European Commission

Second Report on the Clean Energy Innovation Index

Provision of technical assistance and study to support the development of a composite indicator to track clean-energy innovation performance of EU members

Independent Expert Report

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Research and Innovation

Second Report on the Clean Energy Innovation Index

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EUROPEAN COMMISSION

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Trinomics

In association with:

Science-Metrix

cambridge econometrics

clarity from complexity

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Abbreviations

AC	Air conditioning
CCMTs	Climate change mitigation technologies
CCS	Carbon capture and storage
CCUS	Carbon capture utilisation and storage
CEII	Clean energy innovation index
CET	Clean energy technology
CO_2	Carbon dioxide
DEA	Data envelopment analysis
EC	European Commission
EU	European Union
EV	Electric vehicles
FCV	Fuel cell vehicles
GDP	Gross domestic product
GHG	Greenhouse gas
$HCP_{10\%}$	Highly cited publications (those among the 10 % most cited)
HEV	Hybrid electric vehicle
HVP/GDP	High value inventions per unit of GDP
ICE	Internal combustion engine
ICT	Information and communications technology
JRC	Joint Research Centre
JRC-COIN	Joint Research Centre - Competence Centre on Composite Indicators and Scoreboards
LEDs	Light emitting diode
MI	Mission Innovation
MS(s)	Member State(s)
N/A	Not available
OECD	Organisation for Economic Co-operation and Development
PCA	Principal component analysis
PV	Photovoltaic
R&I	Research and innovation
SET Plan	European Strategic Energy Technology Plan
UN	United Nations
VA	Value added

Executive Summary

This report provides the methodology for and calculation of a composite indicator to track clean energy innovation performance of EU27 member states and Mission Innovation (MI) members. The composite indicator (also known as the 'clean energy innovation index' or CEII) covers three core output-related dimensions: scientific publications, patents and trade. The dimensions cover the core R&I activities from research to market innovation:

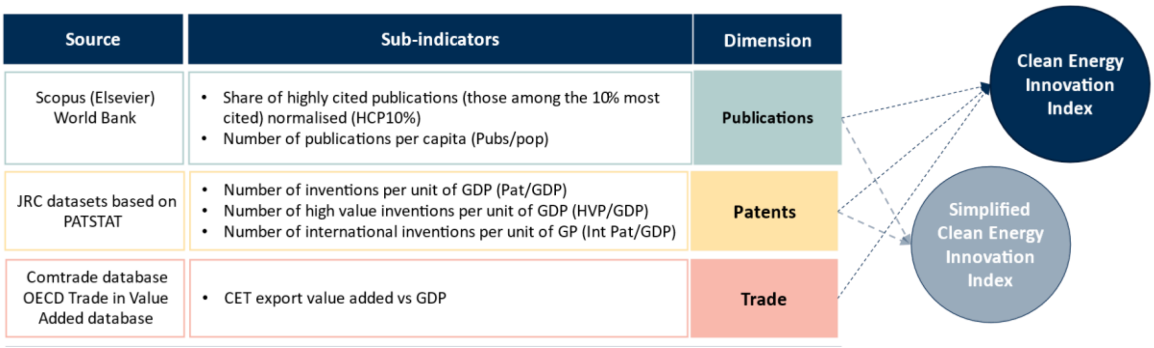
- **Scientific publications** - bibliometrics are an effective way of tracking the scientific output and impact of any entity conducting and/or funding research, particularly basic and applied research;

- **Patents** – the ability to patent an invention is a clear sign of successful innovation activity;

- **Export** - export performance provide a useful measure of the market uptake of clean energy technologies (CET) and development of the technological sectors.

Each of the dimensions is disaggregated by sub indicator (Figure ES.1), but also according to the SET Plan key actions, and by the technologies included in the SET Plan key action "Performant renewable technologies integrated in the system - Reduce technology costs".

Figure ES.1: Key dimensions of the Clean Energy Innovation Index



Once the indicators to be included in the three dimensions of the CEII were selected and calculated for all relevant countries and at the required level of disaggregation, we calculated the CEII following the Commission's JRC-COIN guide[1]. This consisted of compiling the underlying data and calculating the indicators; undergoing data transformations and normalisation; performing statistical coherence tests; weighting and aggregating into the CEII; and finally validating the results using statistical coherence, robustness and sensitivity analyses.

The CEII results indicate a strong performance of the EU27 in clean energy innovation as the top 5 performers in most of the key actions and technologies are EU27 member states. The Scandinavian countries are performing particularly well both at key action as well as at renewable technology level, with Denmark showing an exceptional performance in the wind energy technologies. The Republic of Korea (also referred to as 'South Korea') also performs well among the in-scope countries in several key actions and particularly in key action 7 "Competitive in global battery sector (e-mobility)" and 8 "Renewable fuels". Both the EU27 and MI members have a strong performance in the key action 1 Performant renewable technologies, while "CCUS" and "Nuclear safety" are the key actions that they score the lowest.

1 https://composite-indicators.jrc.ec.europa.eu/?q=10-step-guide

The last section of this report includes an overview of the innovation profiles for some of the major economies at global scale at the three levels of disaggregation. The innovation profiles were constructed by using the three dimensions (publications, patents and export) as a proxy of research, commercialisation and market development. The results provide an overview of how well the countries performed compared to the average of all in-scope countries as well as whether the countries are more focused to a certain phase of innovation activity. The EU27 shows equally distributed efforts in all stages of innovation activities, while the US shows a stronger performance on publications in all key actions and renewable technologies. China, Japan and South Korea are performing particularly well in patents and above average in export in the majority of the key actions.

Some of the outcomes of this study appear to contradict some common assumptions regarding particular countries. For example, the EU27 is commonly considered to be a high performer in publications but a relative underperformer in terms of exports of many technologies, with the exception of wind technologies. However, the analysis of the data indicates that this perception is not correct, with particularly high export values in the majority of the key actions. In addition, the EU27 seems to outperform major key players such as the US and China at all levels of disaggregation, which is not in line with the results of the first-year report. That change is attributed to the code revisions conducted as well as to the indicator used in the export dimension.

1 Introduction

This report is a deliverable of the study to support the development of a composite indicator to track clean energy innovation performance of EU member states and Mission Innovation (MI) members (see Table 1)[2], which contributes to the overarching aim of assessing progress in clean energy innovation by analysing output-related indicators.

Table 1: List of EU27 and MI members

EU27 members		**MI member countries**	
Austria*	Italy*	Australia	Indonesia
Belgium	Latvia	Austria*	Italy*
Bulgaria	Lithuania	Brazil	Japan
Croatia	Luxembourg	Canada	Mexico
Cyprus	Malta	Chile	The Netherlands
Czechia	Netherlands	China	Norway
Denmark*	Poland	Denmark*	Saudi Arabia
Estonia	Portugal	Finland*	South Korea
Finland*	Romania	France*	Sweden*
France*	Slovakia	Germany*	United Arab Emirates
Germany*	Slovenia	India	United Kingdom
Greece	Spain		United States
Hungary	Sweden*		
Ireland			

Aim of the Clean Energy Innovation Index

The composite indicator (also known as the 'clean energy innovation index' or CEII) covers three dimensions: scientific publications, patents and export. The primary objectives of the CEII are three-fold:

- To **track clean energy innovation performance** of EU Member States and Mission Innovation members for the 4+2 priorities of the R&I and competitiveness dimension of the Energy Union, and identify technology-related trends relevant to the RIC pillar of the Energy Union;
- To support the following EC policy instruments or initiatives:
    - Accelerating Clean Energy Innovation;
    - State of the Energy Union report;
    - Strategic Energy Technology Plan.
- To contribute to the Tracking Progress work stream of the Mission Innovation initiative.

[2] The Mission Innovation member countries listed in Table 1 and included in the analysis (referred to as MI-23) are those with MI membership as of the end of 2018 (when the CEII project was designed). Morocco also became an MI member in 2019, and in September 2021, a new phase of MI (MI 2.0) was launched, in which Indonesia and Mexico are not participating. The European Union (EU27) is also a member of MI, but EU27 data are not included in the total values of indicators estimated for the MI category to avoid double counting of seven EU Member States that are also MI members.

The intended audience for the CEII includes policy makers, the research community, the sustainable energy industry and the general public.

Structure of this report

This report covers the work on the methodology and calculation of the CEII and has the following objectives (as detailed in the ToR):

1. Provide the detailed methodological approach to develop the CEII based on the data collected for scientific publications, patents and export in previous work packages;

2. Provide the calculated CEII for the countries and groups of countries in scope.

The report is structured according to these objectives. In chapter 2, we discuss the conceptual framework for the CEII, by introducing the policy context and describing the existing methods for measuring clean energy innovation. The distinction between the three dimensions that constitute CEII is stressed and the challenges for the construction of the composite index are also discussed.

In chapter 3, the methodological steps applied for the construction of the CEII, based on JRC[3] principles are also detailed. Chapter 4 provides insights on the CEII results at country level, as well as at SET Plan and technology level. Finally, chapter 5 presents the innovation system profiles. Annex A includes the CEII dataset.

3 JRC (2008). Handbook on Constructing Composite Indicators

2 CEII Conceptual Framework

This section provides the conceptual framework behind the index. This section begins with an introduction to the policy context and explanation of the overall framework to measure innovation related to clean energy technology (CET). We then focus on the aspects that can be measured given the current data constraints.

2.1 The policy context

The EC established the Energy Union in 2015 with the aim of providing European citizens with secure, sustainable and affordable energy, while positioning Europe at the forefront of the global renewable energy market.[4] Although the work undertaken in this project is relevant to all five pillars of the Energy Union, it focuses on the fifth pillar, that is the research, innovation and competitiveness aspects.

The SET Plan (see Textbox 1) was established to help boost Europe's transition towards a climate neutral energy system with the ultimate goal of fundamentally transforming Europe's energy system in a cost-effective way.[5] In doing so, the SET Plan will deliver on the priorities of the Energy Union by identifying and implementing ten key actions. Accordingly, the CEII must depict progress along each of these ten[6] key actions in monitoring the progress of European and Mission Innovation member countries[7] towards the SET Plan's objectives (especially those focused in R&I performance). This highlights a key limitation in selecting the indicators to be chosen in building the CEII, that is, the data sources must enable the indicators to be disaggregated by each of the SET Plan key actions.

Textbox 1 The SET Plan

The SET Plan supports research and innovation policies that create an **open innovation** ecosystem that capitalises on the results of research and **open science**.[8] It also favours transparency and exchange of information to avoid unnecessary duplication of efforts and to stimulate **cooperation and coordination between Member States**.[9] It also wishes to build synergies between European and national programmes, especially **joint investment programmes** in order to leverage **investment from the private sector**.[10] In the final stage of innovation, regulatory measures are essential to guarantee **large scale market uptake and successful commercialisation of innovation**.[11] **The public also needs to be informed and educated** on how to transition to more efficient energy systems and on how to optimise its energy consumption. European citizens and civil society, as energy consumers, are expected to actively participate in the energy transition and to benefit from it.[12]

[4] European Commission. A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy. Brussels, 25/02/2015, pp. 4–17. https://eur-lex.europa.eu/resource.html?uri=cellar:1bd46c90-bdd4-11e4-bbe1-01aa75ed71a1.0001.03/DOC_1&format=PDF
[5] European Commission. Towards an Integrated Strategic Energy Technology (SET) Plan: Accelerating the European Energy System Transformation. Brussels, 15/09/2015, p. 2. https://ec.europa.eu/energy/sites/ener/files/publication/Complete-A4-setplan.pdf
[6] In this study key action 1 "Performant renewable technologies integrated in the system" and 2 "Reduce technology costs" are merged and treated as one (hereinafter key action 1). Therefore, for the remainder of this report we will refer to 9 key actions.
[7] The EU27 is not included in the CEII for MI (as a group) in order to avoid double counting of European countries.
[8] European Commission. Towards an Integrated Strategic Energy Technology (SET) Plan: Accelerating the European Energy System Transformation. Brussels, 15/09/2015, p. 3. https://ec.europa.eu/energy/sites/ener/files/publication/Complete-A4-setplan.pdf
[9] Ibid. p. 9.
[10] Ibid. p. 4.
[11] Ibid. p. 16.
[12] Ibid. p. 11.

The SET Plan is based on the principle that researchers and companies should be supported through public action, not only to conduct basic research, but all the way through the innovation chain, including the market uptake of innovation. The **private sector**, especially energy producers and suppliers, **is expected to innovate**,[13] and is therefore **also expected to participate in funding its own innovation**, which it will ultimately benefit from, since energy efficiency is now seen as a **business opportunity** that will make Europe more competitive.[14] It also aims to reduce the **cost of energy** for European citizens and organisations.[15] The EC wishes to strengthen the financial commitment from Member States as well as the private sector. At the moment, the EC grants large sums of money to energy-related research, in collaboration with the private sector (through Public-Private Partnerships, for example).[16] In the final stage of innovation, **risk-financing** is also necessary to ensure that innovation gets successfully commercialised at a large scale.[17]

The collaboration aspect has already been mentioned in this report, but its importance should not be neglected. The EC stresses the **necessity of Member States collaborating** not only **among themselves**, but also with the EU **and with other countries** globally. The **public** and the **private** sectors are also strongly encouraged to **collaborate together**. **Collaborations should be fostered throughout the innovation chain**, from funding and conducting basic research, to adapting research to applications, all the way to commercialising the applications for large scale market uptake. The EC wishes **all stakeholders** with common interests and mutual benefits **to coordinate their research, funding and innovation activities** to avoid unnecessary duplication of efforts.[18] In its communication titled "Towards an Integrated Strategic Energy Technology (SET) Plan: Accelerating the European Energy System Transformation", the EC states: "The aim is to avoid working in silos."[19]

The SET Plan's documentation mentions **policy, funding and collaboration** as three essential aspects to implement the SET Plan's innovation goal. These three aspects are intertwined throughout all stages of research, innovation and commercialisation of innovation.

The dimensions highlighted in the previous paragraphs are key to the successful implementation of the SET Plan from its inputs to its longer-term social, economic, and environmental impacts.

2.2 Measuring clean energy innovation

A theoretical framework is the starting point in the construction of a composite indicator, given that theory can play a key part in guiding the choice for the multi-dimensional structure. However, measuring innovation is very complex and challenging. There are several complex models to measure innovation in academic literature. National innovation systems have, for example, been modelled on a so-called triple-helix, with innovation occurring in three different sectors (academic, governmental and private) and involving a

[13] Ibid. p. 2.
[14] Ibid. p. 6.
[15] European Commission. A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy. Brussels, 25/02/2015, p. 2, 11. https://eur-lex.europa.eu/resource.html?uri=cellar:1bd46c90-bdd4-11e4-bbe1-01aa75ed71a1.0001.03/DOC_1&format=PDF
[16] European Commission. Towards an Integrated Strategic Energy Technology (SET) Plan: Accelerating the European Energy System Transformation. Brussels, 15/09/2015, p. 15. https://ec.europa.eu/energy/sites/ener/files/publication/Complete-A4-setplan.pdf
[17] Ibid. p. 14.
[18] Ibid. p. 8.
[19] Ibid. p. 2.

complex set of interactions between them.[20] In essence, these more complex models emphasise that the innovation system cannot be readily understood without its complex interactions between heterogeneous actors, which can be captured through network indicators, as well as its multiple feedback loops, which are much more difficult to grasp[21] through the simple use of indicators.

As such, there are a number of aspects that play a role in a measurement framework for the CEII. For instance, one can make a clear distinction between the wider framework conditions that are conducive to innovation (e.g., indicators of macro-economic stability, basic scientific skills, business regulations, infrastructure and financial markets), innovation indicators per se (i.e., which are covered broadly in this study, including those part of the CEII), and the social, economic and environmental outcomes to which innovation contributes. Note that the triple-helix nature of the innovation process can also be captured through integration of network indicators (e.g., joint investment programmes, public/private co-publications) across the different stages (e.g., inputs, throughputs, and outputs) of the innovation chain.

Others have attempted to create measurement frameworks for innovation: including the conceptual models of the Innovation Output Indicator 2017[22], the European Innovation Scoreboard 2018[23] and the Global Innovation Index[24]. Existing indicators tend to follow the linear model of innovation while incorporating interactions between government, academia and industry in specific indicators in the different sections of the innovation chain. The European Innovation Scoreboard, for example, captures framework conditions, investments, innovation activities and impacts; while the Global Innovation Index is split between innovation input and output sub-indices.

This measurement framework should be informed by R&I policies specific to clean energy innovation since the purpose of the future index is to track clean energy innovation performance of EU27 Member States and Mission Innovation countries for each of the SET Plan key actions. The goal is to build a solid knowledge base on progress towards the 4+2 priorities of the R&I and competitiveness dimension of the Energy Union. However, many of the necessary indicators to be included in an 'ideal' measurement framework for innovation are not readily available and are difficult to produce with existing data for each SET Plan key action.

This project focuses on three core output-related dimensions, scientific publications, patents and export statistics, to evaluate the EU's and MI members' performance in clean energy innovation.

2.3 Dimensions of the Clean Energy Innovation Index

Given that one of the key drivers for this index is the need to access complete and robust data by SET Plan key action, the CEII focusses on three dimensions for which relevant indicators and data are available by key action; several other relevant indicators are not available at the required level of disaggregation. The dimensions cover the core R&I activities from research to market innovation:

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[20] Lowe, C.U., 1982; Leydesdorff & Etzkowitz, 1998; OECD, 2010a; Hekkert et al, 2017

[21] Understanding such feedback loops require more advanced statistical modelling (for example using structural equation modelling) which cannot be summarised in a composite indicator. Such modelling is beyond scope of the CEII.

