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Tracking research and innovation performance in the clean energy sector

Research and Innovation

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European Commission
Directorate-General for Research and Innovation
Directorate C – Clean Planet
Unit C1 – Clean Energy Transitions
Contact Daniele Poponi
Email RTD-C1-ASSIST@*ec.europa.eu*
Daniele.Poponi@*ec.europa.eu*
RTD-PUBLICATIONS@ec.europa.eu
European Commission
B-1049 Brussels

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Authors :

Daniele Poponi

Aikaterini Mountraki

Francesco Pasimeni

Tiago Pereira

Aliki Georgakaki

Giulio Caperna

Michal Dlugosz

Ingrida Murauskaite-Bull

Directorate-General for Research and Innovation
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Daniele Poponi from RTD.C1 was the lead author and had overall responsibility for the concept design and production of the report, and authored the sections on export, composite indicator analysis and EU performance. Aliki Georgakaki led the contribution from JRC.C7, whose team authoring the section on patents and contributing to different sections of the report consisted of Aikaterini Mountraki, Francesco Pasimeni (currently at the School of Innovation Science at Eindhoven University of Technology, the Netherlands), Michal Dlugosz and Ingrida Murauskaite-Bull. Tiago Pereira from RTD.G1 authored the section on publications. Giulio Caperna from JRC.I1 authored the methodological part of the composite indicator section. Daniel Vertesy (formerly at JRC.I1 and currently at the International Telecommunications Union), provided guidance on the methodological aspects of the composite indicator during the initial phase of the project.

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Executive Summary

The report assesses research and innovation performance in the clean energy sector of the European Union (EU) Member States and members of the Mission Innovation (MI) initiative between 2015 and 2020. Time trends, country rankings and a sectoral breakdown of indicators related to scientific publications, patents and export are discussed, with the aim of providing insights to policymakers on the effectiveness of research and innovation policies in the clean energy sector.

Indicators related to scientific publications can provide useful information as to the effectiveness of research and development (R & D) programmes in producing novel scientific knowledge that may enable technological development. Sectoral indicators can provide insights as to the scientific productivity of a given field that warrants special attention from policymakers due to its importance in achieving societal goals, such as the clean energy transition. The global trend in scientific publications related to clean energy technologies (CETs) shows a marked increase in scientific activity in this field, with a 50 % growth between 2015 and 2020. A significant driver of this global growth has been China, which almost doubled its scientific publications related to CETs in 5 years, increasing its share of the world's publications from 26 % in 2015 to 32 % in 2020 and reinforcing its global leadership. India more than doubled its CET-related publications between 2015 and 2020 and became the second highest (country) performer in 2020, with a share of 9 %, slightly above the United States (US) ranking third with 8 %. The EU accounted for 16 % and MI member countries for 77 % of CET-related scientific publications in 2020, respectively. The sector with the largest share of publications related to clean energy technologies in 2020 was smart systems (36 %), followed by sustainable transport (25 %) and renewable energy (20 %). When scaling publications by population, Denmark becomes the top performer with 195 CET-related publications per 1 000 000 people in 2020, followed by Norway (163) and the Republic of Korea (hereinafter South Korea) (135). MI members had on average 32 publications while the EU had 62 CET-related publications per 1 000 000 people in 2020. The quality of scientific publications on CETs was also assessed by looking at the share of publications in this field amongst the top 10 % cited. Overall, the share of CET-related publications in the 10 % most cited at the global level has remained constant at around 15 % between 2015 and 2020. With a share of 32 %, Luxembourg was the top (country) performer for this indicator, followed by Australia (23 %) and Denmark (22 %).

Patents are an important element in the innovation chain and indicators capturing patenting trends give insights into the inventive activity in specific technology areas. Inventions (patent families) related to CETs globally increased by 47 % from 2015 to 2018. A significant driver behind this trend has been the output by applicants from China, which more than doubled their filings. Among the other top performers, South Korea also experienced significant growth, while Japan and the US maintained their level of performance. Over the same period, the EU increased the annual number of filings by one fifth, with the strongest growth recorded in Slovenia, Denmark and Germany. In terms of high-value inventions, the top performer was Japan followed by the EU and the US. The number of high-value inventions in the EU grew by 16 % with the top performers being Slovenia, Hungary and Denmark. Overall, the global inventions landscape is heavily dominated by MI members, accounting for 97 % of the total CET inventions and 95 % of the high-value output. The biggest contributions to these come from China, Japan, South Korea, the EU and the US. EU Member States accounted for approximately one tenth of the total and one quarter of high-value inventions in this period. In addition, the EU and the US have the largest share of high-value inventions, with two thirds of their inventions being protected in more than one jurisdiction. The sector with the highest share of high-value inventions in 2018 is sustainable transport (46 %), followed by smart systems (26 %) and energy efficiency (21 %). The share of inventions in 'sustainable transport' has demonstrated a steady growth in patenting activity over the years, both in absolute terms and in terms of share of the high-value inventions.

Greater export performance of countries and firms can also be the result of successful innovation activities. While it is not always feasible to single out the effect of innovation versus other factors driving export performance, export indicators – when placed in the context of broad frameworks of indicators – can provide useful insights to policymakers as to the impacts of innovation on industrial competitiveness. Estimated export of CET-related products reached USD 120 billion (EUR 107 billion) in 2019, with an 8 % increase from 2015. Products related to renewable energy technologies had a predominant role in CET export in 2019, representing two thirds of the market (66 %). The sector with the second highest share on CET export is sustainable transport (22 %), followed by energy efficiency (10 %). Similarly to patents, sustainable transport has increased its share over time, in parallel with a slight decrease of renewable energy technologies. The EU had the highest share (33 %) in the global CET export market in 2019, followed by China (25 %) and the United States (7 %). Germany (10.1 %), Denmark (3.5 %), Italy (2.6 %) and the Netherlands (2.5 %) accounted for more than half of EU export and about one fifth of the global market. The share of global CET export was about 0.1 % of the world's gross domestic product (GDP) in 2019, and has remained stable since 2012. Denmark has the highest share of CET export in relation to GDP (1.2 %), followed by Slovenia (0.9 %) and Czechia (0.3 %). Amongst major economies, South Korea had the highest ratio of GDP export in relation to GDP in 2019 (0.20 %), followed by the EU (0.19 %) and China (0.13 %). The share of domestic value-added content in relation to CET export was 76 % in 2018, reaching USD 70 billion (EUR 60 billion). The domestic value-added content of CET export of EU and MI members increased by a compound annual growth rate (CAGR) of 1 % between 2012 and 2019, whereas CET exports increased by a 0.6% CAGR. This difference in growth rates may be explained by the increased self-sufficiency of domestic value chains. Overall, the trends observed for all indicators related to CET export point to reduced market shares of mature economies and an accelerated 'catching up' of emerging economies (e.g. China and India).

