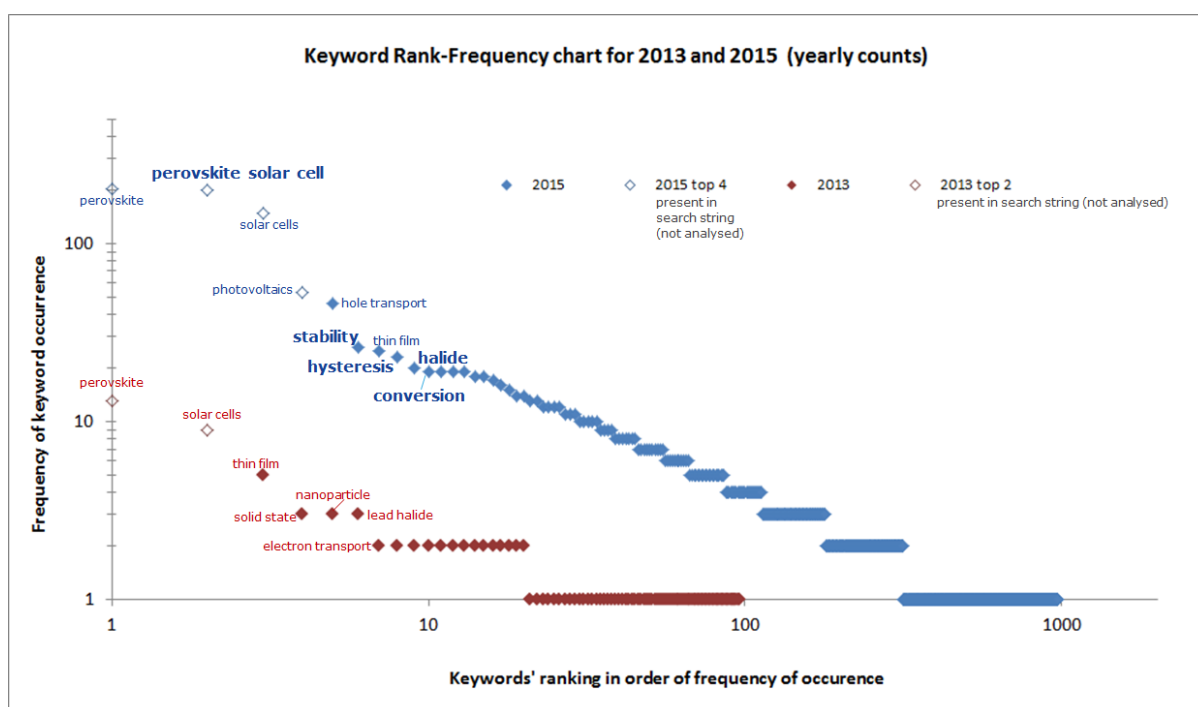


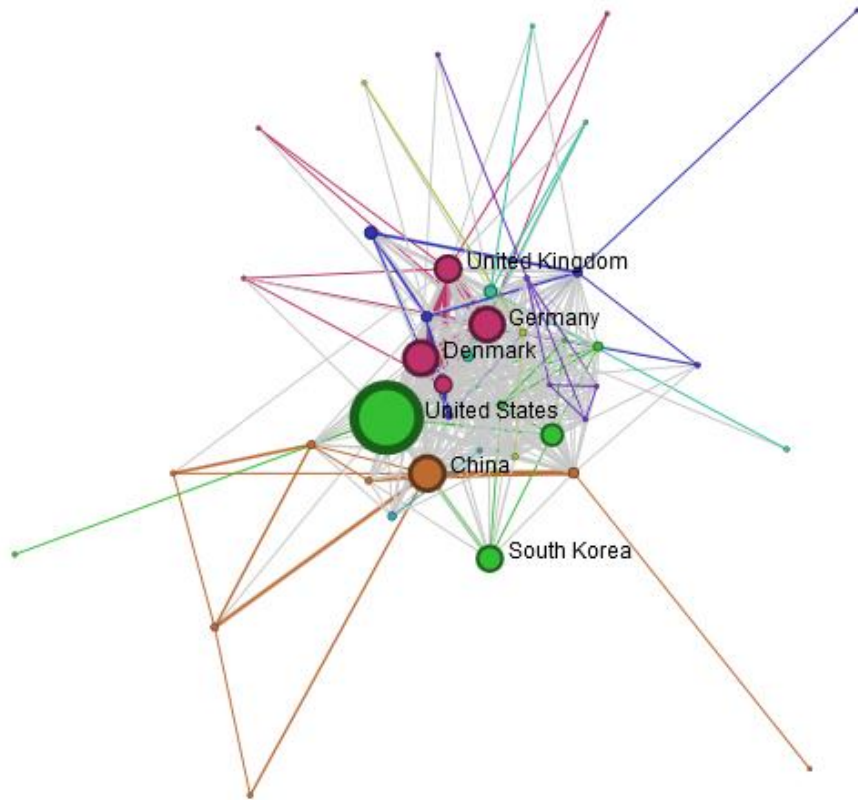
Figure 7 Frequency-rank plot of author keywords for Perovskites retrieved by TIM (years 2013 and 2015)

3.1.4 Collaboration mapping for countries – example for manufacturing technologies

Roll to roll (R2R) is a manufacturing technique involving continuous deposition of an photovoltaic layer on a flexible substrate as it is transferred between two moving rolls of material. R2R enables substantial savings in energy from higher throughputs and from more efficient deposition processes. Breakthroughs of high impact and therefore high value are expected in nano-manufacturing, with research efforts needed on controlling film thickness, evenness and quality. Complex multi-layer structures are likely to be significant challenges to the manufacture of a robust organic and hybrid solar cells. In addition to flexible solar cell modules, R2R processing is applied in flexible and large-area electronics devices, printed/flexible thin-film batteries, fibres and textiles, metal foil and sheet manufacturing, medical products, energy products in buildings [34].