[22] Vertesy, D. (2017). The Innovation Output Indicator 2017: Methodology Report Publications Office of the European Union. Luxembourg, ISBN: 978-92-79-76474-5. http://publications.jrc.ec.europa.eu/repository/bitstream/JRC108942/jrc108942_ioi_2017_report_final.pdf

[23] European Commission (2018). European Innovation Scoreboard 2018. Luxembourg, ISBN: 978-92-79-77622-9. https://ec.europa.eu/docsroom/documents/33147/attachments/1/translations/en/renditions/native

[24] Cornell University – INSEAD - WIPO (2019). Global Innovation Index 2019: Creating Healthy Lives—The Future of Medical Innovation. Annex I – Conceptual framework. https://www.globalinnovationindex.org/gii-2019-report#

- **Scientific publications** - bibliometrics are an effective way of tracking the scientific output and impact of any entity conducting and/or funding research, particularly basic and applied research;
- **Patents** – the ability to patent an invention is a clear sign of successful innovation activity;
- **Export** - export performance can provide a useful measure of the market uptake of clean energy technologies (CET) and development of the technological sectors.

The three dimensions are grouped into the CEII (or, the scientific publications and patents dimensions into the simplified CEII). Figure 1 provides the structure of the index and the indicators considered (resulting from the different Work Packages).

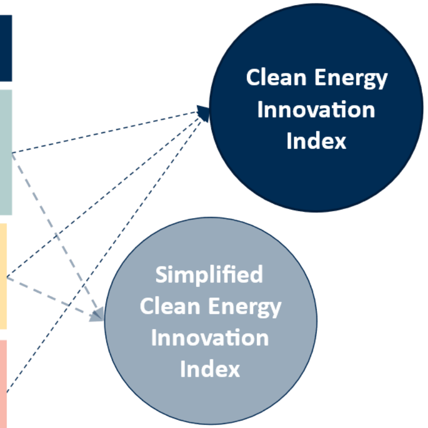
Disaggregation of the different dimensions

Each of the dimensions is disaggregated by sub indicator, but also according to the SET Plan key actions, and by the technologies included in the SET Plan key action "Performant renewable technologies integrated in the system - Reduce technology costs". The table below, adapted from the JRC's report[25], outlines the scope of clean energy research/technologies to be covered by each of the nine SET Plan key actions for the publication, patent and export data. Annex 1 of the JRC's report provides a more detailed definition of the SET Plan key actions.

[25] JRC (2017). Monitoring R&I in low-carbon energy technologies.

Figure 1: Key dimensions of the Clean Energy Innovation Index.

Source	Sub-indicators	Dimension
Scopus (Elsevier) World Bank	• Share of highly cited publications (those among the 10% most cited) normalised (HCP10%) • Number of publications per capita (Pubs/pop)	Publications
JRC datasets based on PATSTAT	• Number of inventions per unit of GDP (Pat/GDP) • Number of high value inventions per unit of GDP (HVP/GDP) • Number of international inventions per unit of GP (Int Pat/GDP)	Patents
Comtrade database OECD Trade in Value Added database	• CET export value added vs GDP	Exports
Supporting dashboard of indicators		
Scopus (Elsevier) 1findr (1science) World Bank	• Number of publications per capita • Specialisation index • Share of international copublications • Share of public/private copublications • Share of open access publications • Share of highly cited publications at the 10% level	Publications
JRC datasets based on PATSTAT	• Inventions (abs. and per unit of GDP) • Granted inventions (abs. and per unit of GDP) • High value inventions (abs. and per unit of GDP) • International inventions (abs. and per unit of GDP)	Patents
Comtrade database (+ Comext database for EU MSs)	• CET exports vs GDP • High-tech export	Exports



Disaggregated by SET Plan Key Actions
01 & 02. Performant renewable technologies- Reduce costs
03. New technologies & services for consumers
04. Resilience & security of the energy system
05. New materials & technologies for buildings
06. Energy efficiency in industry
07. Competitive in global battery sector (emobility)
08. Renewable fuels
09. Carbon capture Utilisation and Storage (CCS/U)
10. Nuclear safety

Disaggregated by SET Plan Key Action Performant Renewable Technologies
1. Solar energy
2. Geothermal Energy
3. Hydroenergy
4. Ocean Energy
5. Wind energy

Note: Export data on Key action 4. Resilience & security of the energy system, and in Performant Renewable Technology 4. Ocean was not available.

Table 2: Mapping of topics within the Energy Union R&I and Competitiveness priorities, produced by SETIS[26]

Energy Union R&I priority	SET Plan (key actions)	Publications technologies	Patents technologies	Export technologies
Number 1 in renewables	1. Performant renewables	Solar energy	Solar energy (PV + Concentrated solar power)	Solar energy (PV+ Solar thermal)
		Wind	Wind	Wind
		Hydroenergy	Hydroenergy	Hydroenergy
		Geothermal	Geothermal	Geothermal
		Ocean	Ocean	N/A
Smart system – Smart EU energy system with consumers at the centre	3. New technologies & services for consumers[27]	Energy management systems (including smart meters) and ICT	Efficient end-user side electric power management and consumption & Others	Smart meters
		Heating, cooling and ventilation technologies (including AC, water heaters	Energy efficient heating, ventilation or air conditioning	N/A
		Lighting technologies and control systems (including halogen lamps, LEDs)	Energy efficient lighting technologies	N/A
		Residential and commercial building appliances and equipment (including batteries for portable devices)	Home appliances & elevators, escalators and moving walkways	N/A
		N/A	ICT aiming at the reduction of own energy use & Market activities	N/A
		N/A	Systems supporting end-user of stationary applications & in the sector of transportation	N/A
		Combustion technologies, coal, oil and gas	Combustion technologies with mitigation potential	Clean coal & gas

[26] Adapted from the JRC's "Monitoring R&I in low-carbon energy technologies," 2017, in which this allocation was applied to the extent made possible by the structure and granularity of publicly available data.
[27] Based on the JRC's mapping of CPC codes to the SET Plan key actions, key action-2 covers smart solutions for energy consumers and new technologies aimed at improving/reducing energy consumption. In this scheme, aspects of smart applications, tools and integrated energy management for consumers, as well as energy efficient technologies (LEDs/halogen lamps) are considered.

	4. Resilience & security of the energy system[28]	Electric power generation	Adapting or protecting infrastructure or their operation in energy generation or distribution	N/A
		Electricity transmission and distribution	Efficient electrical power generation, transmission or distribution	
		N/A	Enabling technologies to GHG emissions mitigation and Others	
		Grid communication, control systems and integration	Systems supporting electrical power generation, transmission or distribution and ICT	
		Energy storage: non-transport applications; thermal, electromagnetic and mechanical storage; batteries and other stationary electrochemical storage (excluding vehicles and general public portable devices)	N/A	
		Energy system analysis		
Efficient energy systems	5. New materials & technologies for buildings	Efficient heating, cooling and ventilation technologies (refers to the structure/envelope, thermodynamic and technology of the facility, and to some external equipment such as heat pumps but not to the indoor equipment, such as AC systems, water heaters)	N/A	Heating
		Design and envelope: improving thermal performance	Adapting or protecting infrastructure or their operation in buildings, dwellings, or related infrastructures	Insulation
		Integration of renewables (hybrid systems, PV, solar thermal, wind power, etc.)	Integration of renewables in buildings	N/A
		N/A	Passive houses technology & elements improving the thermal performance of buildings	N/A
		Energy efficient heat pumps and chillers	N/A	N/A

[28] key action-3 covers energy efficient systems specifically in grids and cities.

	7. Energy efficiency in industry	Industrial techniques and processes, equipment and systems for energy efficiency: process efficiency in metal, chemical, oil, minerals, agroalimentary processing (i.e., reduction of GHG emissions/waste, better storage, transport)	CCMTs for production process for final industrial or consumer products	N/A
		N/A	CCMTs for sector-wide applications & Others	
			Conservation, efficient supply or use, relating to industrial water supply	
			Food processing	
		Waste heat recovery and utilization	Heat recovery other than air pre-heating	
		N/A	Technologies related to metal processing	
			Technologies relating to chemical industry	
			Technologies relating to oil refining and petrochemical industry	
			Technologies relating to the processing of minerals	
		Efficient energy usage, usage of renewables	N/A	
Sustainable transport	8. Renewable fuels	Biofuel production and use	Biofuels & Fuel from waste	Biofuels
		Hydrogen technology and fuel cell technology	Hydrogen technology & Application to transportation	Hydrogen technology
			Fuel cells & Application to transportation & in buildings	Fuel cells
			Hydrogen technology & Application to transportation	Hydrogen technology
		Advanced power electronics, motors and EV/HEV/FCV systems, and combustion engines	Internal combustion engine [ICE] based vehicles	Energy Storage and electric powertrains
		Waste management (reuse, recycling, recovering technologies)	N/A	

		Battery technology for transport (vehicles, railway, aeronautics, air)	Battery technology & Recycling of batteries	
		Storage for electromobility, fast charging technology	Efficient propulsion technologies & Energy recovery propulsion system in locomotives or motor railcars	
		Electric vehicle infrastructure	Road transport of goods or passengers	
			Technologies related to electric vehicle charging	
		Solid waste management, second-use, recycling	N/A	N/A
Carbon capture, utilisation and storage (CCUS)	9. CCS/U	CO2 capture, transport, utilisation, combustion and storage	CCS	Carbon capture, utilisation and storage (CCUS)
		Reduction of GHG emissions (also in key action-5)	N/A	N/A
Nuclear safety	10. Nuclear safety[29]	Safety, integrity, environmental protection	Nuclear safety	Nuclear energy
		Waste management, decommissioning, reprocessing, recycling		
		Nuclear fission/fusion (reactors, fuel cycle, fusion energy within tokamaks)		
		Efficiency, sustainability		N/A
		Innovation, development and assessment of technology, new generation reactors		

[29] Key action-10 does not relate solely on nuclear safety and waste management as its label suggests. It also covers technologies for nuclear energy (fusion, reactors).

2.4 Key challenges in creating the CEII

When dealing with a composite index, there are several issues and peculiarities that need to be considered for proper interpretation of the data. In this section, we discuss the main issues and challenges, namely the choice of the different dimensions, subdimensions and indicators to be used in the composite index; their weighting; and the presentation of the results.

Structure of the index

The construction of the tool involves stages in which choices based on expert judgements were made including the selection of dimensions, sub-dimensions and indicators, as well as methodological choices throughout the process. In order to aid transparency these choices are documented in this report. Different existing innovation indices and relevant literature on innovation has been reviewed to define the 'ideal' framework to measure innovation. Limitations regarding data availability have led to a more simplified approach for the CEII. Additional robustness and coherence checks have been performed to ensure the selected dimensions and indicators are appropriate.

Weighting

One of the main issues in the construction of a composite index is the weighting given to each dimension and indicator. This is often a subjective choice which may lead to a similarly subjective valuation of the different dimensions of the index. As such, an unbiased and transparent choice for the weighting is key. The previous report on the CEII methodology describes the alternatives weighting approaches considered for the CEII, along with the testing performed and our final weighting selection. The Excel tool (See annex) allows for the end-user to modify the weightings for both the dimensions and the indicators within them, according to their own preferences, showing the results in a graphic and intuitive way. This mirrors the approach adopted by the OECD's better life index.[30]

Presentation of the results

One of the main benefits of an index is the simplification of information for ease in decision making. However, the simple 'big picture' results which the index shows may create a risk of misinterpretation of the results due to aggregation and may invite decision-makers and stakeholders to draw simplistic policy conclusions. Therefore, as with any indicator, the index should be used in combination with contextual information and with granular information regarding the three dimensions as well as sub-indicators and context indicators to draw detailed policy conclusions.

30 http://www.oecdbetterlifeindex.org/

3 Methodology for the Construction of the CEII

Once the indicators to be included in the three dimensions of the CEII were selected and calculated for all relevant countries and at the required level of disaggregation, we calculated the CEII following the Commission's JRC-COIN guide[31]. The following sections describe the steps taken in preparing the indicators for inclusion in the CEII. After each step, we went back to the data in an iterative process, to ensure that the CEII is robust and coherent, and that it includes the right data to measure clean energy innovation.

3.1 Compile the underlying data and calculate the indicators

The first steps were performed as part of the dimension specific Work Packages. The raw data was compiled, and indicators were calculated as described in Table 3.

Table 3: Overview of selected indicators per dimension

Dimension	Indicator name	Description & calculation	Data source
Publications	Share of highly cited publications (those among the 10 % most cited) normalised ($HCP_{10\%}$)	The number of citations received by publications is a proxy for measuring contributions to subsequent knowledge generation; however, because citation practices vary between the disciplines of science, a simple count inevitably creates biases. To correct this shortcoming, the number of citations of each publication is normalised by field, publication type and publication year. This measure is known as the relative citation (RC) score. The 10 % most cited articles are determined by their RC scores instead of their raw number of citations. The share of scientific publications among the 10 % most cited is the number of scientific publications among the 10 % most cited proportional to the total number of scientific publications. Fractional counting (across authors and key actions) is used, and self-citations are excluded. It is calculated for each Member State and country with Mission Innovation membership as follows: $$\boldsymbol{Share\ of\ pubs.among\ 10\%\ most\ cited} = \frac{\boldsymbol{X_{10\%}}}{\boldsymbol{X_T}}$$ Where: $\boldsymbol{X_{10\%}}$ Number of publications for entity *X* (e.g. Belgium) that are among the 10 % most cited according to their RC scores $\boldsymbol{X_T}$ Total number of publications with a RC score for entity *X*	Scopus (Elsevier)
	Number of publications per capita (Pubs/pop)	The number of scientific publications obtained using fractional counting across authors and key actions, also referred to as output, is measured for each EU27 member and MIM. It is weighted by the population of each country.	Scopus (Elsevier), World Bank
Patents	Number of inventions per unit of GDP (Pat/GDP)	The number of patent applications weighted by the GDP of the countries.	JRC, World Bank
	Number of high value inventions per unit of GDP (HVP/GDP)	The high value inventions are inventions for which patents are filed at multiple patent offices. The indicator is weighted by the GDP of the countries. It indicates the inventions with high market value since filing patents at more than one patent office entails more effort and costs for the applicant.	JRC, World Bank

31 https://composite-indicators.jrc.ec.europa.eu/?q=10-step-guide

	Number of international inventions per unit of GDP (Int Pat/GDP)	International inventions are defined as those with patent applications where the country of the applicant differs from the country of the patent office. The indicator is weighted by the GDP of the countries. Filing patents in more than one country entails more effort and costs for the applicants and may be considered as an indication that the invention is valuable.	JRC, World Bank
Export	CET export value added vs GDP	The indicator measures the domestic contribution to exported CET products, measured against the value of the country's total productive capacities available (the output of which is GDP). The indicator gives a proxy of current embeddedness in global value chains of CETs. It also reflects the domestic value-added content of CET exports, and provides insight regarding a country's actual ability for local production and related to that, the future deployment of CETs. This indicator can provide an insight into the potential for future domestic industry development. The indicator is calculated as follows: Value of domestic value added embedded in CET products exports (in USD and current prices) reflecting value added content of exports of CET products is measured in proportion of country GDP (PPP).	UN Comtrade database, OECD Trade in Value Added (TiVA) database, World Bank

Additional indicators which were also considered are listed below (Table 4). These indicators have been included as supporting indicators for the CEII. Other indicators which were not deemed adequate are further explored in the specific reports for each dimension.

Table 4: Overview of supporting indicators

Dimension	Indicator name	Description & calculation	Data source
Publications	Specialisation index	The specialisation index represents the scientific output of a given entity (e.g. a Member State) in a given research area (e.g. nuclear safety) relative to the intensity in a reference entity (e.g. the world) in the same research area. In other words, when an entity is specialised in an area, it puts more emphasis, relative to the reference entity, on that area at the expense of others. Specialisation is therefore said to be a zero-sum game: the more an entity specialises in an area, the less it does in another. Fractional counting of publications across authors and key actions is used to ensure a true zero-sum game. It is calculated as follows: $SI = \frac{X_S/X_T}{N_S/N_T}$ Where: X_S Number of publications in for entity X in a given research area (e.g. Belgium publications in nuclear safety) X_T Total number of publications for entity X (e.g. all Belgium publications) N_S Number of publications for reference entity N in a given research area (e.g. world publications in nuclear safety) N_T Total number of publications for reference entity N (e.g. all world publications)	Scopus (Elsevier)

	Share of international scientific co-publications	The number of international scientific co-publications is the number of publications that include at least two authors affiliated to different countries. The share is the number of international scientific co-publications proportional to the total number of scientific publications. Publications are fractioned across key actions but not authors. It is calculated for each EU27 member and MI as follows: $$SIP = \frac{X_I}{X_T}$$ Where: X_I Number of publications for entity X (e.g. Belgium) that include at least one author affiliated to another country X_T Total number of publications for entity X	Scopus (Elsevier)
	Share of open access scientific publications	The number of open access scientific publications is the number of publications that are publicly and freely available online without any barriers, either through the publisher (known as gold open access), or through a repository or a personal website (known as green open access). The share of open access scientific publications is the number of open access scientific publications proportional to the total number of scientific publications. Publications are fractioned across key actions but not authors. It is calculated for each EU27 member and MI as follows: $$SOA = \frac{X_{OA}}{X_T}$$ Where: X_{OA} Number of publications for entity X (e.g. Belgium) that are available in open access X_T Total number of publications for entity X	Scopus (Elsevier), 1findr
	Share of public/private scientific co-publications	The number of public/private scientific co-publications is the number of publications that include at least one author affiliated to the public sector (academic, government) and one author affiliated to the private sector (firms, corporations). The share of public/private scientific co-publications is the number of public/private scientific co-publications proportional to the total number of scientific publications. Publications are fractioned across key actions but not authors. It is calculated for each EU27 member and MI as follows: $$SPP = \frac{X_{PP}}{X_T}$$ Where: X_{PP} Number of publications for entity X (e.g. Belgium) that include at least one author affiliated to the public sector and one author affiliated to the private sector X_T Total number of publications for entity X	Scopus (Elsevier)
Patents	Number of inventions	This indicator represents the number of applications for patents in a country.	JRC
	Number of high value inventions	This indicator represents the number of patents applications filed at multiple patent offices, indicating high market value.	JRC

	Number of international inventions	International patent applications are defined as those where the country of the applicant differs from the country of the patent office; because applying for patents in more than one country is more costly, these patents can be regarded as more valuable.	JRC
	Number of granted inventions	This indicator represents the number of inventions that have met a certain minimum quality level in terms of novelty and uniqueness and thereby eliminates several low(er) quality patent applications. It is measured for EU27 and MI members.	JRC
Export	High-tech export (High-tech exp)	The indicator measures the technological competitiveness of the observed countries, i.e. the ability to commercialise the results of research and development (R&D) and innovation in international markets. Creating, exploiting and commercialising new technologies are vital for the competitiveness of a country in the modern economy.	UN Comtrade database

Compared to the previous CEII report, there was a significant change in the trade dimension (see Textbox 2).