The overall research and innovation performance in the clean energy sector was assessed with a composite indicator capturing three phases of the scientific and technology cycle, the productivity of which was assessed with dimensional indexes on scientific publications, patents and export With a Clean Energy Innovation Index (CEII) of 0.81, Denmark was the top global performer in research and innovation performance in the clean energy sector in 2018, followed by South Korea (0.64) and Slovenia (0.61). In 2018, seven out of the ten top country CEII performers were EU members, with the EU scoring above the average of 38 countries for which the CEII was computed. Between 2015 and 2018, 18 countries reported an increment in CEII values, including China which overall produced the largest amount of publications, inventions and also had the highest value added generated in the export of CET related technologies.

Acronyms

CEII	Clean Energy Innovation Index
CET	clean energy technologies
EC	European Commission
EU	European Union
EIS	European Innovation Scoreboard
GDP	gross domestic product
JRC	Joint Research Centre
MI	Mission Innovation
OECD	Organisation for Economic Co-operation and Development
RD & D	research, development and demonstration
RD & I	research, development and innovation
R & D	research and development
R & I	research and innovation

1 Introduction

1.1. The role of indicators in assessing research and innovation performance

In a rapidly changing world, research and innovation policies must continuously respond and adapt to technology and market developments to ensure they support the achievement of societal goals, such as sustainable development and resilience. Indicators ([1]) and analyses built on robust and up-to-date data are strategic tools for policymakers: they can provide the information needed to increase the effectiveness and efficiency of research and innovation policies and programmes.

The Organisation for Economic Co-operation and Development (OECD) issued the *Oslo Manual*, which defines innovation as 'a new or improved product or process (or combination thereof) that differs significantly from the unit's previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process)' (OECD and Eurostat, 2018, p. 20) ([2]). Innovation is the outcome of a range of activities that are not limited to research and experimental development but also include other activities such as engineering, design and intellectual property. The wide spectrum of innovation activities and the complexity of the innovation process (with multiple feedback loops along the entire technology chain) call for the adoption of a systems-based perspective for innovation policymaking to be successful. In fact, the concept of national innovation systems (OECD, 1997), broadly defined as the national network of actors and their linkages shaping innovation processes, is often used in the literature to capture the systemic nature and complexity of innovation.

Accelerating innovation to meet sustainability goals is obviously not only a matter of increasing 'inputs', such as research, development and innovation (RD & I) investments, which would still be necessary given the complexity of the various challenges. It is also a matter of making the most out of existing RD & I efforts to ensure they deliver new and effective innovations at a faster pace. One enabling factor (amongst many) to increase the effectiveness and efficiency of RD & I efforts is adequately tracking the performance of such efforts through indicators.

Indicators are important building blocks in assessing RD & I performance. The construction and subsequent analysis of a wide range of indicators, including outputs (patents, technology cost reductions, technical improvements, etc.) and outcomes (e.g. market diffusion, R & D employment, productivity increases in the high-tech industry and export performance) can provide useful insights to policymakers as to the research and innovation performance of national innovation systems (Sims Gallagher, Holdren and Sagar, 2006). In addition, indicators can be very useful tools for determining policy priorities and can provide policymakers with useful information on the impacts of R & D efforts through either intra-country comparison (the evolution of the indicator at the national level over time) or inter-country comparison (trends in the comparative ranking of the country versus other economies).

More specifically, indicators on scientific publications can help policymakers assess the extent to which national or regional research programmes are impactful in producing scientific outputs, such as new discoveries, insights or concepts. These research outcomes feed into innovation processes, one of the intermediate outputs of which are inventive activities proxied by data on patents. Indicators on patents are often used to assess a country's technological progress. Furthermore, one of the most policy-relevant impacts of the innovation process is industrial competitiveness at both the micro and the macro level. Indicators on trade can provide insights into the market uptake of

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([1]) A statistical indicator is a 'data element that represents statistical data for a specified time, place, and other characteristics' (OECD, 2022a).

([2]) The term 'unit' in the context of the Oslo Manual refers to the actor responsible for innovation, be it the firm or a non-business organisation.

innovative technologies. Exports of products, and in particular high-tech products, are in fact often used as an indirect indicator of innovation performance at the country level. Other economic indicators, such as added value ([3]) can bring additional insights to policymakers as to the extent to which a domestic industry is able to leverage the know-how developed through RD & I investments into commercially viable products.

Innovation in the clean energy sector is a vital element of strategies pursuing climate neutrality and other energy sustainability goals (e.g. increasing energy security, reducing energy poverty) while at the same time reducing the costs to society of the energy transition. In other words, the faster successful innovation processes in clean energy technology advance, the sooner climate neutrality could be achieved at net positive costs to society. A comprehensive indicator-based framework aimed at tracking the evolution of clean energy innovation research performance has the potential to increase the performance of clean energy R & I policies. Such frameworks can be based on a limited set of output and outcome indicators, such as scientific publications, patents and export-related indicators.

The European Commission has long been at the forefront of research and innovation performance analysis in the clean energy sector and the broader innovation system. The Strategic Energy Technology Information System (SETIS) is the open-access information, knowledge management and dissemination system for the European strategic energy technology plan (SET plan) ([4]) (Pasimeni, et al., 2018). The annual report *Progress on Competitiveness of Clean Energy Technologies* (EC, 2021) discusses the research and innovation trends of EU members and major partner countries. Likewise, the *European Innovation Scoreboard* (EIS) enables a customised comparison of research and innovation performance of different countries through a framework of indicators (European Commission, 2021b). The EIS framework provides insights into the strengths and weaknesses of national research and innovation systems and helps policymakers identify priority areas to boost innovation performance.