The bibliometric maps in Figure 3 indicate that R2R and flexible-substrate photovoltaics are among the most important emerging PV technologies mapped (along with kesterites), with sociograms showing less actors and inter-linkages than for more established technologies such as organic and dye-sensitized PV. The bibliometric maps for geographical distribution (Figure 8) point to a strong European (particularly Denmark and Germany) and US presence in the roll to roll PV landscape.

Countrygram



Europegram

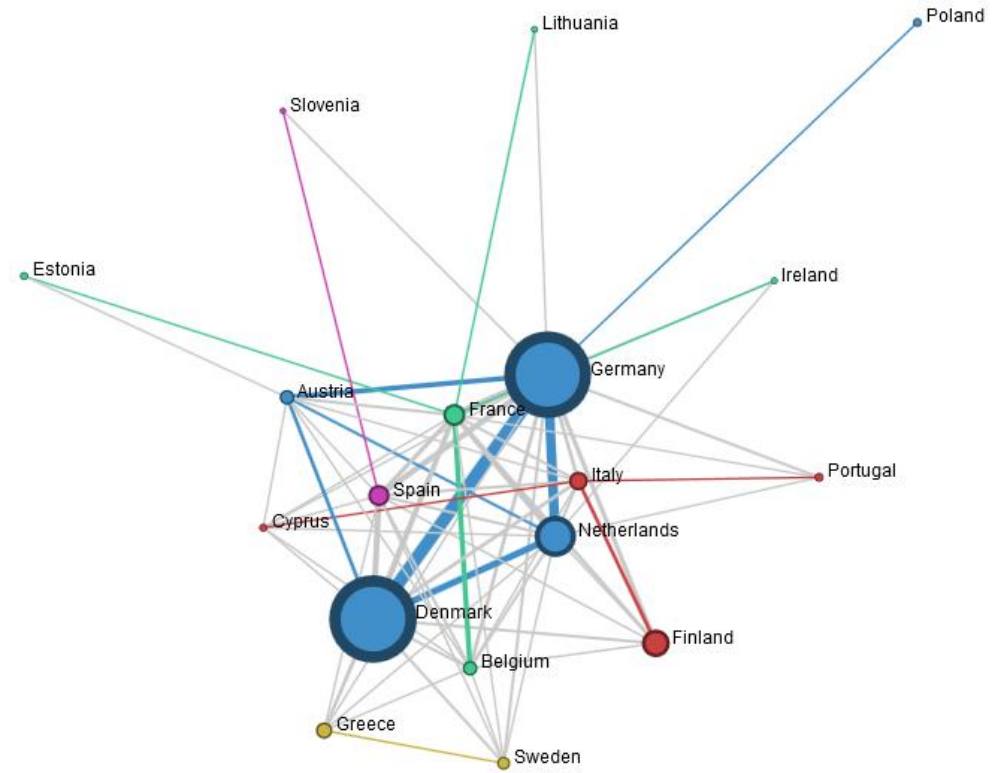


Figure 8 Countrygram (left) and Europegram (right) for roll to roll PV, 1996 to 2016

3.2. Mapping offshore wind technologies

3.2.1 Visualisation of collaboration networks: entities and countries in EU projects

Collaboration networks are visualised in TIM using two different bibliometric maps: sociograms and countrygrams. The results presented in this section refer to Search strings 5-7 in chapter 2.

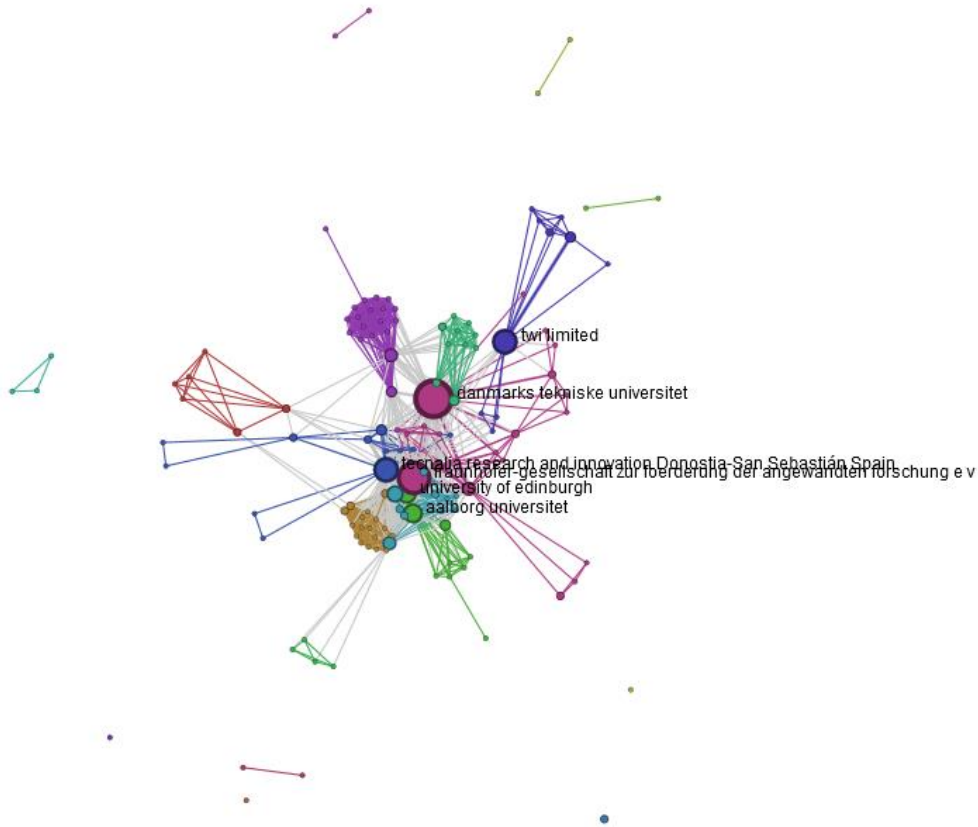
The first result (see Figure 9 below) shows the networking between entities participating in EU projects. The overall picture (left hand side of Figure 9) indicates strong collaborations among entities participating in offshore wind as the sociogram has a dense overall pattern.