Textbox 2 Revision of the export dimension

The indicators proposed for the export sub-index previously showed a negative correlation and were implicitly conflicting. Therefore, for this revision we have replaced the indicators with the CET export value added vs GDP. The new indicator measures the domestic contribution to exported CET products, measured against the value of GDP. The indicator shows the domestic contribution in CET exports relative to all the resources available in the country (GDP). Detailed correlation analyses of this new indicator were included in the previous CEII report. The previous indicators (CET exports/GDP and High-tech exports) have been kept as part of the supporting dashboard.

It is also important to highlight that there have been some changes to the HS product codes used for the assessment of export in CET categories. The most important changes in the HS codes from year 1 to year 2 are the following:

- *Codes related to 'Other gas turbines' (HS 2012 841181, 841182) have been excluded as there is not substantive evidence suggesting that the majority of exported products in this category are used in natural gas power plants that would crowd out coal power plants (hence leading to net carbon emission reductions).*

- *Codes related to 'Ethyl alcohol' (previously used to assess export in Biofuels, HS 2012 220710, 220720) were excluded because they most likely capture exports of first-generation biofuels, hence it is a code capturing flows of 'fuels' and not technologies.*

- *Hydrogen (HS 2012 280410).*

- *Several codes related to 'Electrical transformers' (HS 2012 850421, 850422, or 850423) have been excluded as they were assessed likely to capture products used in the combustion of fossil-fuels or non-energy related.*

- *New trade codes have been included, such as those related to 'Electric accumulators' (used for Energy storage) and 'Electrical machines and apparatus' (used for Hydrogen technology), such as HS 2012 850750, 850780, 854330, 854370. Overall, 50 HS codes have been selected and mapped to the assessed clean energy technologies for the second year of indicator calculation.*

These changes led also to some differences in the results calculated for the last year and those presented in this report. In particular, changes in the EU results vs US results are explained by a combination of code revisions and the new export indicator being measured vs country GDP (which was not the case in the first year's indicator calculation).

3.2 Data treatment & normalisation

3.2.1 Unreliable and missing data points

During the work under the dimension specific Work Packages, the data was checked for unreliable and missing data points. The data sets used have some gaps, especially at the more disaggregated levels (SET Plan key action and renewable energy technologies). Some of the key data gaps are as follows:

- The HCP10% indicator is missing values for several countries and disaggregation levels. This is because, by definition, the share of HCP10% includes a small share of publications, which can cause important year-to-year fluctuations at the country level that might not capture true performance. For that reason, the share of HCP10% was only calculated for countries and disaggregation levels that have published at least 30 publications (with an RC score) in any given year;

- The HCP10% indicator is not available for Malta, as a result, the CEII cannot be calculated for this country at any level of disaggregation.

- There are no values for export indicators for the SET key action 4 'Resilience & security of the energy system' (the reason why this key action was not included was that codes related to this specific key action - mostly codes related to gas turbines - were not deemed consistent with a definition of "clean energy" based on low-carbon technologies), nor for the renewable technology 'Ocean';

- There are missing values for several countries in the three dimensions for SET key action 'Carbon Capture Utilisation and Storage (CCUS)' and 'Nuclear Safety'. As a result, the CEII can only be calculated for half of the countries (17 and 9 countries out of 42 respectively) for these SET key actions at this disaggregation level;

- RES technologies 'Geothermal' and 'Hydroenergy' are missing values for the majority of the countries, mainly in indicator HCP10%, but also in the three patent indicators. As a result, the coverage of the CEII for these technologies is very limited.

The export data set was complete for all the considered indicators, with the exception of the Value Added vs exports (VA/exports) indicator for which no data were available for the United Arab Emirates. In order to address this, Saudi Arabia was used as a proxy since they are countries with a similar industry structure/trade characteristics. Regarding publication data, no missing data were identified, while outlier and break in series tests were conducted to detect any problematic data points (these are detailed in the Publication Dimension Report[32]).In addition, the data set for the patents dimension is complete up to 2017[33], therefore the results of CEII regard the period 2015-2017.

[32] Publications as a measure of innovation performance: Selection and assessment of publication indicators. Submitted August 2020.

[33] The patents data are based on PATSTAT database 2021 spring version, in which the dataset for 2018 is incomplete. For that reason, this year is excluded from the presentation of the results.

When data is not available for one country at the indicator level, the dimension sub-index and CEII have not been calculated for that country, allowing the rest of the countries to be compared using the CEII (as all the countries have the same data coverage of indicators).

3.2.2 *Data transformations*

As part of the verification and validation of data, we tested the distributions of each indicator to identify those with highly skewed data via graphical inspection of the data and statistical rules based on skewness and kurtosis.[34] Table 5 presents the overview of the transformations selected per indicator.

Table 5: Overview of transformations for highly skewed indicators

Dimension	Indicator name	Transformation
Publications	Share of highly cited publications (those among the 10 % most cited) normalised ($HCP_{10\%}$)	None
	Number of publications per capita (Pubs/pop)	Square root
Patents	Number of inventions per unit of GDP (Pat/GDP)	log(x+1)
	Number of high value inventions per unit of GDP (HVP/GDP)	log(x+1)
	Number of international inventions per unit of GDP (Int Pat/GDP)	log(x+1)
Export	CET exp. VA vs GDP	Square root

3.2.3 *Normalisation*

Once the skewed data was accounted for and transformed accordingly, the country scores were normalised for each of the indicators using the following formula:

$$\frac{S_X - S_{min}}{S_{max} - S_{min}}$$

Where:

S_X Score for entity *X* (e.g. Belgium);

S_{min} Minimum score among the distribution of entities;

S_{max} Maximum score among the distribution of entities.

This normalisation was performed using the minimum and maximum scores across years 2015-2017 and countries to allow for the cross-comparison of countries as well as to allow for the analysis of trends. As a result, all indicators are on a comparable scale (i.e., between 0, the worst performance, and 1, the best performance) prior to aggregating the countries' scores across indicators into the CEII.

[34] As a rule of thumb, the indicators that had a skewness higher than 1 were transformed to shape their distribution closer to the normal "bell curve".

3.3 Statistical coherence of individual indicators

Linear Correlation between the levels of the CEII and Multivariate analysis were used to test for the impact of each data item, to ensure that the data items that account for the widest span of clean energy innovation performance variance were selected while redundancy was controlled. This process is intended to identify the set of baseline conditions that influence clean energy innovation to the greatest extent.

The CEII was designed to combine a small, yet highly informative set of innovation performance indicators for each of its three core dimensions (i.e. publications, patents and export). After the normalisation of data, we conducted correlation analysis of the indicators within each dimension, as well as across dimensions to ensure each indicator provided useful and additional information. Finally, a multivariate analysis was conducted using Principal Component Analysis (PCA)[35] to test for the impact of each data item, to check how they are associated and to ensure that the data items that explain the greatest share of variance in clean energy innovation performance are selected, while redundancy is controlled. Detailed results were presented in the previous CEII report.

3.4 Weighting & aggregation

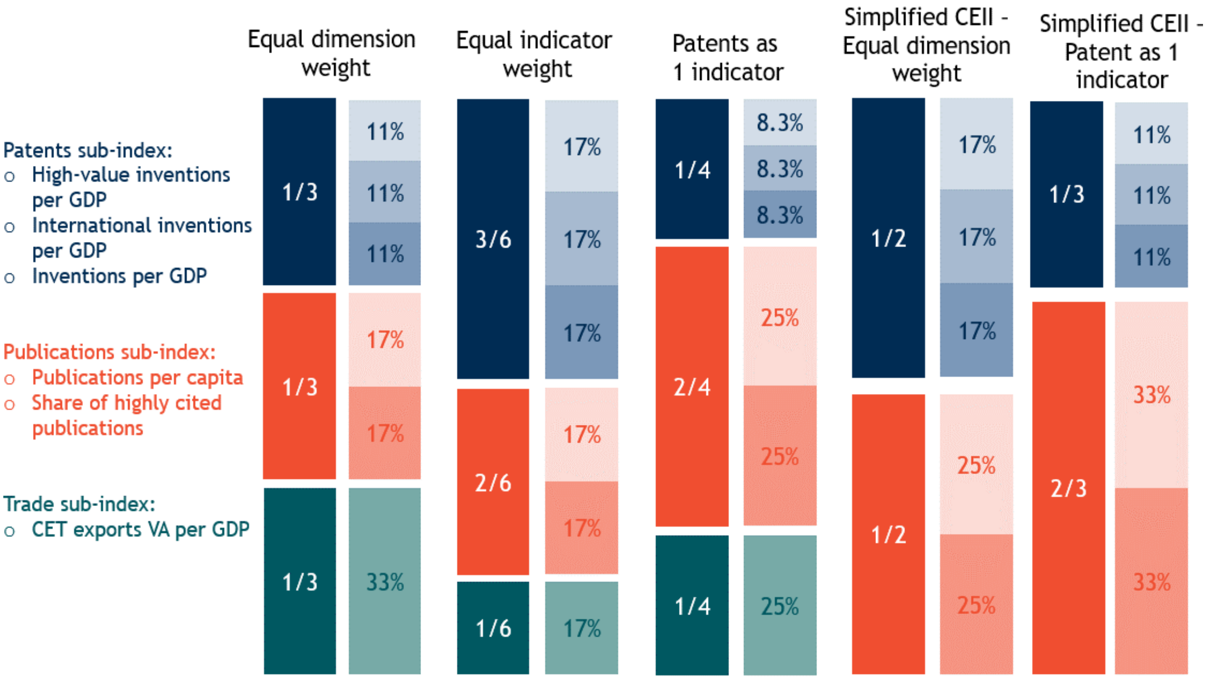
A number of weighting approaches[36] were tested using exploratory data envelopment analysis (DEA), using a 'benefit-of-the-doubt' (BoD) approach, as well as data envelopment analysis benchmarking and additional sensitivity analysis to assess the effect of weighting options in the CEII country rankings (detailed results were presented in the previous CEII report). Based on these analyses, the weighting approach, which considers the three patents indicators as one indicator, was selected. This option aims to account for the high correlation among the three patent indicators by giving them a lower weight (i.e. considering them all together as one indicator). The weighting has been combined with the aggregation using weighted arithmetic mean (or average) of the normalised indicators.

The diagram below shows the different weighting approaches analysed and available in the CEII tool.

[35] With the use of the web tool https://biit.cs.ut.ee/clustvis/ . The full methodology can be found in Metsalu, Tauno and Vilo, Jaak. Clustvis: a web tool for visualizing clustering of multivariate data using Principal Component Analysis and heatmap. Nucleic Acids Research, 43(W1):W566–W570, 2015. doi: 10.1093/nar/gkv468.

36 This included 1) equal dimension weight; 2) equal indicator weight and 3) limiting the weight of patent indicators.

Figure 2 : Weighting options



3.5 Statistical coherence, robustness and sensitivity analyses

To validate the composite index, we analysed the patterns of **correlation** between the individual indicators and the sub-indicators and CEII. A **sensitivity analysis** was also undertaken to assess the robustness of the composite indicator scores/ranks. Throughout the process the following approaches have been used in an iterative way to assess uncertainties:

- **Inclusion and exclusion of individual indicators** – Several of the supporting indicators were included as part of the CEII for testing purposes.
- **Using alternative data transformation schemes** – Different transformation approaches were tested including log, ln and square root to reduce data skewness and their potential implications for the CEII (e.g. one indicator or dimension sub-index being close to zero for most of the countries).
- **Using different weighting–** A number of weighting approaches and weights, based on both statistical analysis and expert opinion, were tested and assessed.
- **Linking and comparing the CEII to other variables –** The CEII was tested against other related indicators including GDP; GDP/capita; Gross domestic spending on R&D as % of GDP; the Innovation Index and the Innovation Output Indicator.

Detailed results of this analyses are presented in the previous CEII report.

4 CEII Results and Analysis

This chapter aims to present the most important CEII results, using visual aids and tables. We present the CEII as one individual number and the sub-indices for each of its dimensions along with the necessary analysis. By presenting the disaggregated results along with the CEII value, we limit the potential concerns regarding subjective weighting of both the dimensions and the sub-indicators within each index dimension. We present the results for the period 2015-2017, as for these years there are available and complete data for the three dimensions. The updated datasets of the second year's analysis for the three dimensions include data also for the year 2018; however, for the patents dimension, the data are not complete and for that reason this year is excluded from the presentation of the CEII results.

The Excel tool included in the annex provides the detailed CEII data and calculations, disaggregated by sub-indicator, SET Plan key action and renewable energy technology within each dimension for the period 2015-2018[37].

Compared to the results of the first year, some differences are recorded regarding the leading countries at all levels of disaggregation (i.e. all SET Plan key actions, key action and renewable technology level. Specifically, the updated dataset indicates that in all SET Plan key actions as well as in most of the key actions, the key players of innovation are in the majority EU27 countries, including the key action 7 "Competitive in global battery sector (e-mobility)", key action 9 "Carbon capture Utilisation and Storage (CCUS)" and key action 10 "Nuclear Safety", which in the results of the first year analysis were led by the US, South Korea and Japan. It is also noticeable that the EU27 countries, and especially the smaller ones (e.g. Slovenia) perform particularly well in the export dimension, which was not the case in the results of the first year report.

At a EU27 scale, Scandinavian countries, specifically Denmark and Sweden, and Germany are still performing exceptionally well both at key action and renewable technology level.

4.1 Overview of CEII and dimensional sub-indexes

4.1.1 Distribution across countries

Figure 3 presents the CEII results for 2017 for all SET Plan key actions. At the overall level, the top scoring countries are Denmark (0.87), South Korea (0.65), Sweden (0.63), Finland (0.62) and Germany (0.61). On average, the EU27 scores 0.47 while MI members score 0.41[38]. The average value for all available in-scope countries is 0.45.[39]

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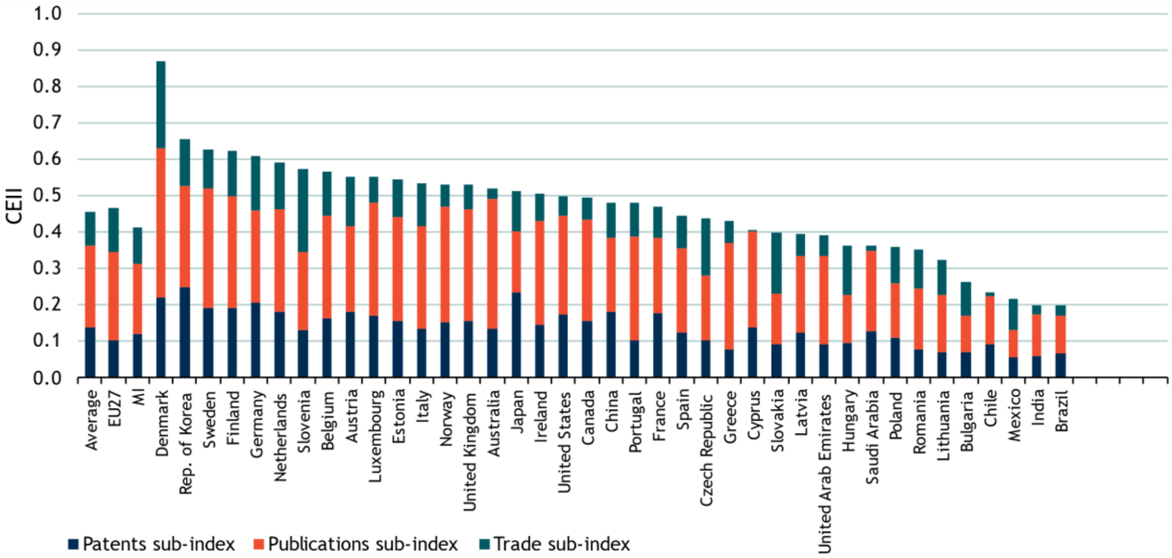
[37] For purposes of completeness, we provide the results for the year 2018 in the excel tool, with the caveat that the dataset for patents is not complete and as such the results of the CEII might not be accurate.
[38] Note that when referring to EU27 and MI members' scores, these are calculated in the same way as the country level indicators (including e.g. transformations and normalisation steps). Further, these values include information for countries for which data is available.
[39] Note that the average values are calculated by using simple average at the indicator level and they include the countries for which data is available (i.e. Malta is not included). An alternative approach is to calculate the average with the raw data as done for EU and MI members; however, this option was not further explored due to time constraints.

Figure 3: CEII per country in 2017



The results of the CEII for the top five performers in 2017 as well as for the EU27 and the MI members (for all SET Plan key actions) between 2015 and 2017 are presented in Figure 4. CEII values for all of the top five performers remained relatively stable throughout the years, with slight increases observed between 2015 and 2017. Denmark is the only country among the top five performers that recorded a decrease in CEII value from 0.89 in 2016 to 0.87 in 2017. When looking at the other countries, a mixed picture emerges: Luxemburg, Estonia, Greece, Cyprus, the United Arab Emirates, Hungary and Romania showed a significant increase from 11% up to 30%. For these countries, the increase can be attributed both to an increase of the patents sub-index as well as to the publications sub-index (as an indication, the value of the patents sub-index for the United Arab Emirates increased by 50% from 2015 to 2017). On the other hand, Belgium, Norway, the US, Spain and Latvia are the countries that recorded the strongest decrease in CEII values from 2015 to 2017, ranging from 3% to 8%. Croatia and Indonesia do not have available data for the patent sub-index in 2017 and therefore they are excluded from the ranking.