In 2018, the Directorate General for Research and Innovation and the Joint Research Centre of the European Commission developed the concept for a composite indicator aimed at tracking research and innovation performance in the clean energy sector: the Clean Energy Innovation Index (CEII). A project funded by Horizon2020 was launched in 2020 and concluded in 2022 with the publication of eight different reports ([5]) and the construction of four datasets on scientific publications, patents, export and the CEII. Furthermore, in 2020 the Directorate General for Research and Innovation European Commission launched the 'Tracking Energy Innovation Impact Framework' project together with the International Renewable Energy Agency ([6]), which also included an in-depth analysis of costs and performance of seven renewable energy-related technologies (onshore and offshore wind, solar photovoltaics, concentrated solar power, hydrogen electrolysis, behind the meter batteries and large-scale solar thermal) and in-depth

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([3]) 'Gross added value' is defined by the OECD as the value of output minus the value of intermediate consumption; 'net added value' is defined as the value of output minus the value of intermediate consumption and the consumption of fixed capital (OECD, 2022a).

([4]) https://setis.ec.europa.eu/index_en

([5]) The reports, published by the EU Publications office and written by authors from Cambridge Econometrics, Science-Metrix and Trinomics under the supervision of the EC Directorate General for Research and Innovation and the Joint Research Centre are (in order of publication):

- Publications as a Measure of Innovation Performance (2021);
- Patents as a Measure of Innovation Performance (2021);
- Trade as a Measure of Innovation Performance (2021);
- First Report on the Clean Energy Innovation Index (2021);
- Publications as a measure of innovation performance in the clean energy sector (2022);
- Patents as a measure of innovation performance in the clean energy sector (2022);
- Export as a measure of innovation performance in the clean energy sector (2022);
- Second Report on the Clean Energy Innovation Index (2022).

([6]) https://cordis.europa.eu/project/id/899899; the project also received support from the United Kingdom government.

analysis of patents and standards of offshore wind and hydrogen electrolysis (IRENA, 2021; 2022). Both projects were launched with the aim of supporting the research, innovation and competitiveness pillar of the Energy Union and the work on indicators of the Mission Innovation Secretariat (see Textbox 1).

This report builds on the work carried out by the consortium executing the Clean Energy Innovation Index study (7). It aims to present the latest evidence on clean energy research and innovation progress to EU members and the Mission Innovation community.

Textbox 1: The European Commission and Mission Innovation

> In 2015 the European Commission joined – on behalf of the European Union – the Mission Innovation (MI) initiative. By its fifth year of membership, the EU had almost doubled its clean energy research, development and demonstration (RD & D) investments, reaching over EUR 1.8 billion. In addition, the EU had programmed a minimum of EUR 7.5 billion for energy RD & D in 2021–2027 through Horizon Europe. Mission Innovation 2.0 was launched in June 2021 as an action-oriented forum to accelerate innovation and make clean energy affordable, attractive and accessible to all. This second phase focuses on seven 'missions', namely, green-powered future, clean hydrogen, zero-emission shipping, carbon dioxide removal, urban transition, integrated biorefineries and net-zero industries (Mission Innovation, 2021). MI members need to identify their innovation needs per 'mission' and measure their innovation outcomes and developments. Through the 'Insights module', the Mission Innovation Secretariat aims to strengthen the evidence on clean energy technology progress, public- and private-sector investment and accelerate learning from national programmes.

1.2. Technology and geographical scope

The technology scope of the data collection and analytical work underlying this report is based on the key actions of the European Union Strategic Energy Technology Plan (SET Plan) (8) (EC, 2015a) which were aggregated into six categories consistent with the Energy Union (9) R & I priorities (EC, 2015b):

- renewable energy technologies,
- smart systems,
- energy efficiency,
- sustainable transport,
- carbon capture, utilisation and storage (CCUS),
- nuclear.

Broadly speaking, in the context of this report, clean energy technologies are those (a) used or enabling the production, conversion and final uses of primary and secondary energy sources that either do produce greenhouse gas emissions (e.g. electricity generation from renewable energy sources) or entail net emissions reductions (e.g. more efficient technologies used in the conversion of fossil fuels into secondary energy vectors); and (b) technologies for carbon capture, utilisation and storage.

The analysis builds on a dataset of 12 indicators on scientific publications, inventions, export, along with a composite indicator (Table 1) covering 42 countries, namely EU

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(7) The consortium was led by Trinomics and included Cambridge Econometrics and Science-Metrix.
(8) European Strategic Energy Technology Plan (SET plan) key actions.
(9) https://energy.ec.europa.eu/topics/energy-strategy/energy-union_en

Member States (EU-27) as of May 2021 and Mission Innovation members (MI-23) as of December 2018 (Table 2) [10].

Table 1: Indicators underlying the analysis on research and innovation performance in the clean energy sector

Indicator	Dimension	Time-frame	Data sources
Number of scientific publications	Publications	2015–2020	Science-Metrix
Number of scientific publications by population	Publications	2015–2020	Science-Metrix
Share of highly cited publications	Publications	2015–2018	Science-Metrix
Number of inventions	Inventions	2015–2018	EC JRC
Number of inventions by GDP	Inventions	2015–2018	Author's calculations based on EC JRC and World Bank
Number of high-value inventions	Inventions	2015–2018	EC JRC
Number of high-value inventions by GDP	Inventions	2015–2018	Author's calculations based on EC JRC and World Bank
Trade value of export flows (products)	Export	2015–2019	Author's estimates based on UN Comtrade and Cambridge Econometrics
Trade value of export flows (products) by GDP	Export	2015–2019	Author's calculations based on Cambridge Econometrics, UN Comtrade and the World Bank
Domestic value added content of export Flows (trade value of products)	Export	2015–2019	Author's estimates based on Cambridge Econometrics and OECD
Domestic value added content of export flows (trade value of products) by GDP	Export	2015–2019	Author's calculations based on Cambridge Econometrics, OECD and the World Bank
Clean Energy Innovation Index	-	2015–2018	Author's calculations based on Trinomics

[10] Table 2 lists MI members as of the end of 2018 (MI-23), when the CEII project was launched. In September 2019, Morocco joined MI while Indonesia and Mexico did not join the second phase of MI that started in September 2021. The European Union (EU-27) has also been a member of MI since its launch in 2015. To avoid double counting of those EU members that are also MI members, EU-27 aggregate values are not included in computing the values for indicators related to the MI-23.