A more detailed look on the top 10 entities participating in EU funded projects (right hand side of Figure 9) was created by using the 'vis' functionality in TIM to adjust node complexity, so that only the ten biggest nodes would be visible. TIM identifies especially four strong networks between the following actors:

- DTU, Fraunhofer and Carl von Ossietzky University (red group)
- San Sebastián and TWI Limited (dark blue group)
- Aalborg University and University of Edinburgh (green group)
- University Stuttgart and Gamesa (turquoise group)

With seven entities in the Top 10 of actors that participate in EU projects, the strongest participants are research facilities followed by three companies. The organisation type of entities can be visualised in the TIM by using the 'modularity' functionality. It allows changing the aspect of the sociogram regarding the organisational type of the entities displayed.

All R&I actors



Detail – Top 10 R&I actors

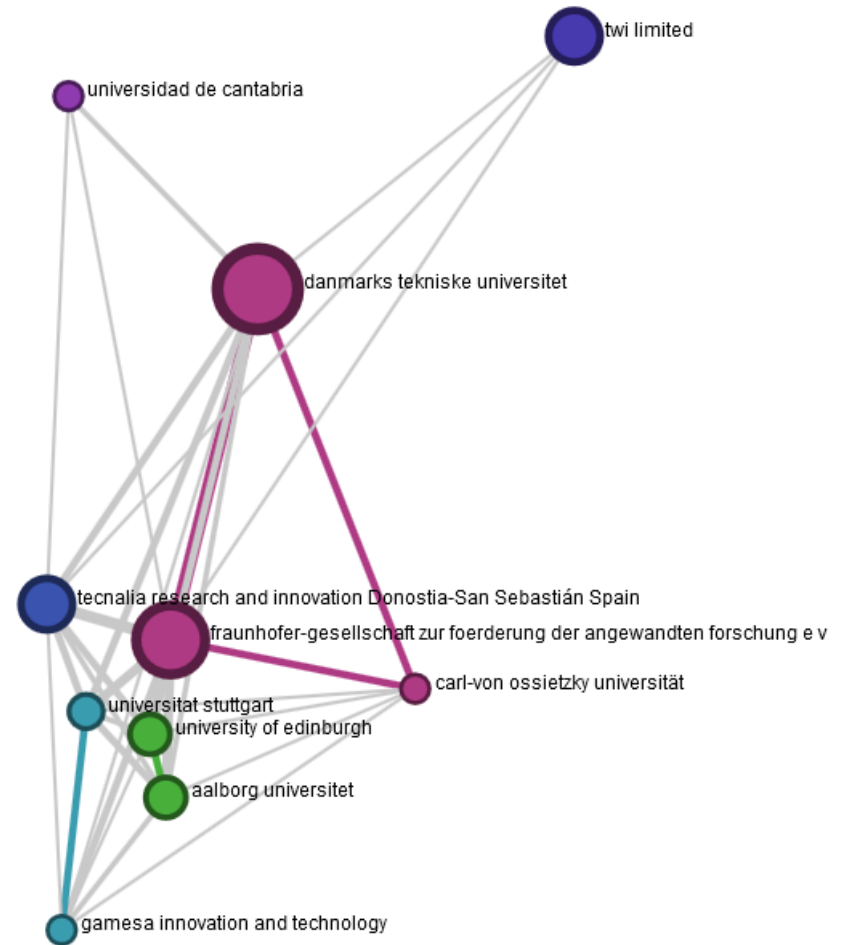


Figure 9 Entity Sociogram – Participation of entities in EU projects 1996 - 2015. All R&I actors (LEFT) and the Top 10 R&I actors (RIGHT) (Node Complexity 4-15)

The geographical location of the entities participating in EU funding from 1996 to 2015 is shown in a Countrygram in Figure 10. Within this time period the UK, DK, DE and ES showed the strongest participation in EU projects. However, the size of the cluster groups varies significantly. Especially between DE, DK and IT (green group) a strong network with only few participants can be observed, whereas the cluster with FR, BG, HR (yellow group) is small in terms of number of participation in EU projects but consists of many densely connected partners. This might be a sign of an emerging strong cluster. As expected, only a limited number of non-EU countries appear in the visualisation and they are depicted in the periphery of the countrygram, which might be a consequence of their status as additional partners in EU funded projects.