Figure 4: CEII for the top 5 scoring countries (and EU27/MI averages), 2015-17

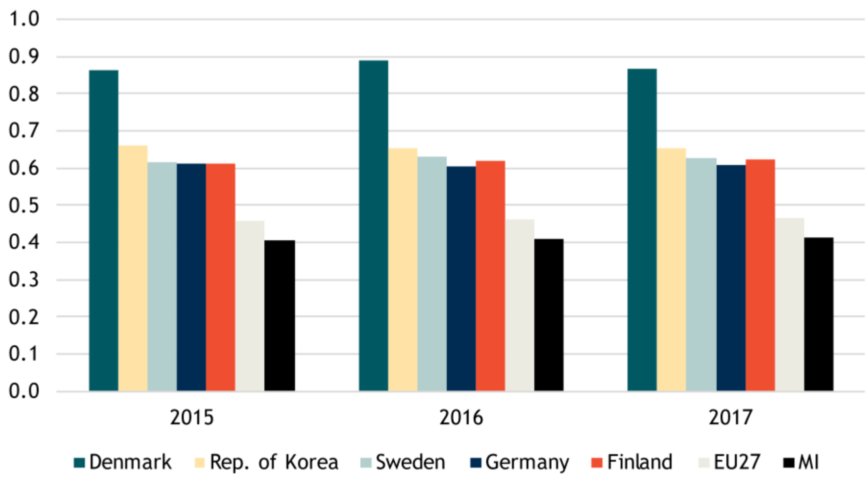


Figure 5 shows the sub-indices per dimension for all countries. Regarding patents, the top scoring countries in 2017 are South Korea (0.99), Japan (0.94), Denmark (0.88), Germany (0.82) and Finland (0.77). South Korea scores relatively high in many SET Plan key actions, with the highest score being recorded in the key action 7 "Competitive in global battery sector (e-mobility)", as well as in several renewable technologies (e.g. 0.77 in solar energy). Japan's high performance in the patent sub-index is also mainly driven by the high scores in the key action 6 "Energy efficiency in industry", key action 7"Competitive in global battery sector (e-mobility)" as well as key action 8 "Renewable fuels", yet it also performed particularly well in the solar and hydroenergy technologies. In 2015 and 2016, however, Denmark and Germany also scored in the top five. On average, the EU27 scores 0.41 while MI members score 0.48, compared to an average of 0.55 for all in-scope countries in 2017. No particular changes have been recorded in the top five performers from 2015 to 2017 patents sub-index values (Figure 6) except for Denmark that showed an increase of 7%.

Figure 5: CEII patents sub-index per country in 2017

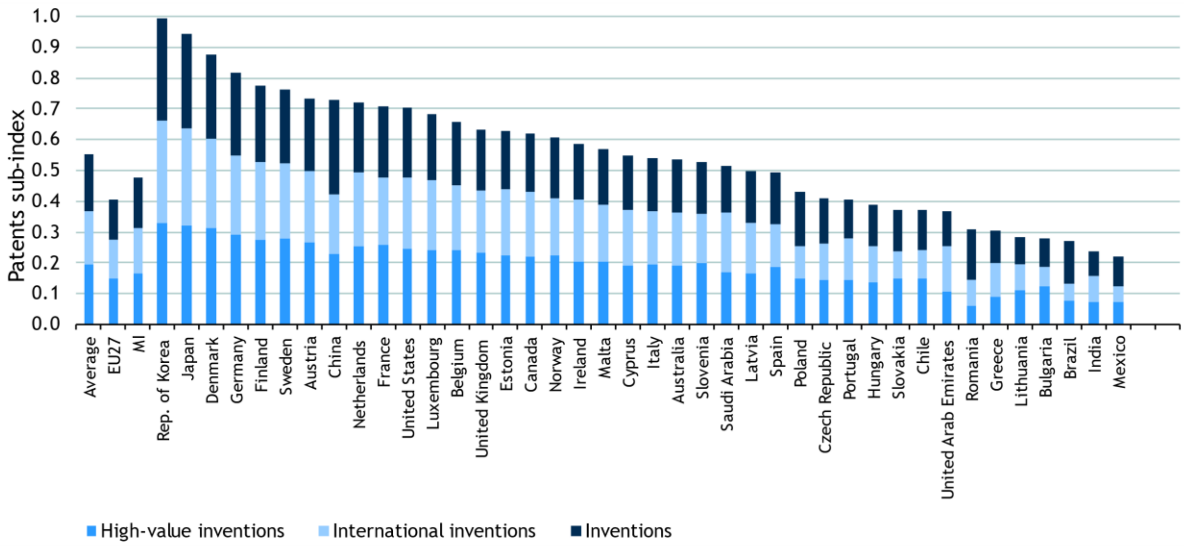
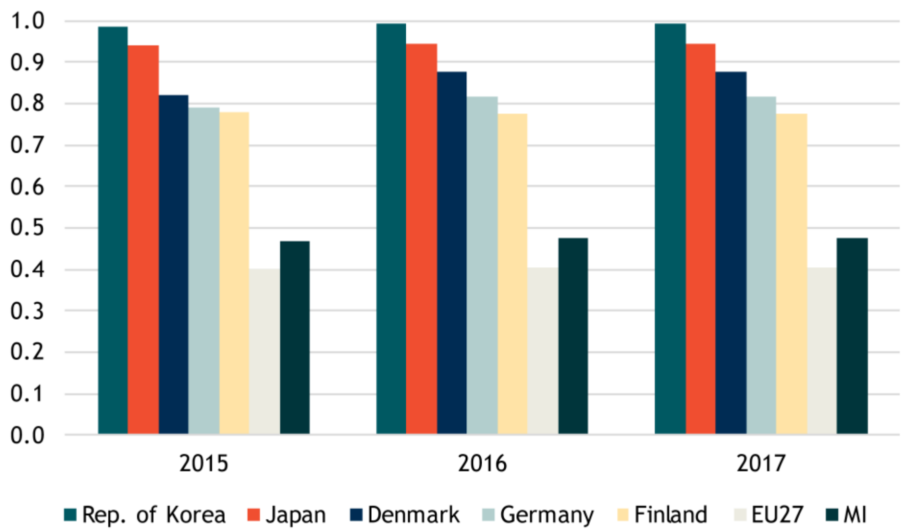


Figure 6: CEII patents sub-index over time for the top scoring countries as ranked in 2017 (and EU27/MI averages)



Regarding publications (Figure 7), the top five scoring countries in 2017 are Denmark (0.81), Australia (0.71), Sweden (0.66), Norway (0.64) and Luxemburg (0.62). However, in 2015 and 2016, Sweden was also among the top five scoring countries. The exceptional performance of Denmark can be mainly attributed to the high score in the publications per capita regarding the key action 1 "Performant renewables" and specifically for the wind energy related technologies. Australia's high performance is driven by the exceptional score of the share of highly cited publications in renewable technologies and especially in ocean energy technologies, as well as by its particularly good performance in the majority of the key actions. EU27 scores on average better (0.49) than the average for all in-scope countries (0.45), while MI members score lower (0.39 – see Figure 8). Norway and Denmark show a slight decrease in the bibliometric index, while the other three top performers improved their publications sub-index values in the respective period, with the most significant one being Luxemburg (+32%).

Figure 7: CEII publications sub-index per country in 2017

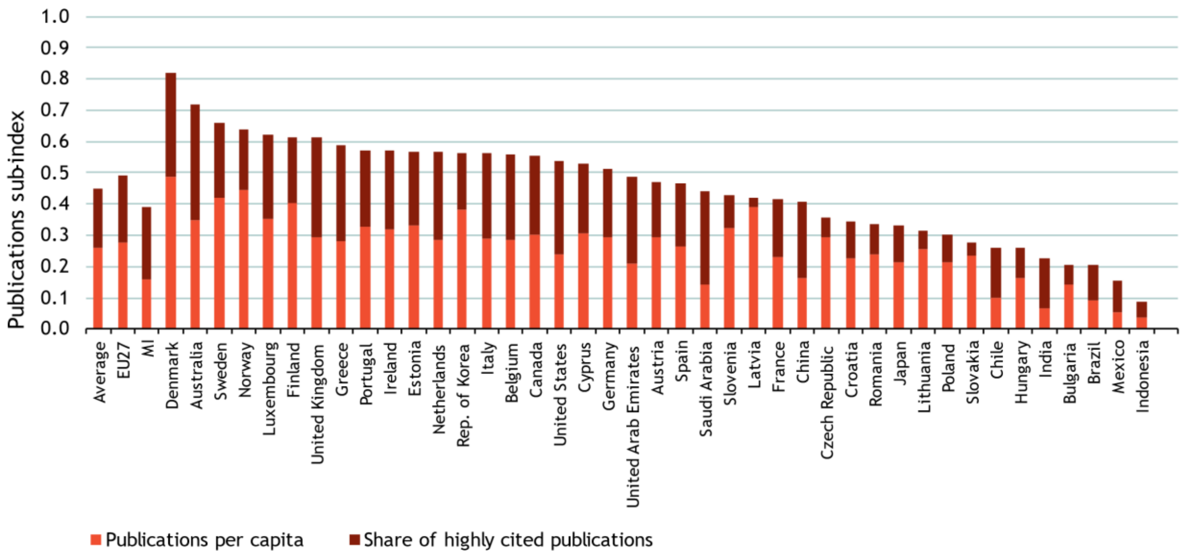
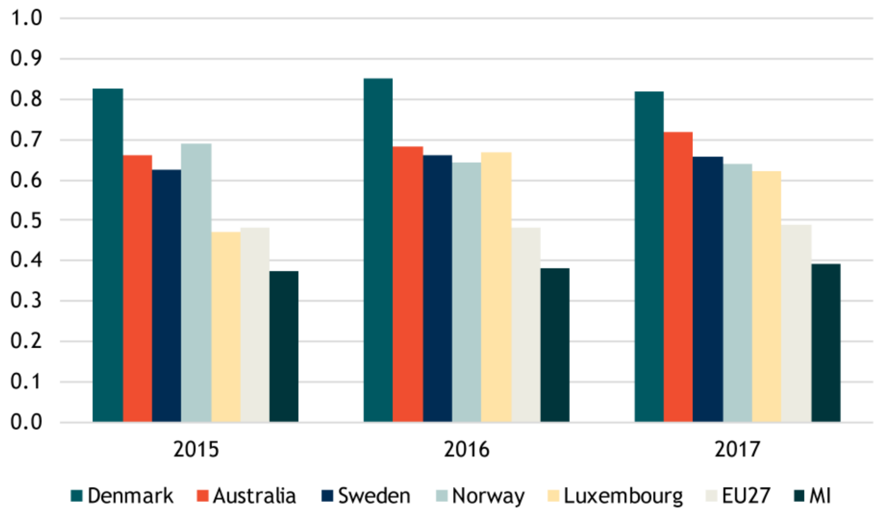


Figure 8: CEII publications sub-index from 2015 to 2017 for the top scoring countries as ranked in 2017 (and EU27/MI averages)



Regarding export (Figure 9), the top scoring countries are Denmark (0.96), Slovenia (0.90), Slovakia (0.66) the Czech Republic (0.62) and Germany (0.59). On average, EU27 scores 0.48 while MI members score 0.39, both of these groups of countries having a higher score than the average for all in-scope countries (0.36). Denmark's high score in the trade sub-index is mainly driven by its outstanding performance in CET exports/GDP in renewable energy technologies, especially in wind-related products. Slovenia ranks first for the majority of the key actions, while it is important to note that the countries of EU27 come first in the top five ranking for most of the key actions. Slovenia and Slovakia show a moderate increase throughout the period 2015-2017, while a small decrease is recorded for Germany and Denmark (Figure 10).

Figure 9: CEII export sub-index per country in 2017

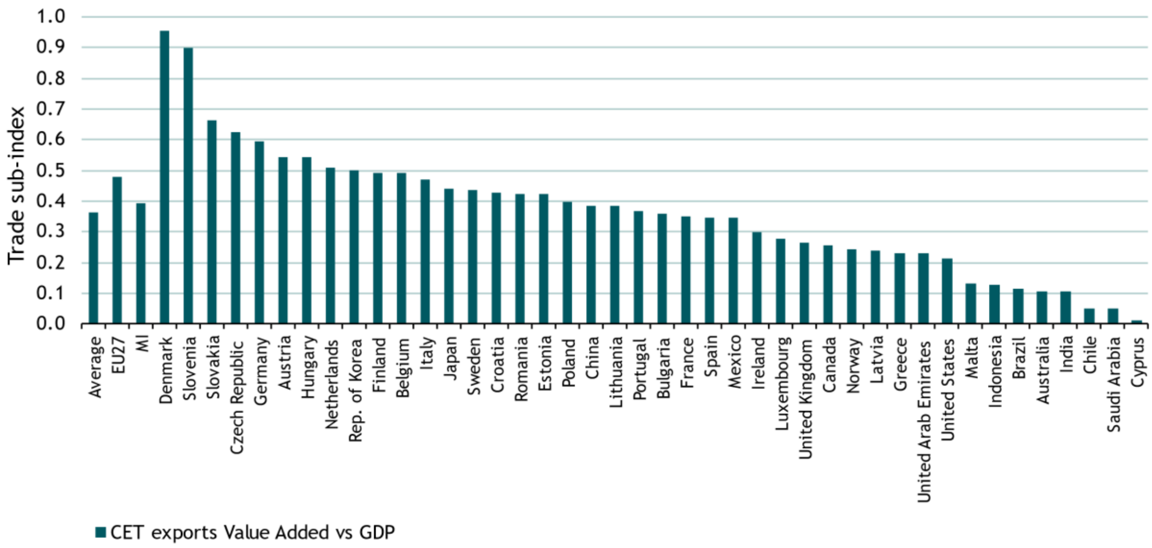
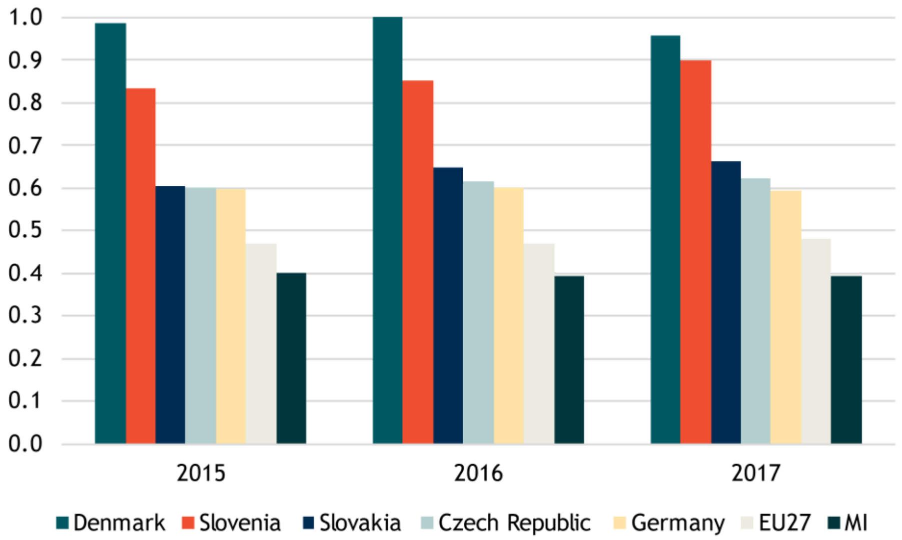


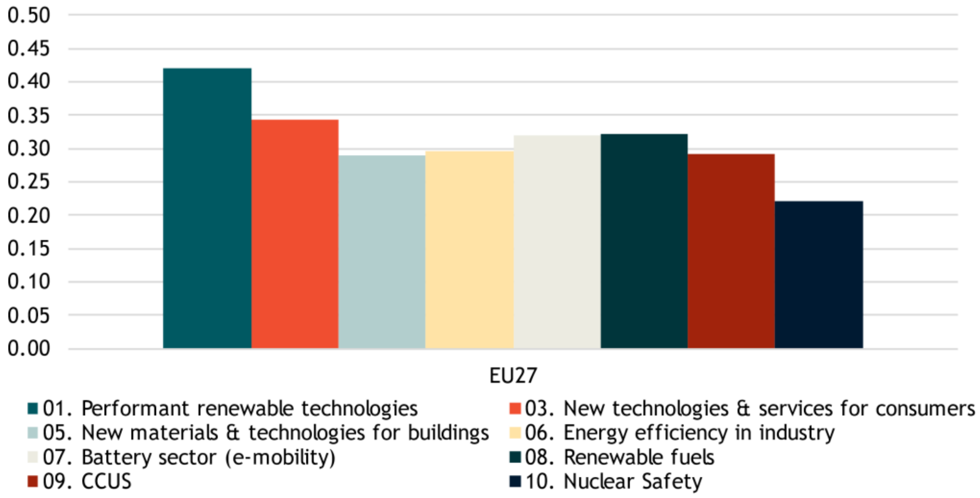
Figure 10: CEII export sub-index for the top scoring countries (and EU27/MI averages), 2015-17



4.1.2 CEII performance for the EU27

Figure 11 shows the distribution of the CEII across SET Plan key actions among the EU27 in 2017[40] is presented. EU27 has the higher CEII score in the key action 1 "Performant renewable technologies" (0.42), while the key action that had the lowest score is "Nuclear Safety" (0.22). In the rest of the key actions, EU27 scores did not show significant differences, ranging from 0.29 for key action 9 "CCSU" and key action 5 "New materials & technologies for buildings" to 0.34 for key action 3 "New technologies and services for consumers".

Figure 11: CEII per SET Plan Key Action for EU27 in 2017



Note: Key Action 02. is merged with Key Action 01.; while Key Action 04. Resilience & security of the energy system is not included in the CEII analysis as there is no data for the export dimension.

The CEII decreased over the years in the EU27 for solar energy by 3% and for hydroenergy by 8% between 2015 and 2017 (Figure 12). In the case of solar, the decrease can be attributed to the small decrease of the publications sub-index. Nevertheless, there is still a significant focus on publications in the solar sector (see section 4.3). The decrease of hydroenergy technologies can be explained by the decrease in the patent sub-index from 0.17 in 2015 to 0.13, which is also justified given the maturity of the specific technology. On the other hand, a small increase of 3% is recorded for wind and geothermal energy technologies in the respective period, which is attributed in both cases to the increase of the patents sub-index.