Table 2: List of countries included in the analysis

EU members (as of May 2021 – EU-27)		MI member countries (as of December 2018 – MI-23)	
Austria*	Italy*	Australia	Mexico
Belgium	Latvia	Austria*	Netherlands
Bulgaria	Lithuania	Brazil	Norway
Croatia	Luxembourg	Canada	Saudi Arabia
Cyprus	Malta	Chile	South Korea
Czechia	Netherlands	China	Sweden*
Denmark*	Poland	Denmark*	United Arab Emirates
Estonia	Portugal	Finland*	United Kingdom
Finland*	Romania	France*	United States
France*	Slovakia	Germany*	
Germany*	Slovenia	India	
Greece	Spain	Indonesia	
Hungary	Sweden*	Italy*	
Ireland		Japan	

NB: '*' denotes EU Member States that joined MI.

2. Publications

2.1. Bibliometric indicators as a measure of research performance

Bibliometric information, i.e. data and analysis related to scientific publications, including citations to these publications and citations in patents, is extensively used in mapping fields or subfields of scientific and technological enquiry. It is also used as a means of assessing the performance of the major actors in those fields and subfields (Verbeek, et al., 2003).

Scientific publications can be regarded as an output of R & D activities, either from public or private sources. In fact, more investment in R & D is likely to translate into more scientific production, including in the clean energy sector (Popp, 2016). Therefore, scientific publications are an important metric to assess the impact of R & I system policies (Haeffner-Cavaillon and Graillot-Gak, 2009). Bibliometric indicators are also used as an assessment metric for funding decisions (Durieux and Gevenois, 2010).

The assessment of quantity and quality of publications can be done using a set of statistical and mathematical indices called bibliometric indicators. Two major categories of indicators are (1) quantitative indicators that measure the research productivity of a researcher, a community of researchers, or a national science and technology system (e.g. the number of scientific publications produced during a given year by a country); and (2) qualitative indicators that evaluate the impact of publications (Joshi, 2014). Bibliometric indicators are also used in other reports to assess the efficiency of the research system, such as in the *European Innovation Scoreboard* or the *Science, Research and Innovation Performance of the EU* report published by the European Commission (2021b; 2022a).

There has been limited research aimed at improving the understanding of the correlation between R & D investment and the production of scientific publications related to clean energy technologies. In one study, Popp found that USD 1 million in additional government funding leads to one to two additional publications, but with lags as long as 10 years between initial funding and publication (Popp, 2016). Broadly speaking, there appears to still be limited attention given to the importance of research productivity and why bibliometric trends should matter to policymakers designing and implementing clean energy innovation policies and funding decisions.

The use of bibliometric indicators is also important to study the evolution over time of the science and knowledge base necessary to assess the increasing use of clean energy technologies. Hötte et al. (2021) used data covering almost all US patents and scientific articles that are cited by them over the past two centuries and were able to describe the evolution of knowledge bases in ten key low-carbon energy technologies. They discuss how technological interdependencies have changed over time and found that low-carbon energy inventions became increasingly science based. Among low-carbon fuels and technologies, nuclear and solar energy are the most science intensive, while hydro power is the least. Furthermore, nuclear, fuels and renewables form three fairly separate knowledge clusters.

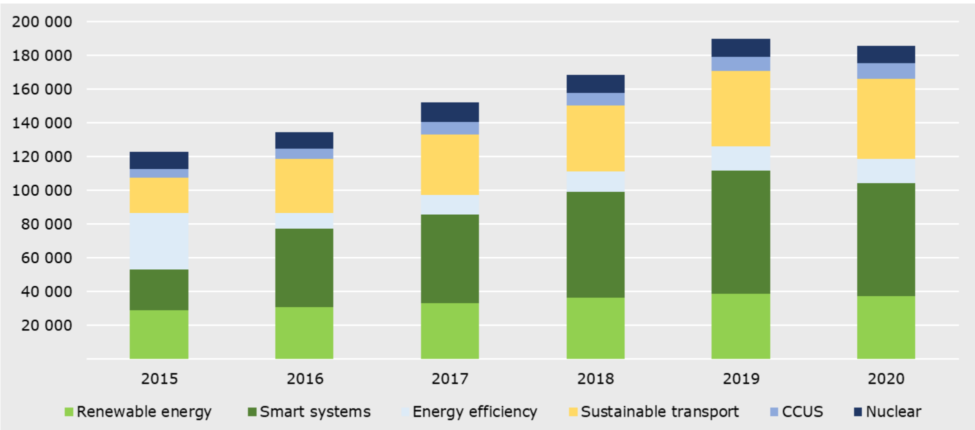
2.2. Scientific production in the CET sector

One of the most used indicators to assess scientific productivity is the number of scientific publications (Verbeek et al., 2003). In absolute terms, the number of scientific publications related to clean energy technologies increased by 51 % in 5 years, from around 123 000 publications in 2015 to more than 185 000 publications in 2020 (Figure 1). However, in 2020 there was a small decline in the number of scientific publications relative to 2019, possibly due to the impact of the COVID-19 pandemic. Looking at the technology breakdown, all different types of clean energy technologies apart from nuclear and energy efficiency saw an increase in research production in the same period. The technology that has seen the biggest increase in the total number of scientific publications is smart systems, with 178 % growth, followed by sustainable transport with 128 %. The field with the largest number of scientific publications in 2020 was smart systems, with about 67 000 publications.

The five leading countries on scientific production related to CETs at the global level are China, which accounted for 32 % of the scientific production worldwide in 2020, followed by India (9 %), the United States (8 %), South Korea (4 %) and Germany (3 %). Japan and the United Kingdom come sixth and seventh, both with a share of around 2.5 % on the global total, respectively.

The MI-23 account for 77 % of total scientific publications in clean energy technologies worldwide, with a percentage change of 45 % between 2015 and 2020. The EU-27 produced 16 % of CET-related publications in 2020, the second highest share after China. Within the European Union, the five countries with the highest number of scientific publications related to CETs are Germany (with a 3 % share of the worldwide total), followed by Italy (2.5 %), Spain (1.8 %), France (1.6 %) and Poland (1.2 %).