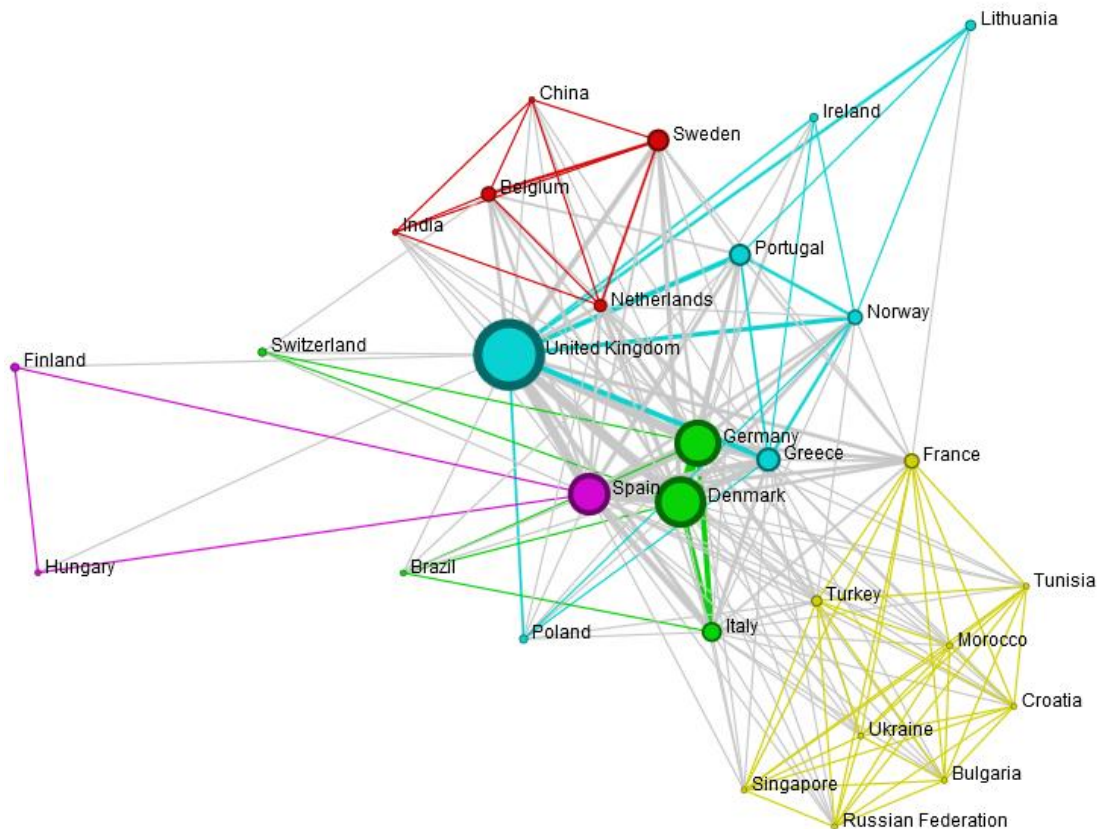
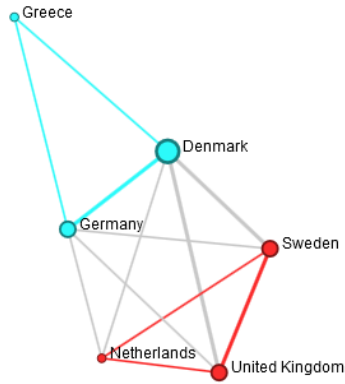


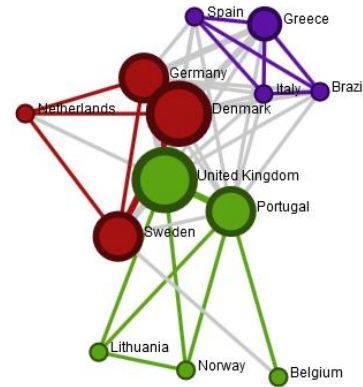
Figure 10 Countrygram – Countries participating in EU projects 1996 - 2015

As explained in chapter 2, TIM offers the possibility to filter searches for different time periods. In case of the countrygram this functionality is used to track the development of the participation in EU projects in different countries (see Figure 11 below). TIM indicates that participation in projects started in two clusters (SE-NL-UK and GR-DK-DE). However, as in the beginning only a small number of projects and participants occur, the grouping of countries should be seen with caution as only limited conclusions might be drawn from that. Between 2000 and 2010 it can be observed that the UK becomes the main actor in EU project participation, followed by DE and DK. Furthermore, the last two periods indicate that more countries are taking part in EU projects. The Countrygrams in Figures 10 and 11 show several links, particularly between FR and a few other Mediterranean countries, with new entrants located outside the EU. Nevertheless the absolute number of participation in this network (yellow) is fairly low, which might have an effect on the way TIM groups countries. Moreover, results show that since 2010 a strong increase in EU funded offshore wind projects occurred.

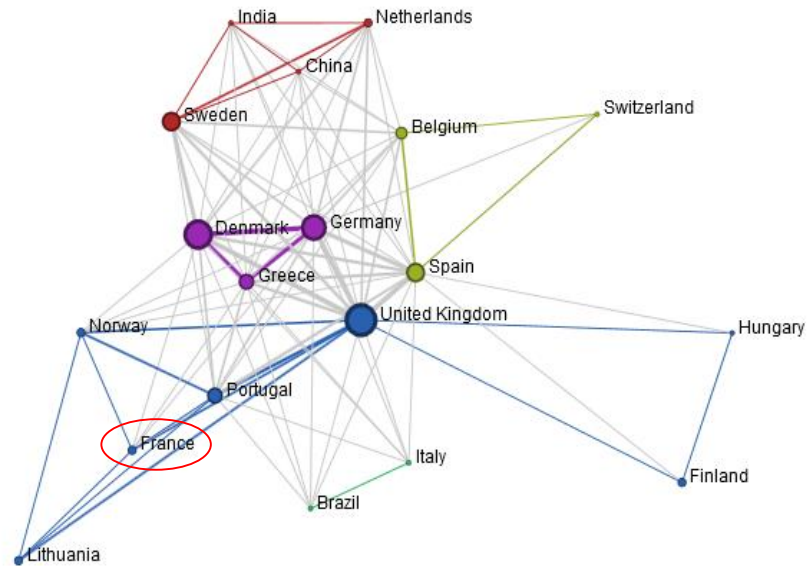
I) Period: 1996-2000 (3 Projects)



II) Period: 1996-2005 (11 Projects)