[40] No major changes have been recorded among the three in-scope years, therefore, only 2017 is presented in the report.

Figure 12: CEII per renewable technology for EU27, 2015-17[41]

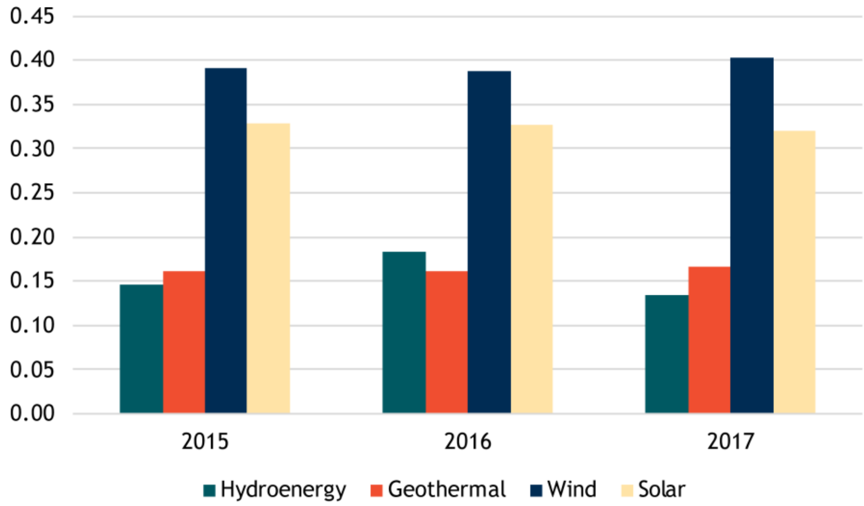
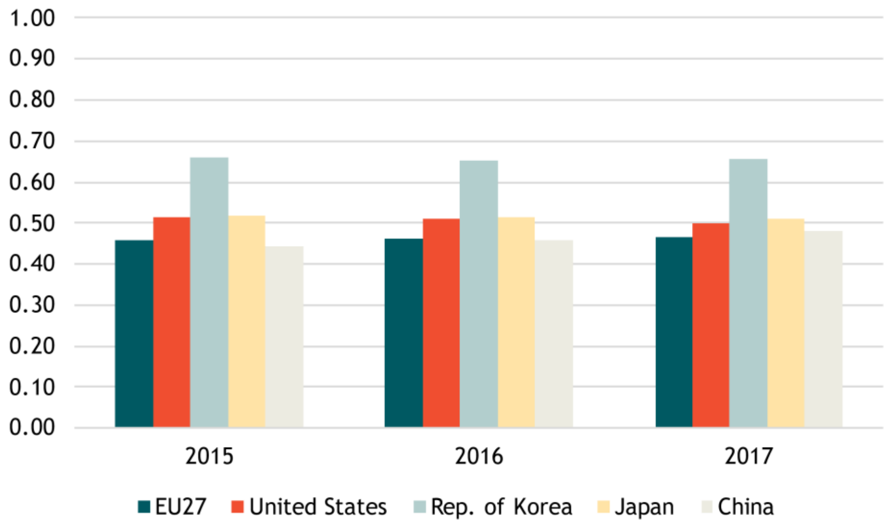


Figure 13 depicts CEII values for the EU27 against key countries, namely the US, South Korea, Japan and China, over time. The value of the CEII decreased from 2015 to 2017 in all cases, except for China, for which it increased by 8%. Furthermore, EU27 lags compared to the US, South Korea and Japan for all the in-scope years, with the most significant difference recorded in 2015 between EU27 and South Korea scoring 0.46 and 0.66 respectively.

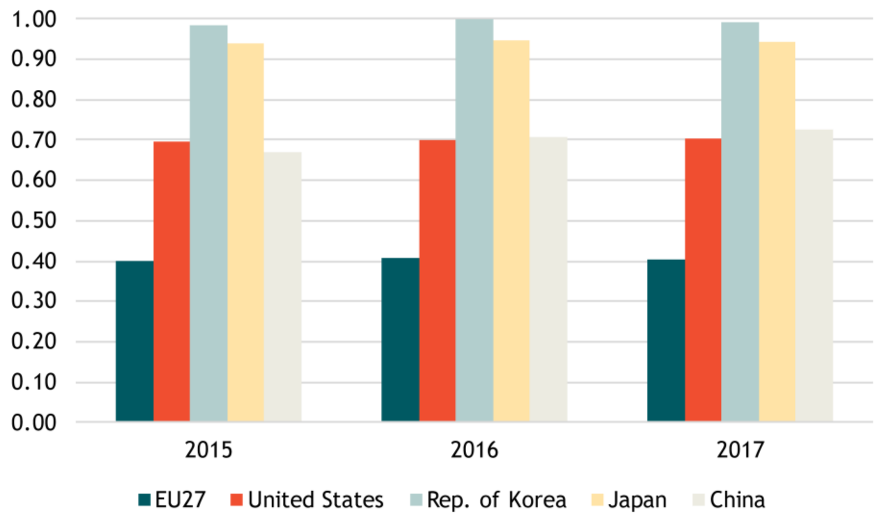
Figure 13: CEII for EU27 against key countries, 2015-17



[41] Note: Ocean technology is not included as no data is available for the export dimension.

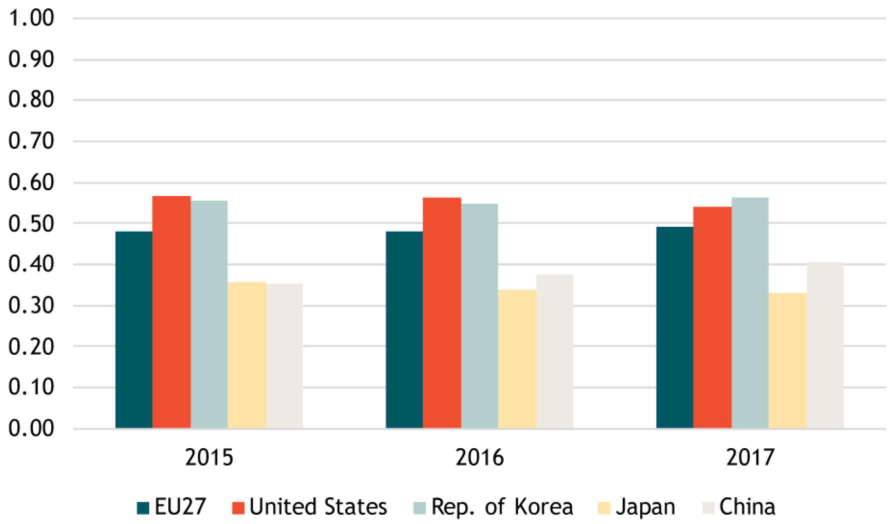
The picture is also similar for the patent sub-index (Figure 14). South Korea has a perfect score with 1 and 0.99 for the years 2016 and 2017, while particularly high values are recorded also from Japan, scoring 0.95 and 0.94 in the respective years. China and the US performed comparably over the years with values around 0.7. Compared to the key players, the EU27 is lagging considerably in terms of patent activity, scoring 0.41 in its best year (2017).

Figure 14: Patents sub-index for EU27 against key countries, 2015-17



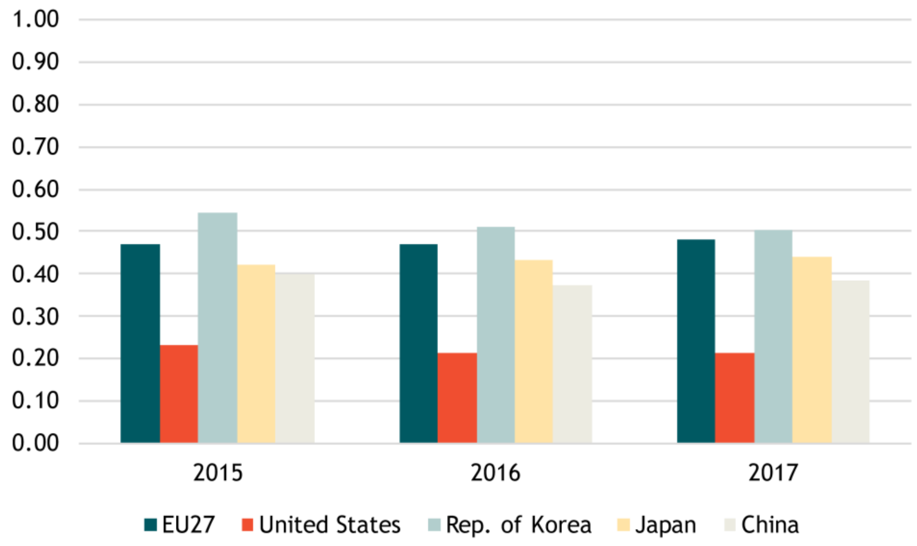
With regard to the publications sub-index (Figure 15), EU27 outperformed Japan and China, showing a marginal increase from 0.48 to 0.49 between 2015 and 2017. However, the US and South Korea surpassed the EU27, scoring 0.54 and 0.56 in 2017, respectively.

Figure 15: Publications sub-index for EU27 against key countries, 2015-17



Finally, in the export sub-index (Figure 16), South Korea outperformed the key players for the whole in-scope period, scoring 0.54 in its best year (2015), yet its performance decreased between 2015 and 2017 by 8%. The EU27 recorded an average performance with 0.48 in 2017, while Japan followed closely, scoring 0.44. The US performed particularly poorly throughout the years with values around 0.2. It is important to note that the results changed dramatically compared to the analysis of the first year, when the US ranked first in the export sub-index, scoring above 0.8 for the whole in-scope period, while the EU27 ranked last. However, that change can be explained by the export indicator now being scaled by GDP as well as by the revision of the HS codes.

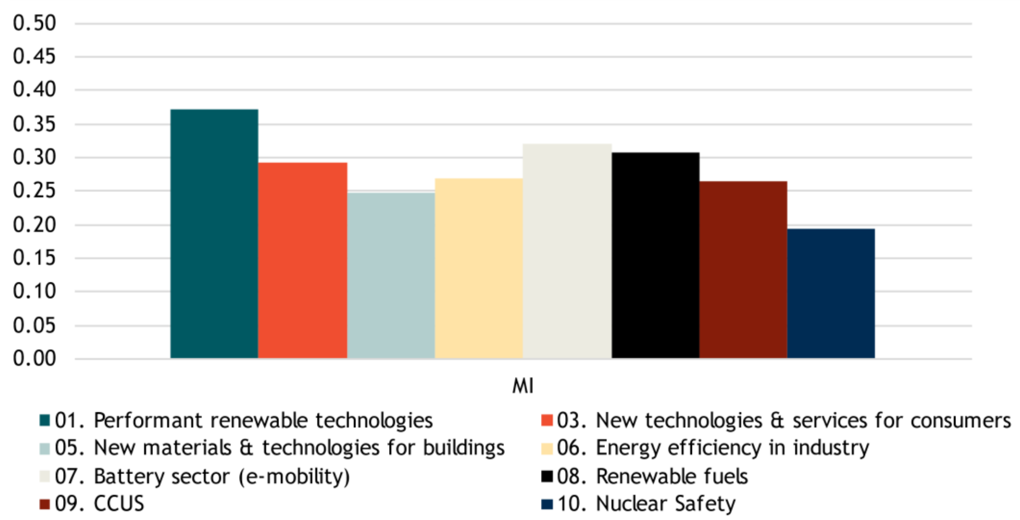
Figure 16: Export sub-index for EU27 against key countries 2015-17



4.1.3 CEII performance for Mission Innovation countries

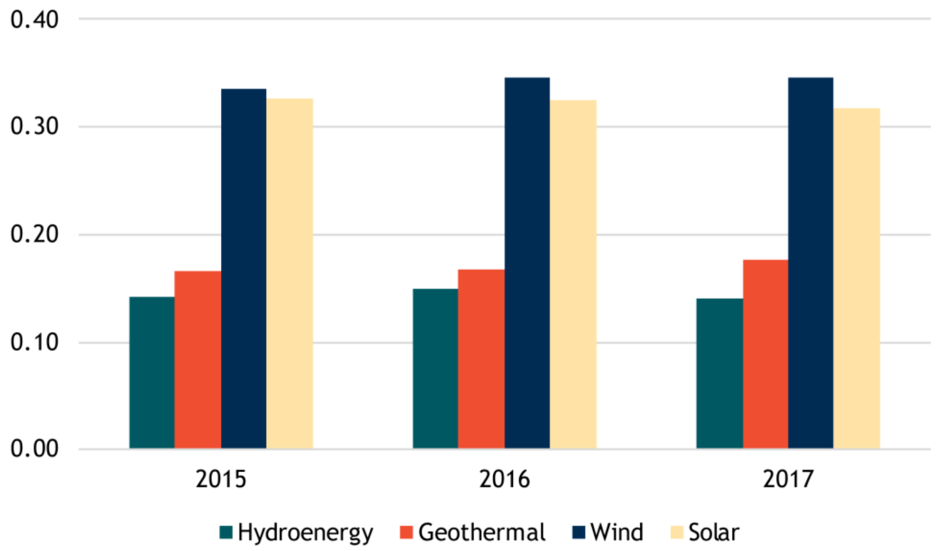
As depicted in Figure 17, the key action that MI members performed the best in, in 2017, was “Performant renewable technologies”, scoring 0.37. For the MI counties, as for the EU27, the least innovation activity was recorded for key action 10 “Nuclear Safety” with 0.19, followed by key action 5 “New materials & technologies for buildings” with 0.25 and key action 9 “CCSU” with 0.26.

Figure 17: CEII per SET Plan Key Action for MI members in 2017



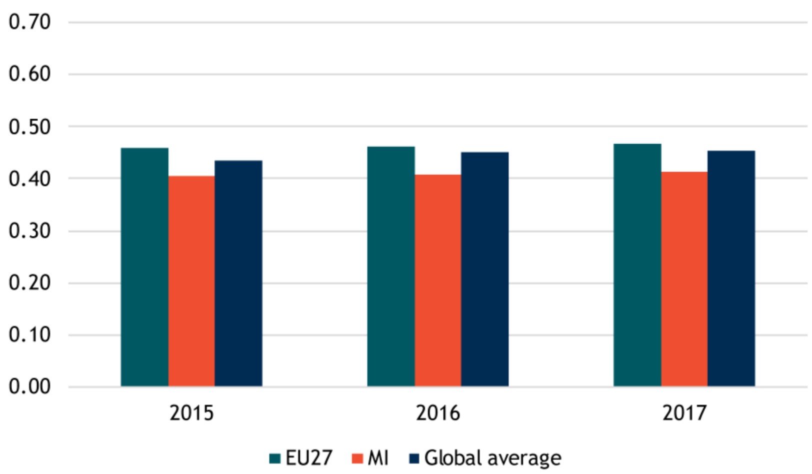
With regard to renewable technologies (Figure 18), CEII values for MI members decreased slightly for solar (-2%) and hydroenergy (-1%) between 2015 and 2017, while a small increase was recorded for geothermal and wind energy, which is in agreement with the findings for the EU27. Nevertheless, wind and solar energy showed the most innovative activity among the renewable technologies for the MI members, with values around 0.3, which is also the case for the EU27.

Figure 18: CEII per renewable technology for MI, 2015-17[42]



Finally, 19 compares the CEII values for the EU27, MI members and global average over the years. The first conclusion is that, in all cases, the CEII increased slightly from 2015 to 2017, by 2% for the EU27 and MI members and by 4% for the global average. The second conclusion that can be drawn is that EU27 performed better than both the MI members and the global average, but the difference was insignificant.

Figure 19: CEII for EU27, MI members and global average, 2015-17



[42] Note: Ocean technology is not included as no data is available for the export dimension.

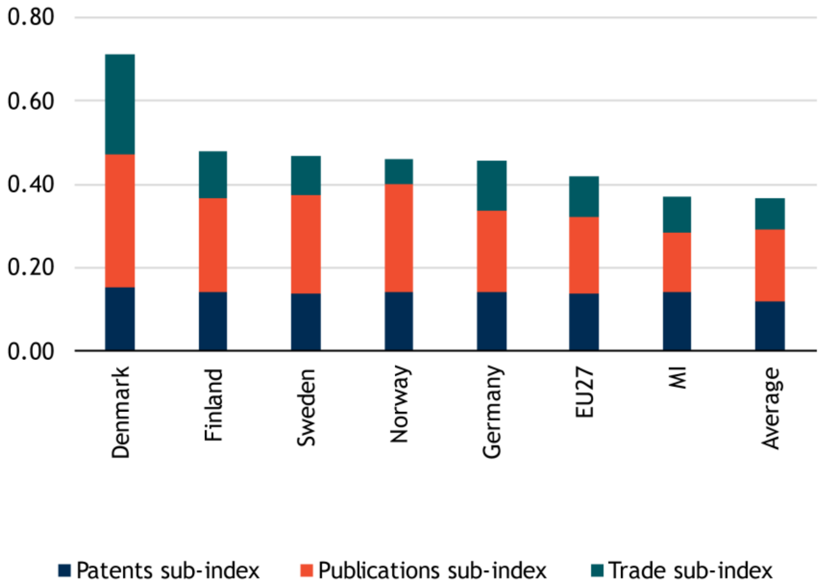
4.2 CEII per Key Action

4.2.1 Distribution across SET plan Key actions[43]

01. & 02. Performant renewable technologies integrated in the system- Reduce technology costs[44]

The EU27 countries and specifically the Scandinavian countries dominate the top five ranking of the key action(s) 1 and 2 "Performant renewables/Reduce Technology Costs" in 2017, along with Germany (Figure 20). With the exception of Denmark, patents and publications are the strongest dimensions for all countries, indicating that industrialisation of renewable technologies is not yet a strong focus in Europe. The EU27 scores higher (0.42) than MI members and the global average, for which both score 0.37. The exceptional performance of Denmark in this key action is mainly based on its strong focus and expertise in wind energy.