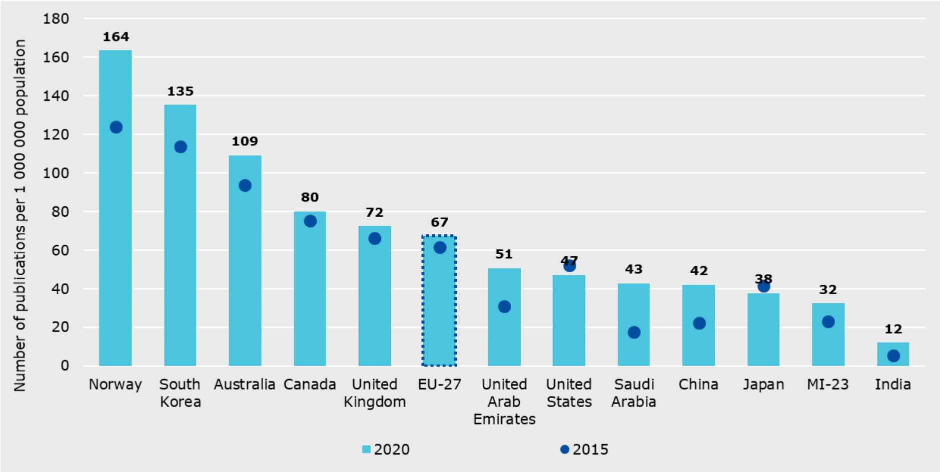
Figure 1: Number of scientific publications in clean energy technologies, 2015–2020



Source: Science-Metrix (2022).

The picture is quite different if the number of scientific publications is scaled by population (Figure 2). In 2020, Norway was the best-performing country with 164 scientific publications in clean energy technologies per million inhabitants, followed by South Korea (135) and Australia (109). Amongst the top performers in terms of the (absolute) number of CET-related scientific publications in 2020, South Korea is followed by the United Kingdom (72), Germany (69), the United States (47), China (42), Japan (38) and India (12). The MI-23 have about 32 scientific publications per 1 000 000 population, whilst the EU-27, with 67 CET-related publications, were in the upper end of top global performers in 2020.

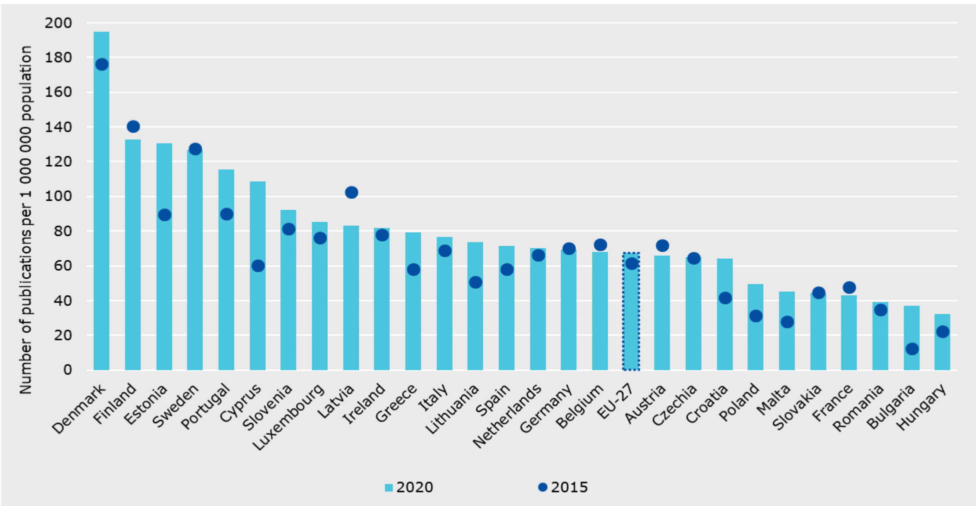
Figure 2: Number of scientific publications in CETs per 1 000 000 population, top global performers and major economies, 2015 and 2020



Source: Science-Metrix (2022).

Almost all the countries and both the EU-27 and the MI-23 showed an improvement on CET-related publications scaled by population over the 2015–2020 time frame. Saudi Arabia (+ 142 %), India (+ 124 %) and China (+ 87 %) had the highest increments in percentage terms (from relatively low levels in 2015). A few countries that already had very high values in 2015, such as Norway, South Korea and Australia, also increased their per capita values of CET-related scientific publications significantly. On the contrary, the United States and Japan where the only two countries showing a drop of 10 % and 9 %, respectively, during the period considered. The EU-27 share increased by 10 %, from 61 to 67. Between 2015 and 2020, nineteen EU countries reported an increase, with important percentage changes in Bulgaria (+ 195 %) and Cyprus (+ 81 %).

Figure 3: Scientific publications related to CETs per 1 000 000 population, EU members, 2015 and 2020



Source: Science-Metrix (2022).

When comparing across EU Member States (Figure 3), Denmark is the top-performing country with a value of almost 200 scientific publications per 1 000 000 population in the field of clean energy technologies in 2020. Finland comes in second place with a share of 133, followed by Estonia with 130. Conversely, Hungary is the least performing country in the EU with 32 scientific publications per capita in 2020, preceded by Bulgaria (37) and Romania (39). Notably, some EU members that have relatively low or moderate R & I performance in general (as measured by the *European Innovation Scoreboard* (EC, 2021b)), such as Cyprus, Portugal and Slovenia, show very strong performances regarding scientific production in the field of clean energy technologies.

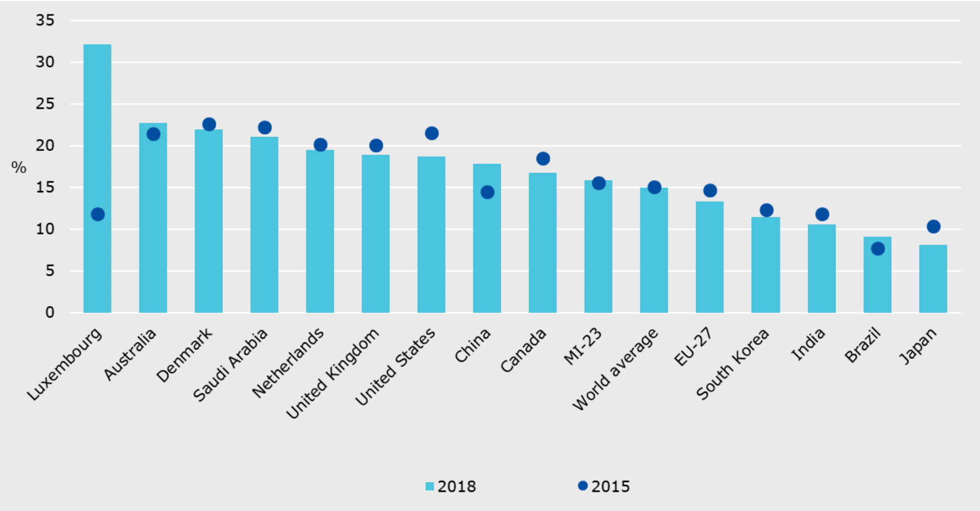
2.3. Quality of the scientific production in the CET sector

Even though the number of scientific publications is an important metric to assess the level of scientific production, it is a merely quantitative indicator that would ideally be complemented by information on the quality of such publications. An insightful qualitative metric is the 'share of highly cited publications among the 10 % most cited'. This indicator can also be an indicator of the efficiency of the research system, since highly cited publications are likely to reflect higher scientific quality.