III) Period: 1996-2010 (19 Projects)



IV) Period: 1996-2015 (62 Projects)

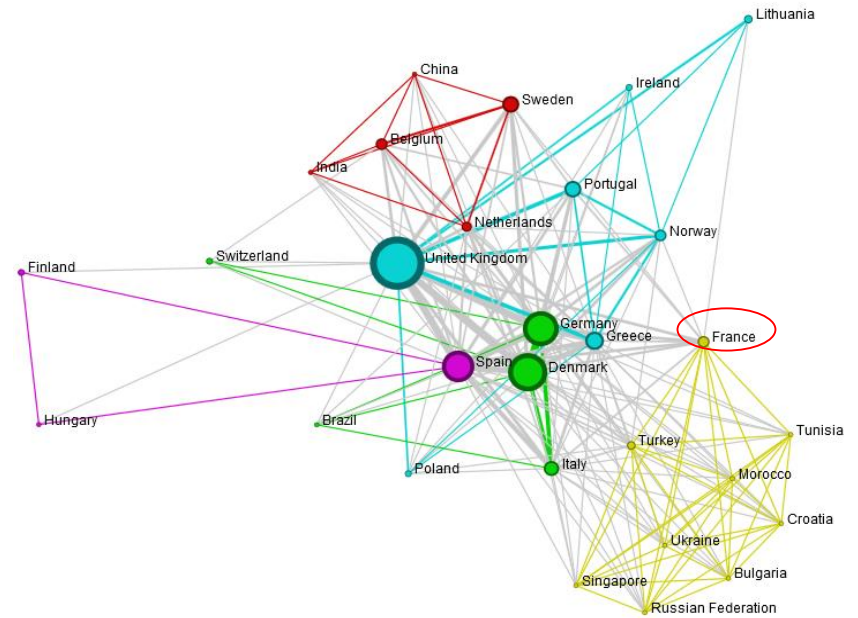


Figure 11 Countrygrams – Development of countries participating in EU projects from 1996 to 2015

3.2.2 EU projects participation and patenting – Using TIM exports to enhance the analysis

To monitor the patenting activity of countries and entities, data derived from TIM are exported to Excel as the geographical location of subsidiaries has to be inserted manually in the datasets. Figure 12 shows that DE, DK, ES and FR show strong patenting activity in the European Economic Area (EEA) between 1996 and 2015.

Data exports are drawn from countrygrams for the queries on EU project participation and sociograms for the entities patenting. For analysing patents, the sociogram was chosen instead of the countrygram, which would have led to misleading results because patents of entities with subsidiaries in EU Member States would be excluded and because country codes are missing in PATSTAT (the database where TIM extracts patent information from). Therefore, Search string 7 was visualised as a sociogram while the data on entities patenting was exported. However, the country codes are missing in this export and therefore additional post-processing of the TIM results is required at the time of writing the report. This is achieved by attributing the respective geographical reference (country code), to each of the identified entities. In a second post-processing step, the analyst manually identifies entities which engage in both EU projects and patenting.

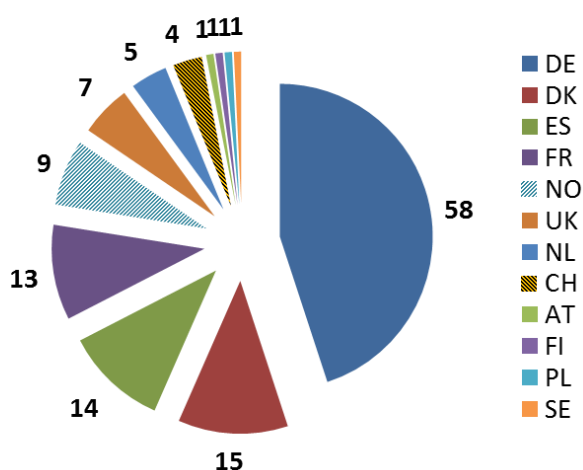


Figure 12 Number of patents issued by EEA countries (1996-2015) (Patent data incomplete from 2011 onwards)

The comparison of exported time series of both EU project participation and patenting shows no obvious clear relationship (see Figure 13 and Figure 14).

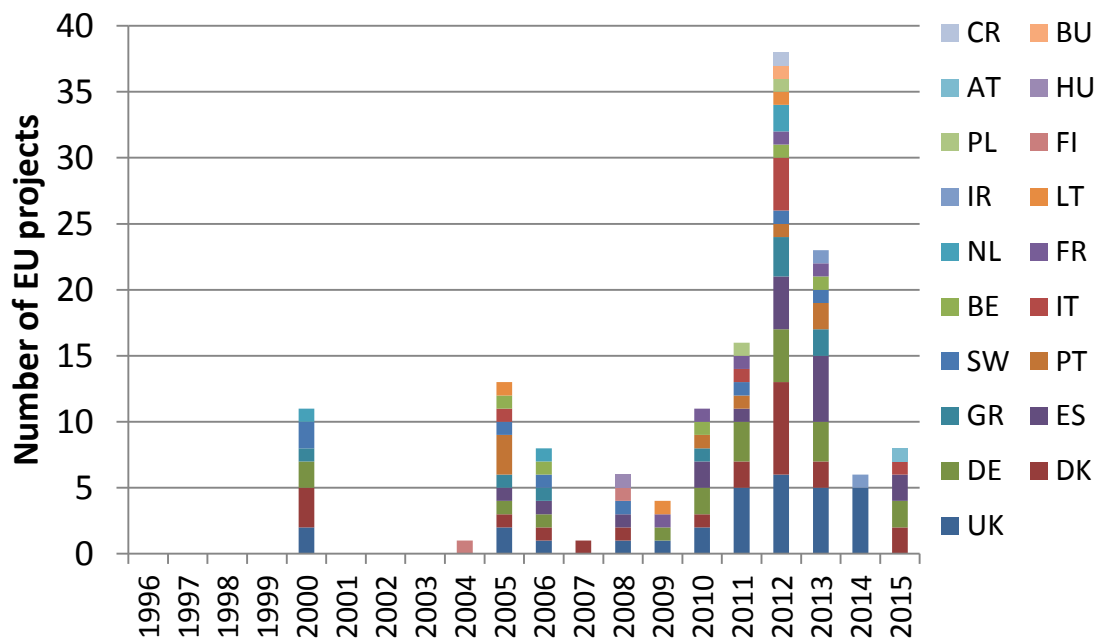


Figure 13 Participation of countries in EU projects (counted by starting date of EU project)