Figure 20: CEII for the SET Plan key action 'Performant renewable technologies integrated in the system- Reduce technology costs' in 2017



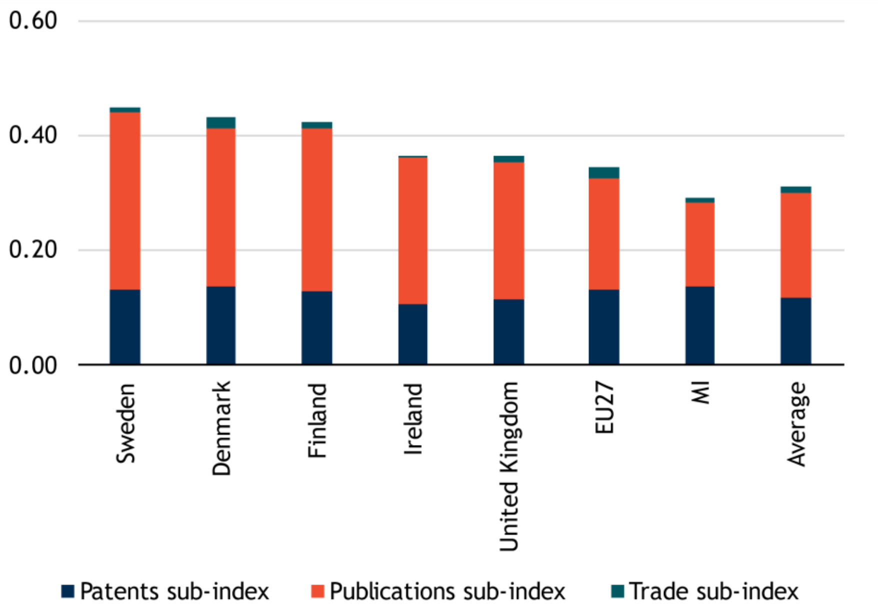
03. New technologies & services for consumers

Sweden, Denmark, Finland and Ireland are on the top performing countries of the key action 3 "New technologies & services for consumers", along with the UK (Figure 21). It is worth mentioning that all top five performers score particularly low on the export sub-index (in the range of 0.01-0.02) while their strong focus is mainly on the publications sub-index, leading to an overall high CEII value. The EU27 (0.34) scores higher than the global average (0.31), while the opposite is true for the MI members (0.29).

[43] Note: export data in not available for technologies included in key action 4 "Resilience & security of the energy system", therefore the CEII could not be computed. For that reason, this key action is not presented in the following section.

[44] Note: We follow the JRC's approach, combining key actions 1 and 2. Source: JRC (2017). Monitoring R&I in Low-Carbon Energy Technologies

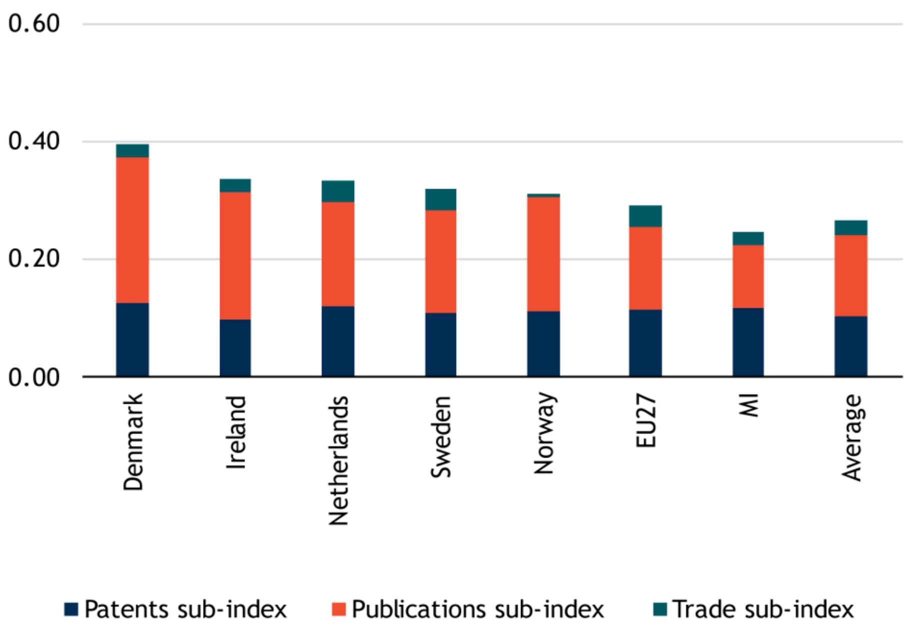
Figure 21: CEII for the SET Plan key action 'New technologies and services for consumers' in 2017



05. New materials & technologies for buildings

The key players of the key action 5 "New materials & technologies for buildings" are northern European countries, namely Denmark, Ireland, the Netherlands, Sweden and Norway which indicates that EU27 is leading in this sector (Figure 22). All countries perform well in the publications and moderately well in the patents dimensions, while the export dimension holds a marginal share for the majority of the countries. As in the previous key actions, the EU27 (0.29) outperforms MI members (0.25) and the global average (0.27), yet the differences in values are rather small.

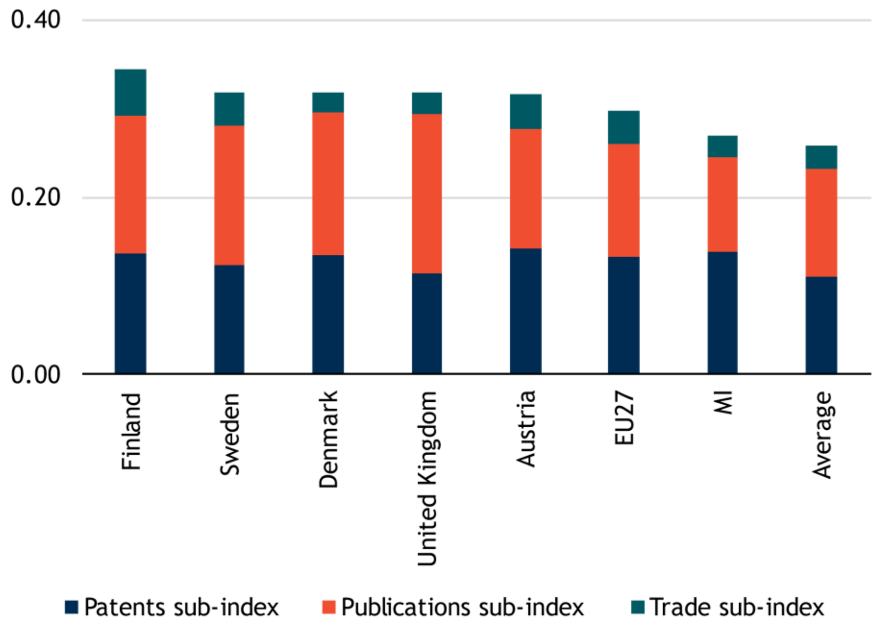
Figure 22: CEII for the SET Plan key action 'New materials & technologies for buildings' in 2017



06. Energy efficiency in industry

Finland, Sweden, Denmark and Austria are the EU27 leading countries of the key action 6 “Energy efficiency in industry” along with the UK (Figure 23). Patents and publications sub-indexes contribute almost equally to the CEII of this key action, while the export sub-index holds a smaller share for all countries. MI members and the global average scoring very closely (0.26 and 0.27, respectively) while the EU27 performs slightly better, scoring 0.30.

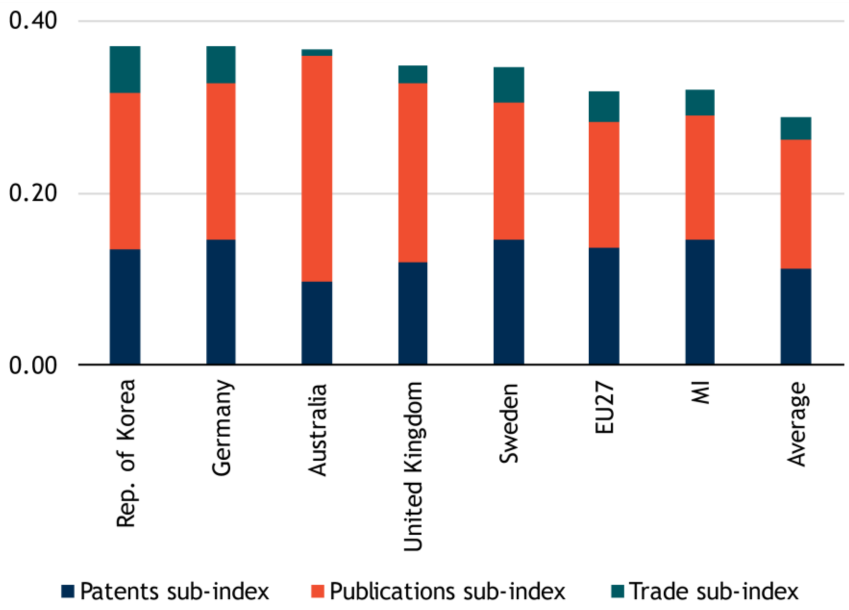
Figure 23: CEII for the SET Plan key action ‘Energy efficiency in industry’ in 2017



07. Competitive in global battery sector (e-mobility)

The composition of the key players is different in the battery sector compared to the previous key actions; South Korea, Germany and Australia lead this sector, with all three scoring 0.37, following by the UK and Sweden with 0.35 (Figure 24). The EU27 (0.36) and MI members (0.42) score higher than the average for all in-scope countries (0.34). The publications sub-index holds the biggest share of the CEII while patents also hold a significant share, indicating that the focus of the innovative activity of this key action is still on the research and commercialisation aspects, rather than on the industrialisation aspect (as reflected by low values of the export sub-index).

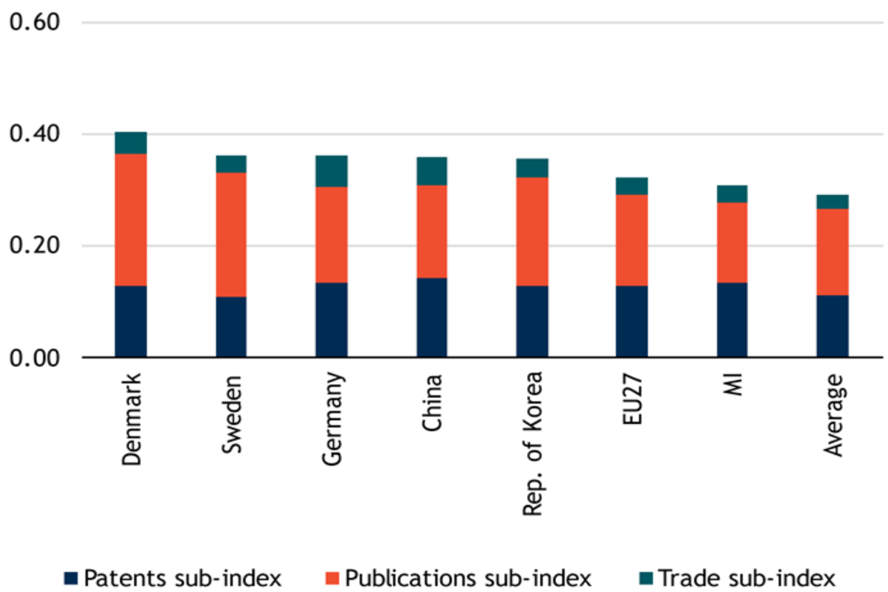
Figure 24: CEII for the SET Plan key action 'Competitive in global battery sector (e-mobility)' in 2017



08. Renewable fuels

The top performing countries for the key action 8 "Renewable fuels" are Denmark, Sweden and Germany, followed by China and South Korea. EU27 and MI members score almost equally (0.32 and 0.31, respectively), slightly higher than the global average (0.29) (Figure 25). In this key action, a change in the dynamic of the sub-indexes occurs depending on the country: for Denmark and Sweden, publications play a significantly bigger role than patents and export, while for Germany and China, the patents sub-index contributes almost equally to the publications sub-index. These differences also give an indication on the innovation stage each country is mostly focused on regarding renewable fuels.

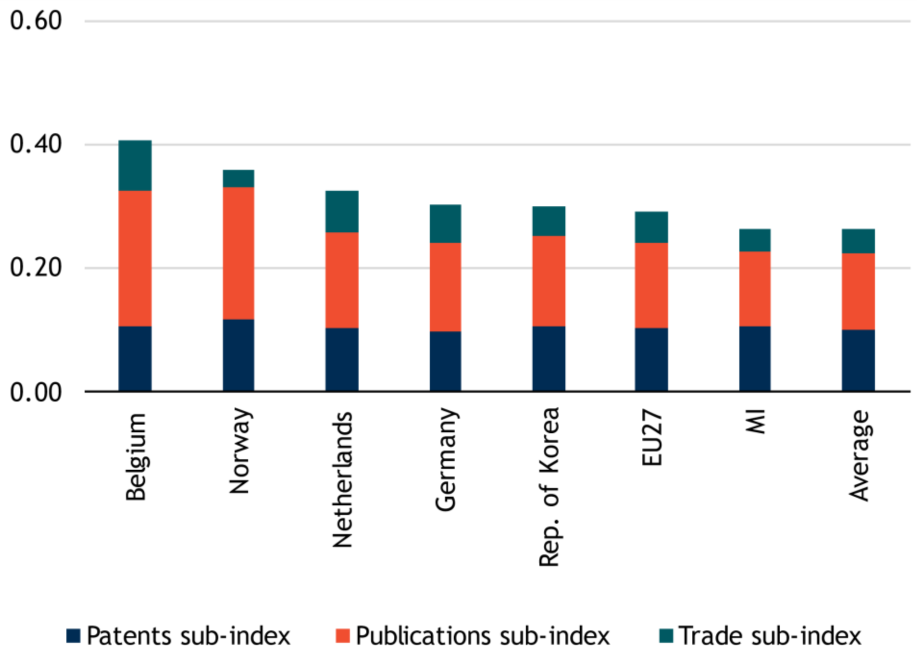
Figure 25: CEII for the SET Plan key action 'Renewable fuels' in 2017



09. Carbon capture Utilisation and Storage (CCUS)

The best performers of the key action 9 "Carbon capture Utilisation and Storage (CCUS)" are mainly European countries, namely Belgium, Norway, the Netherlands and Germany, while South Korea completed the top five (Figure 26). It is noteworthy that Belgium performs particularly better than the rest of countries scoring 0.41, with the publication sub-index holding the biggest share of the CEII. Norway also has a strong focus on research as reflected by the high value of publications sub-index, while for the other countries appearing in the top 5, a more balanced contribution is recorded between the patents and publications sub-indexes. The EU27 performs slightly better (0.29) than MI members and the global average, both scoring 0.26.

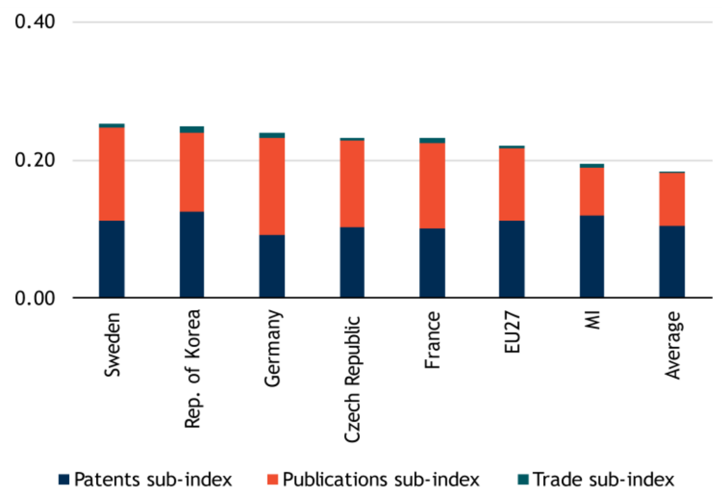
Figure 26: CEII for the SET Plan key action 'Carbon capture Utilisation and Storage (CCUS)' in 2017



10. Nuclear Safety

Regarding the key action 10 "Nuclear safety", Sweden and South Korea rank first, both with 0.25, followed closely by Germany, with 0.24, and the Czech Republic and France, both scoring 0.23 (Figure 27). The EU27 (0.22) and MI members (0.19) score slightly higher than the average for all in-scope countries (0.18). In this key action, publications hold the biggest share, while the export dimension is almost non-existent for all the world players.

Figure 27: CEII for the SET Plan key action 'Nuclear Safety' in 2017



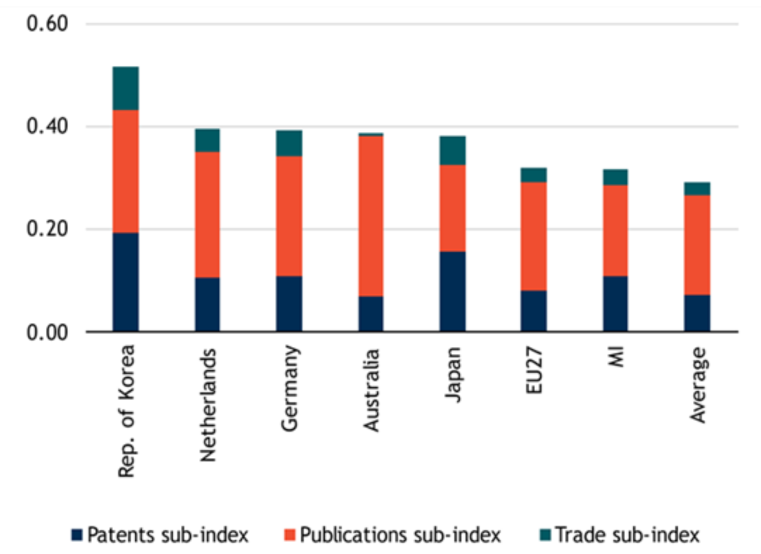
4.3 CEII Performance in the SET key action "Performant renewable technologies"

In this section, we consider the technologies of the key action 1 "Performant renewables" in more detail to capture which countries are leading in the innovation of clean energy technologies (CET) and how EU27 and MI members perform.

Solar energy

South Korea is the top performer among all the in-scope countries in solar energy, scoring 0.52, followed by the Netherlands (0.40) Germany and Australia (0.39 each), while Japan completes the top five (0.38) (Figure 28). The EU27 (0.46) and MI members (0.47) score higher than the average for all in-scope countries (0.43). Publications and patents contribute the most for all world players, while the export sub-index is more important in South Korea and Japan. This result indicates there is a significant focus from the countries for further research on solar technologies combined with a considerable attention on the market development (as reflected from the patents share).