In 2018, Luxembourg was the top global performer with a percentage of 32 % of its CET-related scientific publications among the top 10 % most-cited. In second place came Australia (23 %), followed by Denmark (22 %), Saudi Arabia (21 %) and the Netherlands (19 %) (Figure 4). Amongst the countries that had the highest number of CET-related scientific publications (in absolute levels), the United Kingdom had the highest share (19 %), followed by the United States (19 % – only a few decimals below the UK), China (18 %), South Korea (11 %), India (11 %) and Japan (8 %). By comparison, the EU-27 had a percentage of 14 %, whilst the MI-23, with a share of 16 %, were hovering slightly above the world average (15 %).

Between 2015 and 2018, most of the countries reported a decline in their percentages of top 10 % most-cited publications related to CETs, with the most marked declines in the United States, Canada and Japan. In the opposite direction, countries like Luxembourg, China and Australia showed an improvement in the quality of their CET-related publications. However, it is important to highlight that large variations can occur over time due to the small number in the absolute number of publications.

Figure 4: Percentage of scientific publications related to CETs among the top 10 % most-cited publications, 2015 and 2018 (top 5 + international comparison)

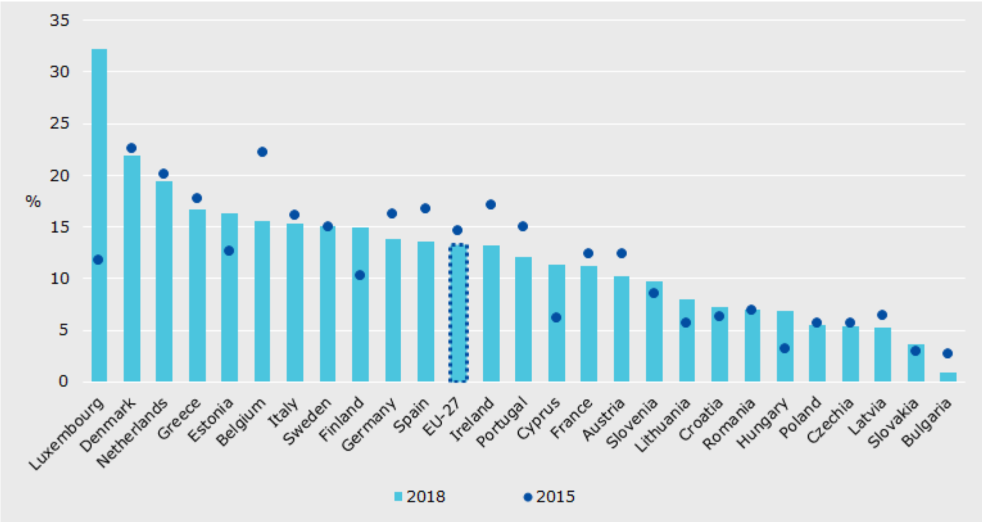


Source: Science-Metrix (2022).

Within the European Union (Figure 5), after Luxembourg which was the top global performer, Denmark comes second with 22 %, followed by the Netherlands (19 %), Greece (17 %) and Estonia (16 %). The lowest values among EU-27 countries for this indicator are those of Bulgaria (1 %), Slovakia (4 %) and Latvia (5 %).

There is strong variation in EU Member State values over the period 2015–2018. At least in a few cases, such as Estonia, Luxembourg or Greece, this variation can be explained by the low number of publications in 2015. 10 Member States saw their share of highly cited CET-related publications increasing, with Luxembourg and Cyprus making the greatest improvements, with an increase of 20 and 5 percentage points, respectively. On the other hand, Sweden's performance stagnated and 15 countries saw their performance decreasing, with Belgium and Ireland having the biggest declines [11].

Figure 5: Percentage of scientific publications related to CETs among the top 10 % most-cited publications in total scientific publications of EU Member States, 2015 and 2018



Source: Science-Metrix (2022).

3. Patents

3.1. Patents as a proxy of the inventive activity

Patents are an important element in the innovation chain and give insights into the inventive activity in specific technology areas. A patent is a legal document that protects an invention from its exploitation for commercial purposes without authorisation and gives the right to benefit from that invention through manufacturing, selling or using. A patent is granted to inventions that are new, bring an inventive step and concern industrial application. A patent protects the invention in the specific national jurisdiction where a patent application is filed, meaning that more than one application is necessary to protect the same invention in more than one county.

Patents concerning the same invention are grouped under the same family, which is, therefore, a reliable proxy of the inventive activity. Since each patent application comes at a certain cost, inventions protected in more than one national jurisdiction are considered of high value, because they indicate the willingness to pay for the protection of the invention in multiple countries. Further, considering the residence country of the patent applicants, it is possible to track the international part of the invention, which is the share of the invention protected in a national jurisdiction different from the

(11) Data for Malta was not available.

applicant's residence country ([12]). The total number of inventions (patent families), high-value inventions and international inventions are the three indicators analysed in this section of the report (Pasimeni, et al., 2021).

A patent application is linked to the technology area where it brings technology advancement. The technology tagging associated with all patent applications permits quantifying the inventive activity in specific technology areas. The Y02 and Y04 schemes of the cooperative patent classification (CPC) allow the analysis to be focused on the inventive activity related to climate change mitigation technologies (CCMTs). Within CCMTs, it is possible to identify the nine key technology areas that are strategic to meeting climate objectives ([13]).