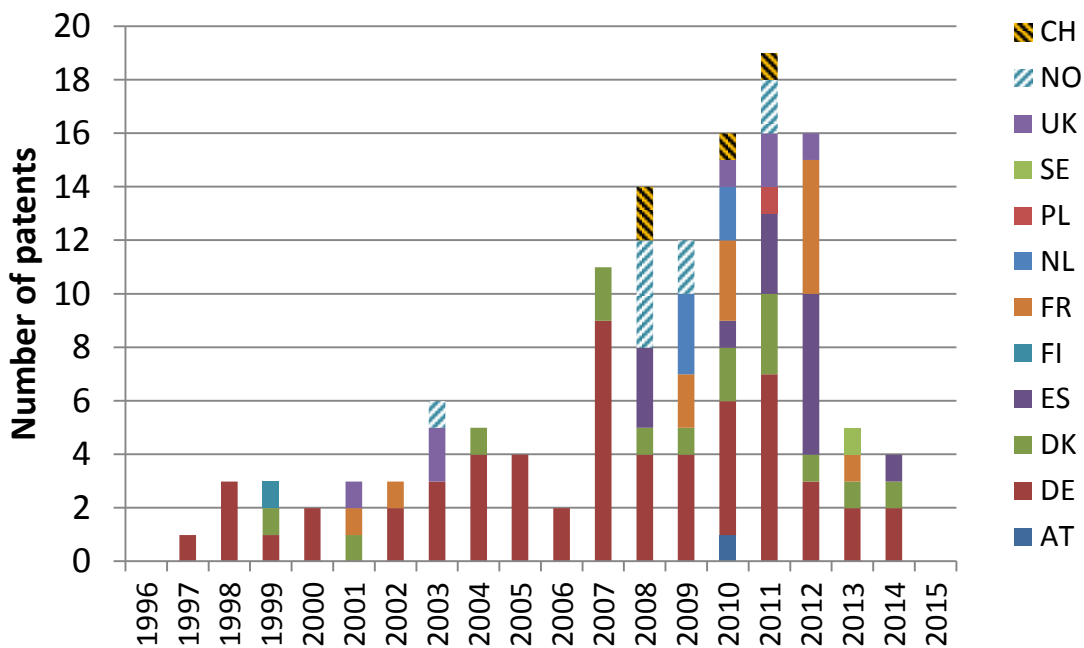


Figure 14 Patents from EEA countries (Patent data incomplete from 2011 onwards)

Finally data exports from TIM are used to detect overlaps in EU participation and patenting. Entities appearing in both export files, EU project participation and patenting, were identified and the start of the EU project participation was compared with the time a patent was issued.

Patents are frequently used as a proxy for innovation even though it is known that companies take internal strategic decisions on whether they file an invention as a patent or not. Therefore the preliminary analysis below is meant only for illustrating possibilities of combining different TIM-based exports to detect innovation trends. The results are highly dependent on the search string used. For the purposes of this report, the search

string design was based preliminary on specific CPC classes in order to filter out as much as possible the results that do not pertain to offshore wind. Discussion on patenting and R&D investment can be found in the innovation literature [35] [36] [37].

Results show that participation in EU projects is dominated by universities (55%) followed by companies (28%) and other research institutes (17%). As shown earlier in Figure 11, these numbers include also entities with geographical location outside the EU. Datasets exported from TIM on patenting activity cover the EEA countries. Patents are mainly issued by EU-based companies accounting for 88% followed by companies from other EEA countries (10%) and EU-based universities (2%). Based on these searches Figure 15 shows the EU entities participating in both EU projects and issuing patents.