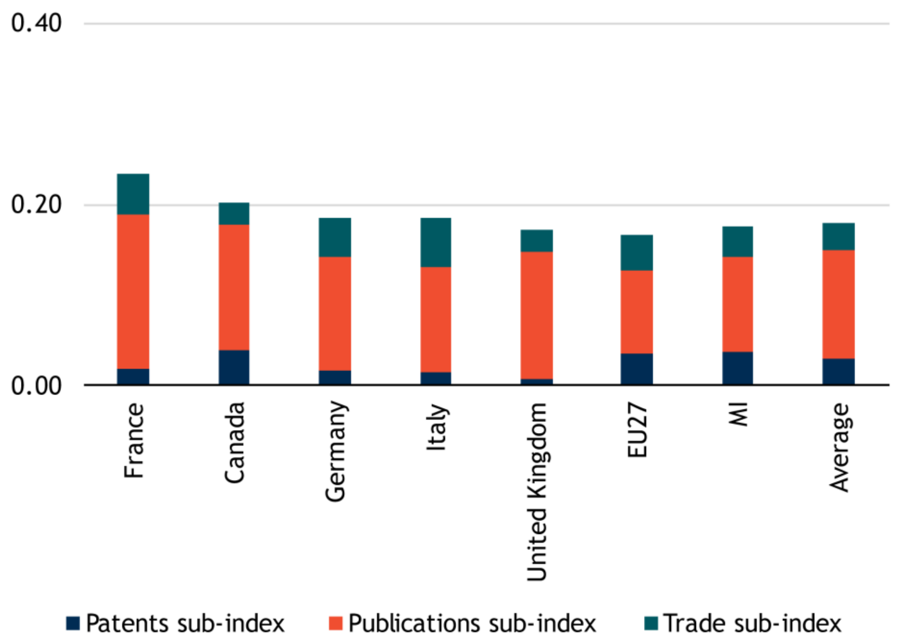
Figure 28: CEII in solar energy for the top 5 scoring countries (and EU27/MI averages) in 2017



Geothermal energy

The innovation developments in the sector of geothermal energy are driven by France, Canada, Germany, Italy and the UK (Figure 29). France is leading among the EU27 countries in the field of geothermal energy since it is a key sector for the country's energy mix in order to cut its emissions and to decrease its dependence on fossil fuels[45]. It is noteworthy that in all leading countries, almost no patent activity is recorded. The EU27 (0.17) scores slightly lower than the MI members and the global average (both scoring 0.18), with an equal share of patent and export activity in the sector.

Figure 49: CEII in geothermal energy for the top five scoring countries (and EU27/MI averages) in 2017



Hydroenergy

The countries that excel in hydroenergy innovation are Norway (0.24), Canada (0.23), the Netherlands (0.20), the US (0.19) and the UK (0.19) (Figure 30). Italy scores marginally lower than the UK and therefore is not included in the graph. Nevertheless is one of the European frontrunners when it comes to hydroenergy[46]. Canada is also a top producer of hydroenergy worldwide and its energy mix relies heavily on that renewable energy source[47]. The EU27 (0.13) performs slightly lower than MI members and the global average, both scoring 0.14.

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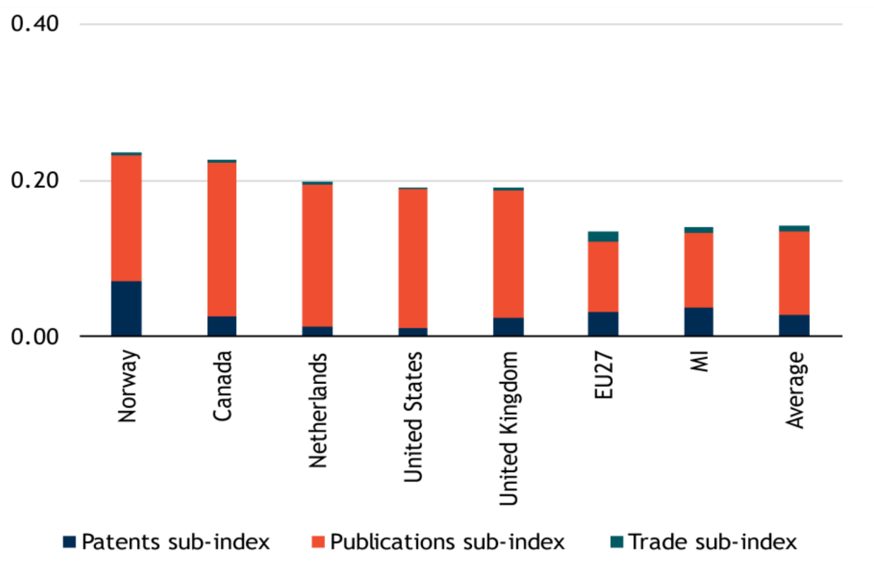
[45] EGEC (2018). France, a European leader in geothermal energy
[46] Hydroelectric power in Italy
[47] IHA (2019). Canada

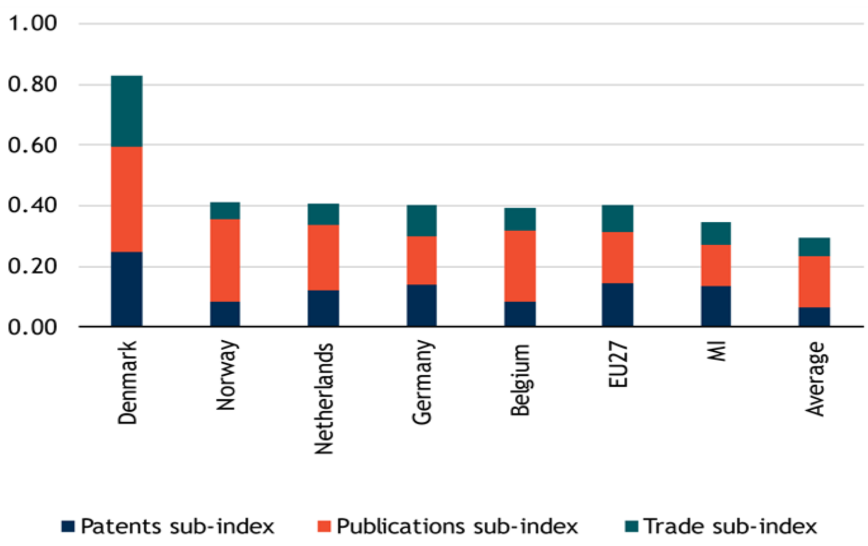
Figure 30: CEII in hydroenergy for the top 5 scoring countries (and EU27/MI averages) in 2017



Wind energy

EU27 leads in wind energy technology innovation, with Denmark, Norway, the Netherlands, Germany and Belgium being in the top five (Figure 31). Denmark clearly outperforms the rest of the key players, scoring 0.83 in the CEII, while Norway is second with 0.41. This can be attributed to the fact that Denmark is a pioneer in terms of wind energy, and it is home to some of the world's biggest manufacturers of wind turbines[48]. The EU27 (0.40) and MI members (0.35) score higher than the average for all in-scope countries (0.30).

Figure 31: CEII in wind energy for the top 5 scoring countries (and EU27/MI averages) in 2017



[48] Denmark.dk. Pioneers in clean energy

5 Profiles of the innovation systems

One of the key challenges for policy makers in innovation is to develop an innovation ecosystem where the whole value chain thrives, with successful R&D, commercialisation (e.g. start-ups), industry development and market development. If the value chain is successful, there is a clear return on the RD&I investment with additional jobs, GDP growth and increase of competitiveness. If not, it becomes harder to justify the continued investment in RD&I. Some key examples for the EU27 are the development of the wind sector (major EU-based players) and the solar PV sector (industry mostly left the EU27).

In this study, we have gathered the most up-to-date data set available regarding several outputs of innovation activity, namely publications, patents and export, from which we have built the CEII. The three dimensions can highlight differences per country/region and per technology, with measures of early-stage R&D (publications), product development/commercialisation (patents) and industry development (value added in export).

In the following sections, we first provide an overview of the methodology that was used to develop the innovation profiles, and then the results of this analysis are presented.

5.1 Methodology

5.1.1 Indicators considered per dimension

As the aim of this exercise is to investigate the links between the R&D investments on clean energy technologies and the resulting innovative activity as measured by publications, patents and export, we first took a closer look to all the available indicators per dimension that were considered under this study. It was concluded that the indicators selected per dimension for the construction of the CEII (see the reports of the previous Work Packages per dimension for the selection methodology) are adequate for the purpose of the creation of innovation profiles. As such, the same methodology for data treatment and normalisation of those indicators was used[49].

An overview of the selected indicators for the creation of the innovation profiles is provided in Table 6.

Table 6: Selected indicators per dimension for the innovation profiles

Dimension	Selected Indicators	Innovation profile indexes
Publications	Number of publications in fractional counting per 1,000,000 population	Publication sub-index
	Share of highly cited publications at the 10% level	
Patents	Number of inventions per unit of GDP	Patents sub-index
	High-value inventions per unit of GDP	
	International inventions per unit of GDP	
Export	CET exports Value Added per GDP	Export sub-index

[49] For more information on this methodology refer to the First report on the clean energy innovation index

To facilitate the interpretation of the results, it was deemed appropriate to transform the values of the sub-indexes to equal, lower or higher than 1, so that a value of 1 indicates average innovation performance, a value higher than 1 indicates strong innovation performance, while a value lower than 1 indicates the opposite. The transformation was conducted by using weighted average values, with GDP used as a weight. The advantage of weighted average compared to the simple average approach is that it reflects the relative importance of each country in the calculation of the total average. This means that countries with smaller GDP (such as Malta) have a respectively smaller weight and therefore, when calculating the average, they do not significantly influence the results. The opposite occurs with the countries with large GDP values (such as China).

5.1.2 Time period and time lag

When computing the innovation profiles, decisions have to be made on which number of years to include and whether or not to assume a time lag between the different innovation outputs. Working with average scores over multiple years may be preferred as this gives a more robust view on the innovation system of a specific country/topic combination than looking at a single year. Working with a time lag may be appropriate as the initial input to the innovation process – the R&D funding that is made available – does not translate to the different innovation outputs (publications, patents, export) at the same pace.

There is limited and very mixed evidence on what the typical time lag is between the initial R&D funding and the different innovation outputs. For publications, Auraren O. & Nieminen M. (2010)[50] consider a 6-year time lag in their study, while Popp D. (2015)[51] estimates different time lags per renewable technology: 10 years for biofuels and energy efficiency, six years for solar energy and seven for wind energy. Lykogianni E. & Verbeek A. (2008)[52] indicate that an increase in public R&D funding correlates with higher publications and patents with a time lag of one to two years. In Trinomics (2018), several time lags (0 to 5 years) were tested between public R&D funding, publications and patents in the renewables sectors, with no clear indication of what the most appropriate time lag is.[53]

Notwithstanding the lack of a clear indication on what the most appropriate time lag is, we still consider that it is appropriate to assume some time lag between the R&D funding and the three dimensions, and would expect the shortest time lag with publications, followed by patents and export. As a pragmatic solution for this exercise, we assume a lag of two years between each dimension and work with three years of data for each dimension, which should offer a more robust analysis than working with only one year, while keeping the picture relatively up to date. The following years of data are included per dimension:

- Publications: 2013-2015
- Patents: 2015-2017
- Export: 2017-2019

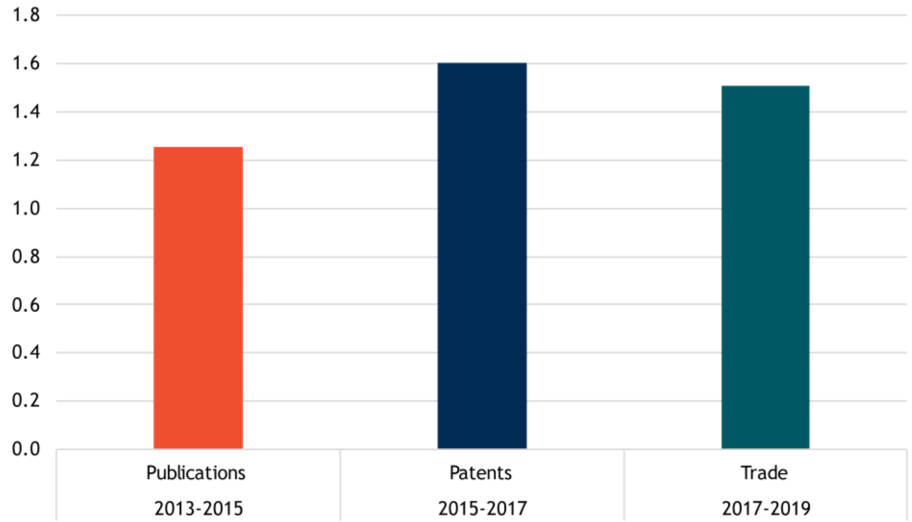
[50] Auraren O. & Nieminen M. (2010), University research funding and publication performance—An international comparison doi:10.1016/j.respol.2010.03.003
[51] Popp D. (2015), Using Scientific Publications to Evaluate Government R&D Spending: The Case of Energy
[52] Lykogianni E. & Verbeek A. (2008) A Time Series Analysis of the Development in National R&D Intensities and National Public Expenditures on R&D
[53] Trinomics et al. (2018), Study on impacts of EU actions supporting the development of renewable energy technologies

5.2 Results of the innovation profiles

The innovation profiles consist of three pillars that reflect the innovative activity of each country in different stages, namely research, commercialisation and market development. These three stages are represented by the three sub-indexes of publications, patents and export respectively. The values of the sub-indexes can reveal firstly how well a country performs against the average performance of all in-scope countries in each stage of innovation, and secondly indicates which phase of innovative activity a country is focused on by comparing the sub-indexes against each other. For instance, as depicted in Figure 32, when comparing to the average values of the in-scope countries, South Korea performs higher than average in all three sub-indexes, indicating a strong activity in all the stages of innovation. On the other hand, when comparing the sub-indexes against each other, South Korea has a stronger performance on the patents and export, and therefore is more interested (or successful) in investing in the commercial and industrial part of innovation chain rather than in the early stage of R&D (i.e. research).

In the following sections, we discuss in more detail how some of the most important economies across the globe (hereinafter world players[54]) perform firstly for the full scope of SET Plan key actions and then for the most relevant key actions and technologies (solar and wind).

Figure 52: Innovation profile of South Korea- All SET Plan Actions



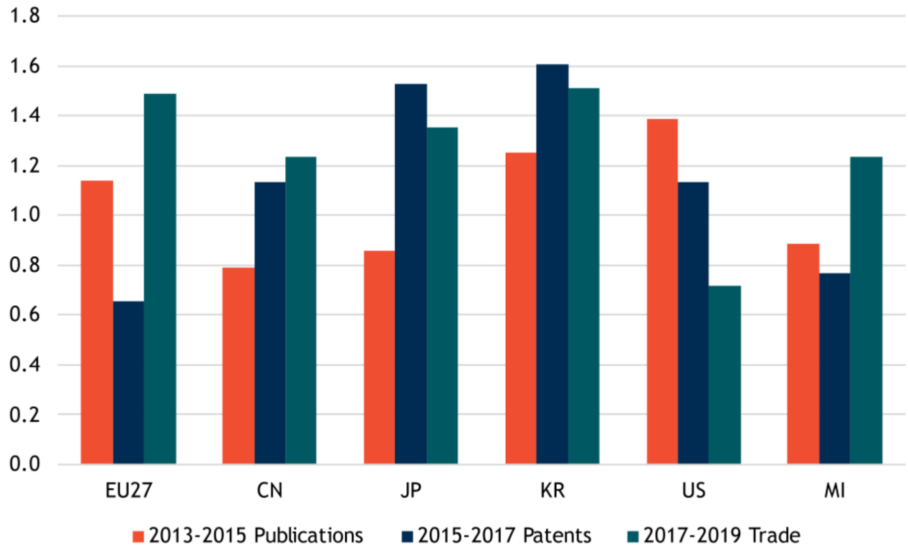
5.2.1 Innovation profiles for All SET Plan key actions

Figure 33 presents the innovation profiles of the world players for All SET Plan key actions in order to get an overview of how well they perform at the higher level of aggregation. The EU27 shows a slightly above average performance in publications (1.1), a rather low performance in patents (0.7) and a strong performance in the export dimension (1.5). China performs slightly above average in patents and export (1.1 and 1.2, respectively) while it lags in publications (0.8). Japan scores slightly below average in publications (0.9)

[54] In the context of this chapter, the world players are the EU27, China, Japan, South Korea and the US based on the fact that these countries/region are amongst the highest-ranking in terms of GDP and in general active in the clean energy innovation technologies.

while it performs particularly well in patents and export, scoring 1.5 and 1.4, respectively. The US shows the opposite behaviour, with a strong performance in publications (1.4), average performance in patents (1.1) and below average in export (0.7). Finally, MI members score above average in the export dimension (1.2), while they score below average in both patents and publications (0.8 and 0.9 respectively). The comparison of the sub-indexes against each other shows that the East Asian players have a clear focus on the commercialisation activities and industry development, while for the EU27 and the US research plays an important role in the R&D chain.

Figure 33: Innovation profiles of world players-All SET Plan Key Actions



5.2.2 Innovation profiles per key action

In this section, we discuss the results of the innovation profiles of the world players for the key actions with the most interesting insights, namely:

- Key action 3: New technologies & services for consumers;
- Key action 7: Competitive in global battery sector (e-mobility); and
- Key action 8: Renewable fuels.

Key action 1 'Performant renewable technologies integrated in the system' is not discussed in this section as we devote a separate section (see 0) to it.