A patent family is composed of more than one patent application, which in turn can have more than one technology tagging associated with it. Moreover, the invention may be developed by more than one entity. Therefore, it is critical to avoid double counting the same invention and to ensure the proper assignment of share to participants in the inventive activity and to the multiple technology areas tackled by this invention. The fractional count technique allocates an equal share of the invention to all distinct combinations of a patent application, technology tagging and participant. This approach follows the European Commission's Joint Research Centre (JRC) patent-based methodology, which also reports the concordance between CCMTs and the key technology areas in the clean energy sector (EC, Joint Research Centre et al., 2017; Pasimeni, 2019; Pasimeni, Fiorini and Georgakaki, 2019; Pasimeni and Georgakaki, 2020; Pasimeni, Fiorini and Georgakaki, 2021).

There is approximately 1 year lag between financing the patent activity and the production of the patent, while there is around 3.5 years delay between submission and publication (EPO, 2020). The patent analysis is based on Patstat (autumn 2021 edition), providing a near-complete dataset for 2018.

3.2. Patenting trends in the strategic clean energy technology areas

During 2015–2018, inventions in clean energy technologies increased by almost 50 % (Figure 6), mainly driven by an exponential growth in domestic filings in China (Figure 7). South Korea also noted a significant growth, while Japan and the US maintained their levels of performance. Over the same period, the EU increased the annual number of filings by one fifth and more than 370 000 inventions were produced globally in the clean energy technology (CET) sector, yet only one in four would be considered high value. MI members accounted for the vast majority of the CET inventions with 97 % of the total and 95 % of high-value filings for the same period, while EU Member States accounted for approximately one tenth of the total and one quarter of high-value inventions.

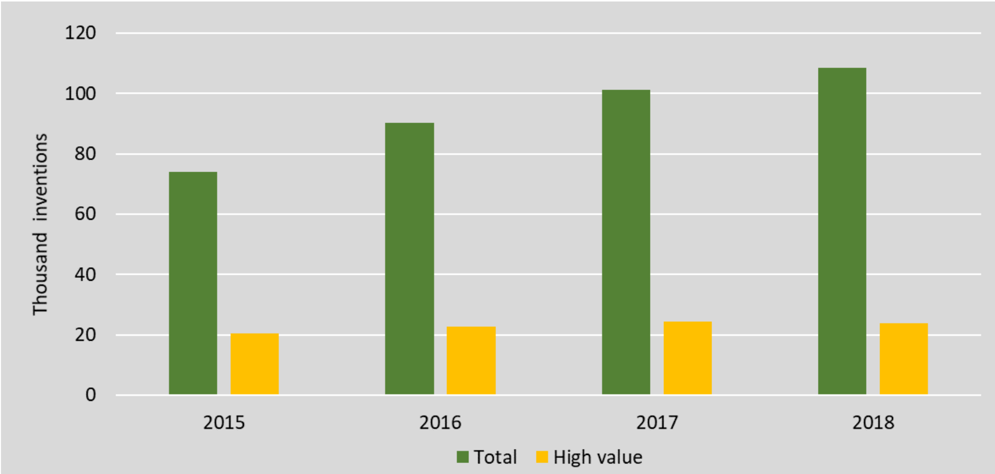
Figure 7 shows the number of patents in clean energy technologies for five major economies participating in MI (China, Japan, South Korea, the EU and the US) over the same period, which accounted for 96 % of the total and 91 % of the high-value filings. Applicants from China filed more than half of the total inventions, yet only 6 % of these applications were also protected in another jurisdiction (and thus considered high value). Japan accounted for approximately one in six CET inventions in the same period, while South Korea, the EU and the US follow, with about 10 % of the total. Japan also leads in

([12]) In other words, each patent has a domestic and an international share for the same invention. The actual values of the shares depend on the number of countries in which the patent was filed. For example, if a patent is filed in four countries, one of which is the country of the applicant, the international share would be 75 % and the domestic 25 %, respectively. A patent can be only international and not high value, i.e. when the invention is protected only in one country that is different than the applicant's country of residence. A patent can be only high value and not international, i.e. when it is filled in multiple countries, all part of the same national jurisdiction (e.g. the US).

([13]) These are the European SET plan key actions for research and innovation.

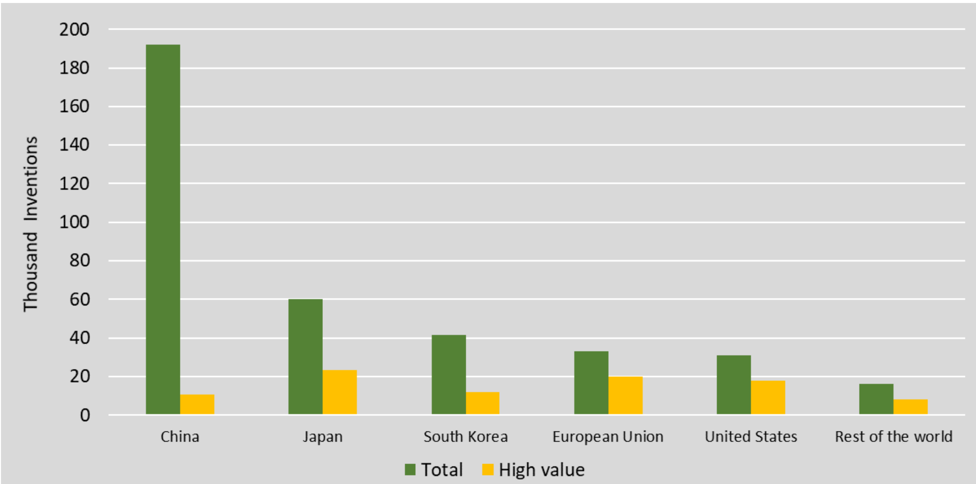
the absolute number of high-value inventions, followed by the EU and the US. Nonetheless, the EU and the US have the largest share of high-value inventions, with two-thirds of their inventions protected in more than one jurisdiction.

Figure 6: Number of global inventions (patent families) in clean energy technologies



Source: Joint Research Centre (JRC) based on European Patent Office (EPO), Patstat 2021 autumn edition.