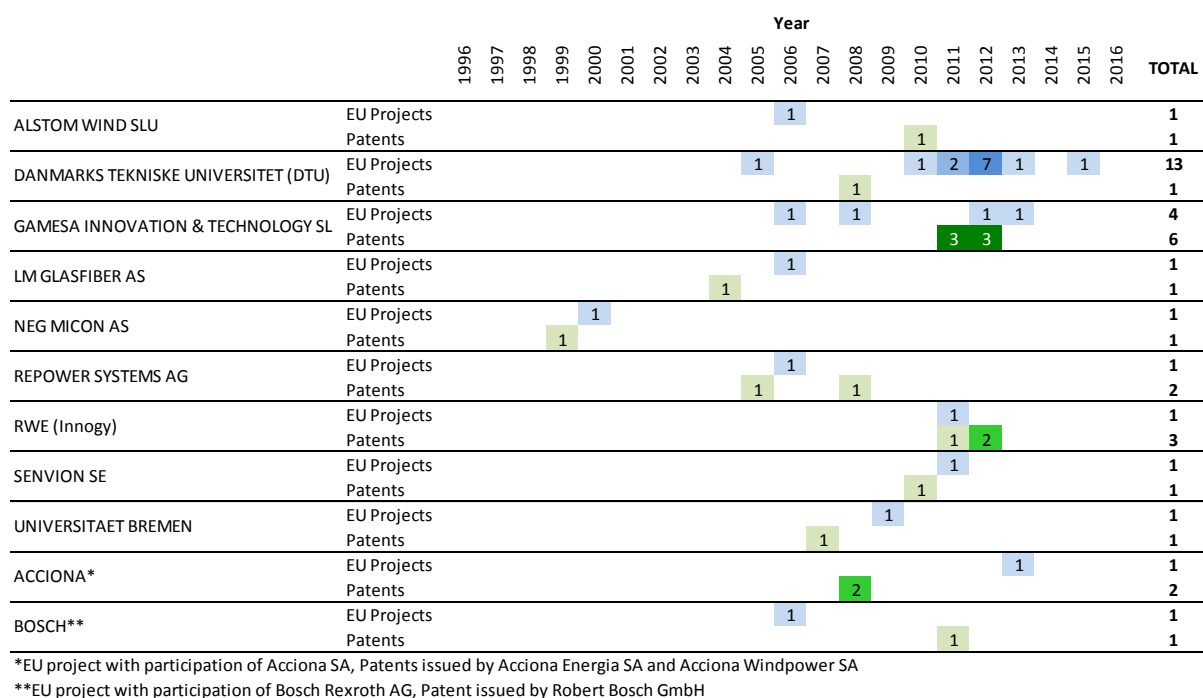


Figure 15 EU entities involved in EU projects and issuing patents (1996 - 2015) (Patent data incomplete from 2011 onwards)

3.2.3 Offshore wind support structures – Selected existing and emerging concepts

The searches performed on the support structure concepts (see Search string 8 and Search string 9) are used to visualise the publication activity for each concept and to identify the main patenting entities. Figure 16 indicates that especially monopiles and floating concepts show increased publication activity in the last years, whereas the search performed on jacket structures leads to a very low number of documents published so far. An increase in both articles and patents can be witnessed for all support structure concepts. Patent data are available until 2011 in view of the fact that there is a 3-4 year time lag between a patent application and the publication of this information in databases such as PATSTAT.

Export of TIM-based data shows that the number of patents issued on monopile concepts is fairly low with KR and JP as the main countries which are active in that field. Contrarily, the sociogram shows that scientific papers on monopiles stem from small networks in the UK, DK, US and CN. Only a limited number of publications and patents was found for jacket support structures with patenting activity by companies from DE, KR, JP and US. The sociogram on floating offshore wind concepts finds small networks, which begin to arise from the periphery of the sociogram. Patenting on floating concepts is dominated by JP, CN, KR.

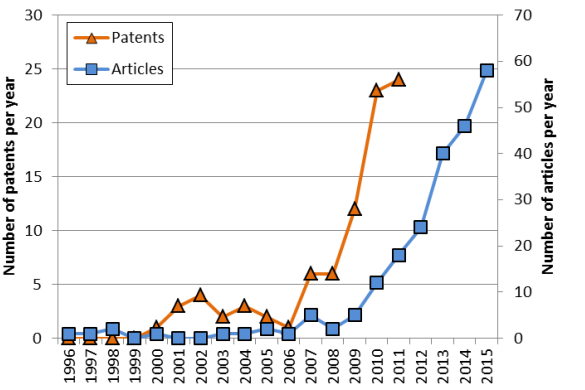
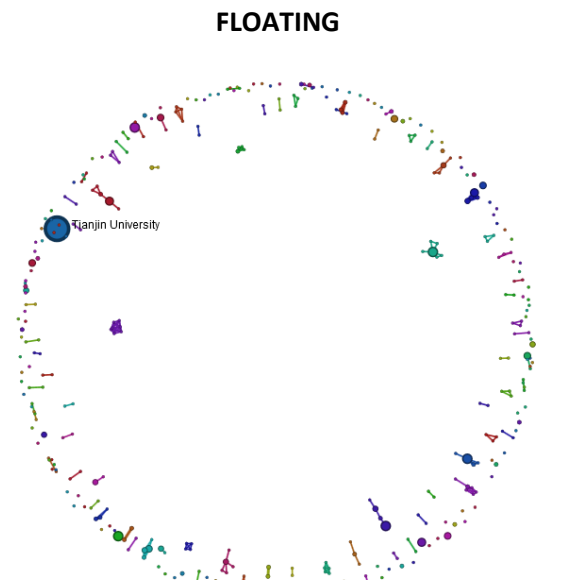
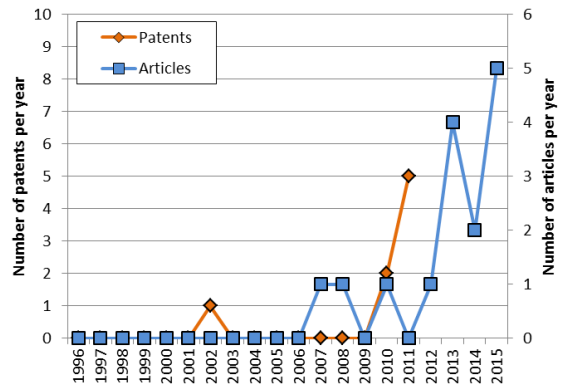
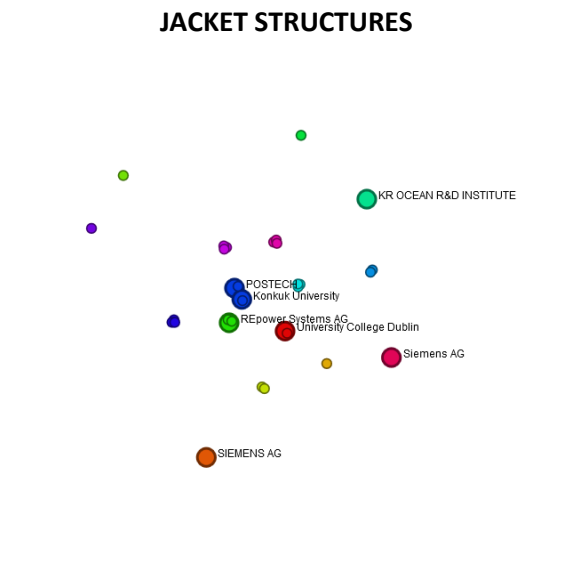
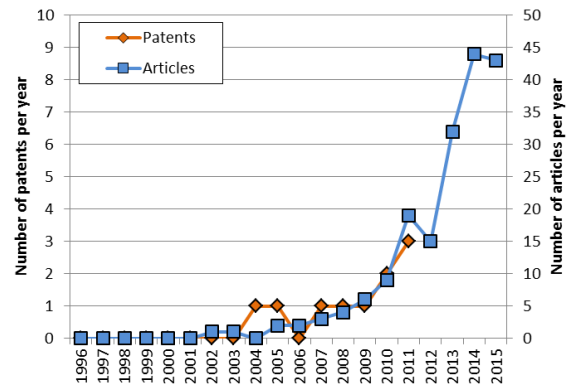
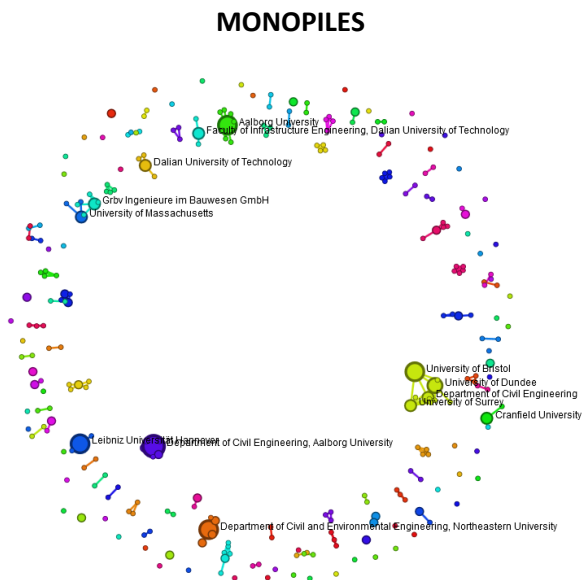