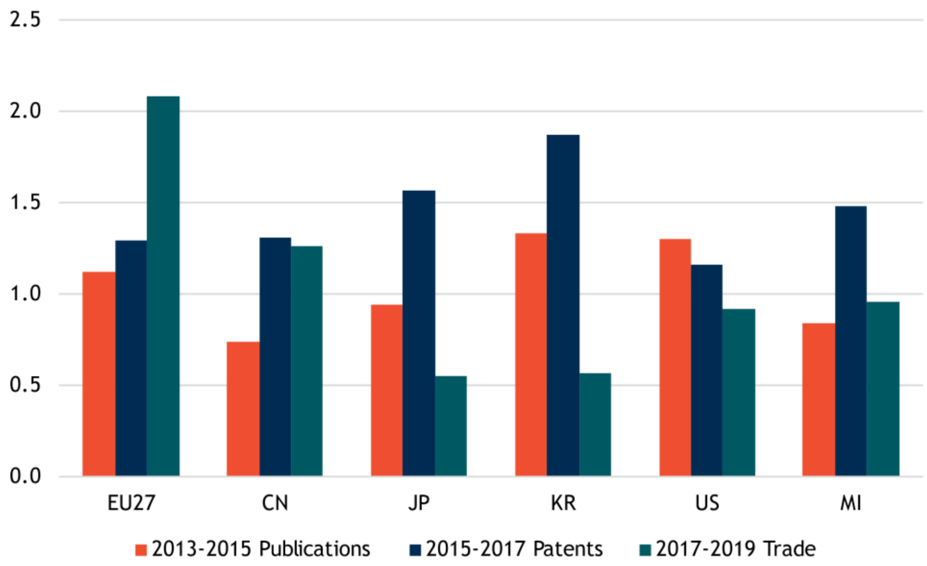
The results of key action 5 'New materials & technologies for buildings' and key action 6 'Energy efficiency in industry' are similar to those of 'New materials & technologies for buildings' and are therefore not discussed in further detail. Finally, key action 4 'Resilience & security of the energy system', key action 9 'Carbon capture Utilisation and Storage (CCUS)' and key action 10 'Nuclear Safety' lack in data availability in certain dimensions and therefore no significant results can be extrapolated.

Key action 3 'New technologies & services for consumers'

The EU27 is the only world player that shows an overall strong innovative performance in key action 3 'New technologies & services for consumers', scoring above average in all the three dimensions and particularly high in export (2.1). Japan and South Korea, on the other hand, show a strong performance on patenting activities which are not converted into considerable export performance, as they both score significantly below average (0.5 and 0.6, respectively). Compared to the high values that they showed for all SET Plan key actions combined, this result indicates that Japan and South Korea lag in commercial activities in this specific key action. No particular differences have been recorded for China and the US between the results of this specific key action and the results of all SET Plan key actions, where China performs well in patents and export, while the US is mostly focused on publications (Figure 34).

Similar results are apparent when looking at key action 5 'New materials & technologies for buildings' (graph not shown), with the EU27 scoring above average in all dimensions and the East Asian players focusing mainly on patents.

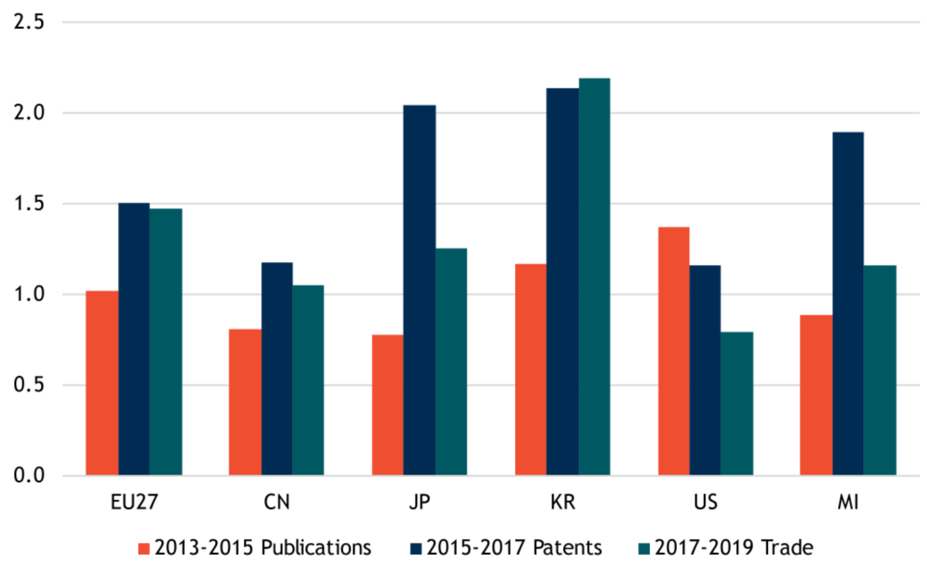
Figure 34: Innovation profiles of world players-key action 3 'New technologies & services for consumers'



Key action 7 'Competitive in global battery sector (e-mobility)'

South Korea has a strong focus on the batteries (key action 7) sector, as reflected by its excellent performance both in patents and export (scoring above 2 in both sub-indexes), and it performs better on those dimensions than most of the world players (Figure 35). Japan is not equally innovative when it comes to export as it is in patents (scoring 1.3 and 2 respectively). It is noteworthy that the EU27 also shows a particularly high performance when it comes to patents and export, scoring 1.5 in both, indicating a strong focus on investing in this specific sector and competing with the Asian key players.

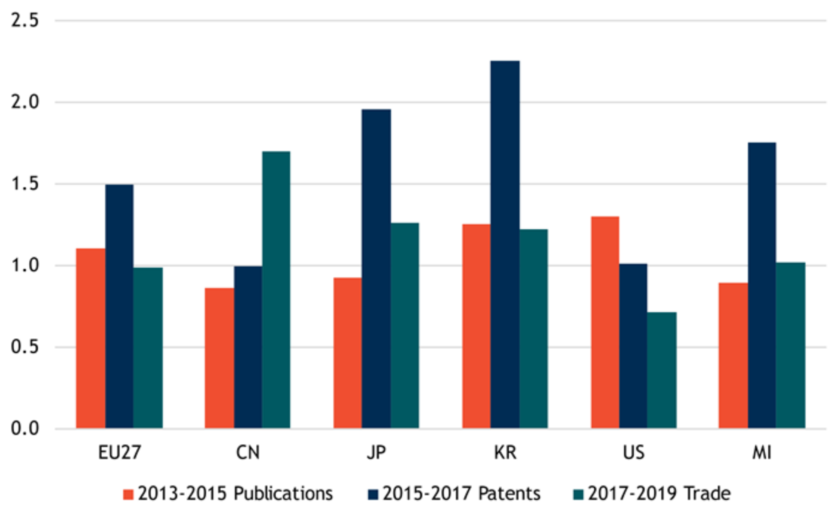
Figure 35: Innovation profiles of world players- key action 7 'Competitive in global battery sector (e-mobility)'



Key action 8 'Renewable fuels'

In key action 8 'Renewable fuels', the EU27 shows a moderate performance in publications and export while it scores above average in patents (Figure 36). China performs particularly well in export in this specific key action, surpassing all the world players, while it has a close to average performance in the other two dimensions. The US lags in export compared to the average (0.7). Nevertheless, it performs better than the world players when it comes to publications. Similar to the results of the majority of the key actions as well as to all SET Plan key actions combined, Japan and South Korea show strong activity in patents, ranking in the first two positions among all the in-scope countries in this key action, while their performance on export is moderate.

Figure 36: Innovation profiles of world players- key action 8 'Renewable fuels'

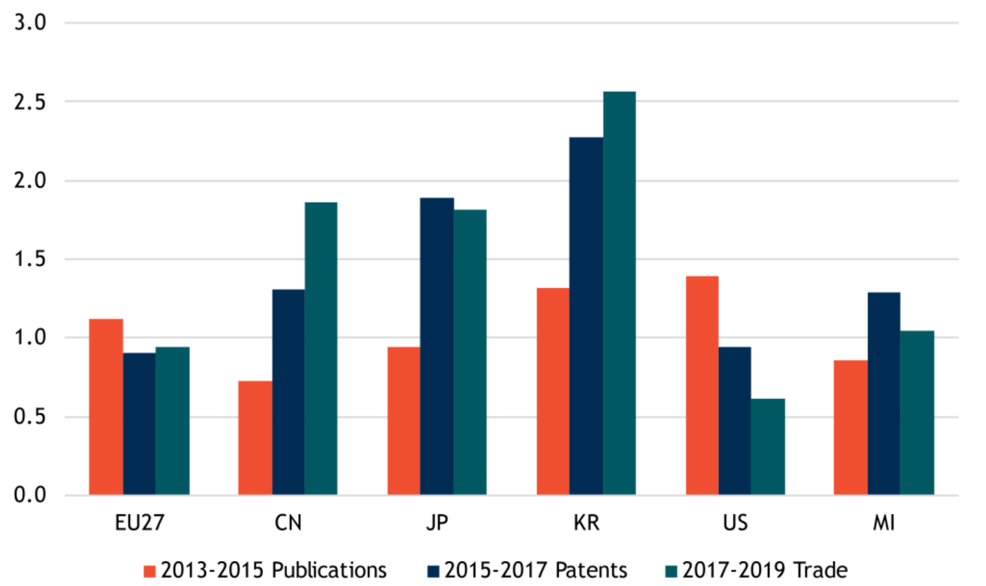


5.2.3 *Innovation profiles per renewable technology*

In this section, we discuss in more detail the main technologies under key action 1 'Performant renewable technologies integrated in the system', namely solar and wind technologies.

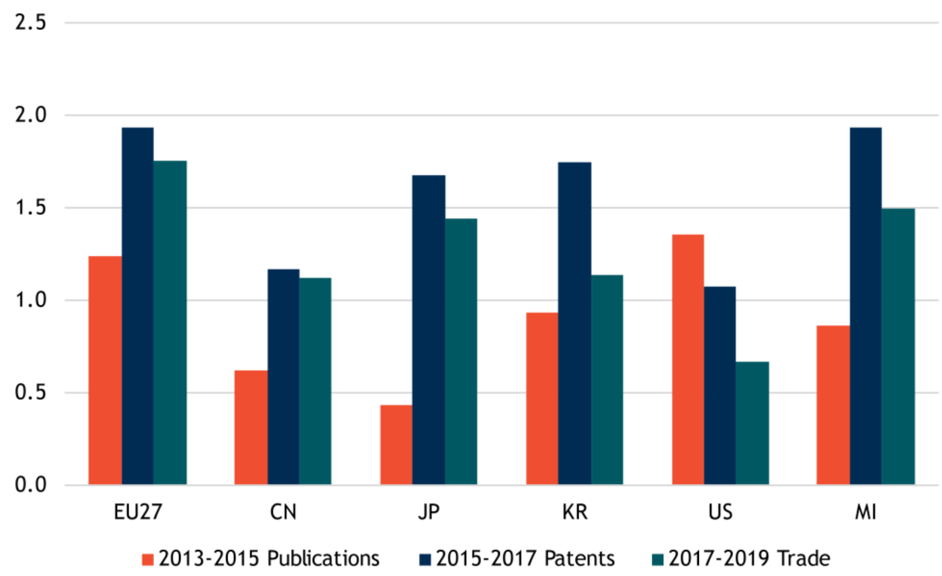
Regarding solar technologies (Figure 37), the EU27 shows an average performance in all three dimensions. China, Japan and South Korea are particularly innovative in patents and export and to a lesser extent in publications. The opposite trend is apparent for the US as it scores below average in both dimensions (0.9 in patents and 0.6 in export). Nevertheless, the US shows strong performance in publications, which is consistent with the trends recorded when looking at the innovation profile at All SET Plan key actions and key actions level.

Figure 37: Innovation profiles of world players in Solar energy technology



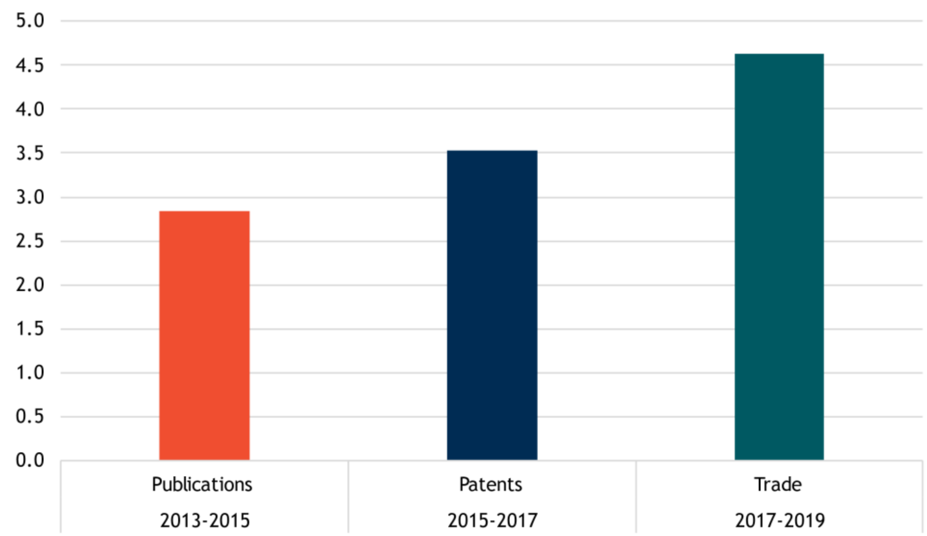
Contrary to the results for solar energy, the EU27 shows a strong performance in wind energy technologies in all the stages of the innovation activity, as reflected in the particularly high values in the three sub-indexes (Figure 38). This result can mainly be attributed to the exceptional performance of Denmark in this specific sector (Figure 39). China is equally innovative in patents and export, while Japan and South Korea have a stronger performance on patent activities compared to the other two pillars. The US lags in trading activity compared to the average (0.7), a trend that is in line with the performance in all disaggregation levels. The case of wind energy also verifies the tendency of China, Japan and South Korea not being active in the research but rather focus on the market development and commercialisation phases.

Figure 38: Innovation profiles of world players in Wind energy technology



When taking a closer look at the innovation profiles of the EU27 Member States in wind energy technologies, Denmark performs exceptionally well in all three dimensions (Figure 39). Denmark shows a remarkable export performance, scoring 4.6, followed by patents (3.5) and publications (2.8). This performance is well above average compared to the other EU27 Member States as well as to the world players, which makes this country the world leader in the specific technology in all stages of innovation.

Figure 39: Innovation profile of Denmark in Wind energy technology



The results of the innovation profiles for all SET Plan key actions combined, the key actions and technologies reveal that the EU27 overall scores above average in the three dimensions indicating equally distributed efforts on the different stages of innovation activities. In contrast, Japan and South Korea are strongly focused on patents as reflected from the significantly high values they recorded in all levels of disaggregation. China shows an average performance in patents and export while it is less focused on research. The US, on the other hand, has a clear focus on publications while it lags in the industry development, which is reflected from the lower-than-average values in most key actions and renewable technologies.

Annex A: Overview of the CEII

In this Annex we provide an overview of the CEII values per country for the period 2015-2017. The sequence of the countries is based on the ranking of the year 2017. A more detailed overview of the CEII structure and disaggregation levels is available in Excel files delivered by Trinomics to DG Research and Innovation.

Table A-1: CEII results per country for 2015-2017 at All SET Plan Actions level

Country name	CEII 2015	CEII 2016	CEII 2017	Ranking 2015	Ranking 2016	Ranking 2017
Denmark	0.86	0.89	0.87	1	1	1
Rep. of Korea	0.66	0.65	0.65	2	2	2
Sweden	0.61	0.63	0.63	3	3	3
Finland	0.61	0.62	0.62	5	4	4
Germany	0.61	0.60	0.61	4	5	5
Netherlands	0.60	0.59	0.59	7	6	6
Slovenia	0.54	0.56	0.57	10	8	7
Belgium	0.60	0.56	0.57	6	9	8
Austria	0.55	0.55	0.55	9	11	9
Luxembourg	0.48	0.57	0.55	20	7	10
Estonia	0.49	0.49	0.55	19	19	11
Italy	0.52	0.51	0.53	13	18	12
Norway	0.56	0.53	0.53	8	12	13
United Kingdom	0.52	0.52	0.53	12	14	14
Australia	0.50	0.51	0.52	17	17	15
Japan	0.52	0.52	0.51	11	15	16
Ireland	0.51	0.56	0.51	15	10	17
United States	0.52	0.51	0.50	14	16	18
Canada	0.50	0.52	0.50	16	13	19
China	0.44	0.46	0.48	23	23	20
Portugal	0.49	0.49	0.48	18	20	21
France	0.47	0.47	0.47	21	21	22
Spain	0.47	0.46	0.44	22	22	23
Czech Republic	0.42	0.43	0.44	25	24	24
Greece	0.35	0.41	0.43	28	25	25
Cyprus	0.33		0.40	31		26
Slovakia	0.37	0.39	0.40	26	26	27
Latvia	0.43	0.38	0.40	24	27	28
United Arab Emirates	0.30	0.34	0.39	33	28	29
Hungary	0.31	0.34	0.36	32	30	30
Saudi Arabia	0.36	0.34	0.36	27	29	31
Poland	0.34	0.32	0.36	29	33	32
Romania	0.29	0.31	0.35	34	34	33
Lithuania	0.33	0.33	0.32	30	32	34
Bulgaria	0.25	0.29	0.26	36	35	35
Chile	0.25	0.24	0.24	37	36	36
Mexico	0.22	0.21	0.22	38	38	37

India	0.20	0.21	0.20	39	37	38
Brazil	0.20	0.21	0.20	40	39	39
EU27	**0.46**	**0.46**	**0.47**			
MI	**0.40**	**0.41**	**0.41**			
Average all countries	**0.44**	**0.45**	**0.45**			

Note: Croatia, Indonesia and Malta do not have values for the year 2017 because of missing data in specific dimensions, therefore they are not included on the table.

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The Clean Energy Innovation Index (CEII) is a composite indicator designed to track progress in clean energy innovation performance. This report describes the context and the methodology behind the CEII, and then assesses the innovation progress of European and Mission Innovation member countries in the clean energy sector. The CEII contains three core dimensions; publications, patents and exports. Each dimension is disaggregated by indicator, by SET Plan key action, and by the technologies included in the key action "Performant renewables".

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