Figure 16 Sociograms on the three investigated support structure concepts and development of articles and patents (Patent data incomplete from 2011 onwards)

Conclusions

This report presents a first overview of how to apply the JRC's Tools for Innovation Monitoring (TIM) software to identify emerging concepts and analyse and visually map collaboration patterns in low carbon energy technologies.

This report presents illustrative examples of possible uses of the JRC-developed TIM software for data analysis and visualisation. It focuses on emerging photovoltaic and offshore wind energy technologies, based on the tailor-designed search strings described in Chapter 2. For emerging photovoltaic (PV) technologies, the search strings hinge upon search terms selected to delineate PV technology as a research field, and subsequently narrow down the results by more specific terms that characterize a specific technology, such as 'perovskite', 'kesterite' or 'roll to roll' (section 2.1). For offshore wind, the tailor-made search strings (section 2.2) complement the use of specific search terms (e.g. 'floating') with filters for e.g. participation in EU projects, country affiliations, CPC patent classes, publication year and/or type.

The results are highly dependent on search string design and availability of custom-dictionaries. Therefore, they should be interpreted as illustrative, non-conclusive examples of analysis and visualisation approaches.

The TIM tool at its current stage of development requires users to be functionally literate in analysis of networks, bibliometrics and inventions, as well as experts on the topic being analysed.

TIM is particularly suited to a rather granular/specialised level of technology, e.g. the offshore wind or emerging PV technologies mapped in this report. Network mapping at the level of individual organisations (companies, e.g. for offshore wind) can be useful for detecting and tracing collaboration patterns, in space and time. This can help position organisations in wider regional or global landscapes, and e.g. track if or how they continue to co-publish after receiving (EU) co-funding. Keyword frequency analysis can help detect and follow emerging trends.

Overall, TIM is a text mining instrument being developed in the JRC for analysis and visualisation of large datasets. It offers an opportunity to better understand and tap into the benefits of text mining, as a first step in the way forward towards a better use of these solutions in policy making.

Continuous collaborative work within the JRC between the text and data mining team and SETIS aims to further improve the performance of TIM-Energy and expand its functionalities. Validation from external experts via crowdsourcing is an essential next step in the development of TIM-Energy.

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List of abbreviations and definitions

- **Bibliometrics:** Quantitative analysis of academic publications. Using academic publications as a data source, bibliometric analysis attempts to answer questions about academic research that lead to a better understanding of how that research is produced, organized, and interrelated. It also attempts to evaluate academic publications - and sets of publications by an author, research group, institution, or country - based on the number of citations these publications have received [38].
- **Boolean operators:** Logical operators to connect and define the relationship between the search terms. Boolean operators are 'AND', 'OR' and 'NOT'.
- **Countrygram:** Visual network map or tabular list generated by TIM showing countries where organisations patenting or publishing are based.
- **CPC:** Cooperative Patent Classification
- **EEA:** European Economic Area
- **Entity:** Organisation, e.g. university, company, research institute...
- **Keywordgram:** Visual network map or tabular list generated by TIM based on keywords. These can be attributed by authors of scientific papers to describe the topic of their paper or else generated by language processing algorithms applied on a dataset.
- **SETIS:** European Strategic Energy Technology (SET-Plan) Information System, run by the JRC
- **Sociogram:** Visual network map or tabular list generated by TIM to show collaboration between organisations (co-)patenting and/or (co-)publishing.
- **TIM:** Tools for Innovation Monitoring

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