Figure 7: Number of clean energy technology inventions for major economies, 2015–2018

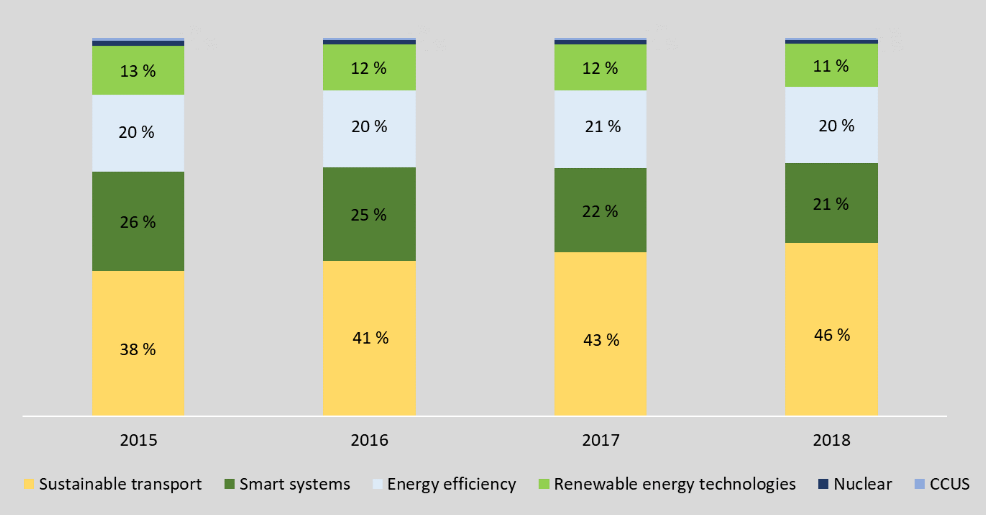


Source: Joint Research Centre (JRC) based on European Patent Office (EPO), Patstat 2021 autumn edition.

Figure 8 shows the evolution of the global patent portfolio over the same period. There has been an increased focus on sustainable transport across the board, from 38 % to 46 % of global high-value inventions. The shift was more pronounced for the EU and Japan (+ 9 % between 2015–2018), followed by Korea, the US and China. Smart systems accounted for a quarter of inventions at the start of the period, dropping to a fifth by 2018, while energy efficiency also accounted for a fifth of high-value inventions. Renewable energy technologies had a 12 % share on average, while nuclear and carbon capture, utilisation and storage only 1 % each.

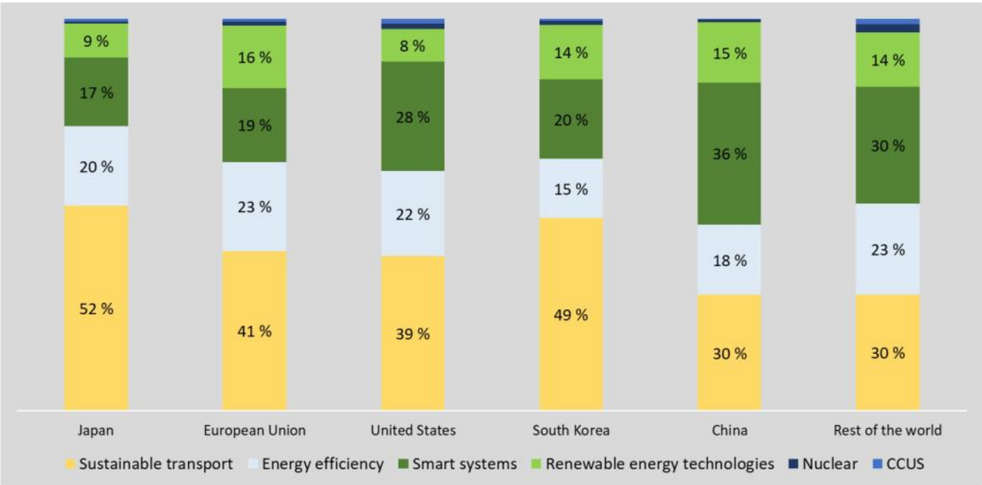
Figure 9 shows the distribution by technology area in the patent portfolios of the major economies participating in MI, over the same period. Relative to the global mix (Figure 8) China has a higher share of inventions in smart systems with a portfolio closer to the average for the rest of the world. The US also displays a higher share in smart systems than the global average. Japan and South Korea show increased effort in sustainable transport, with shares well above the average.

Figure 8: Evolution of the share of high-value global inventions per CET category



Source: Joint Research Centre (JRC) based on European Patent Office (EPO), Patstat 2021 autumn edition.

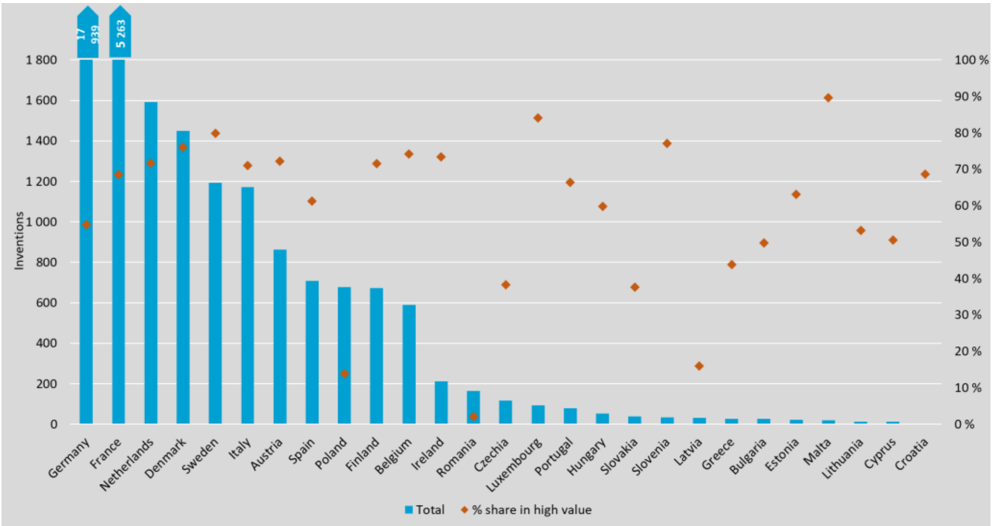
Figure 9: Average share of high-value inventions per CET category for major economies, 2015–2018



Source: Joint Research Centre (JRC) based on European Patent Office (EPO), Patstat 2021 autumn edition.

As previously mentioned, the EU had the highest ratio of high-value inventions among major economies and MI members; 60 % of all filings were of high value, compared to the MI average of 25 %. The majority of the EU Member States contributed to the very good performance of the EU, in terms of share of high-value patents (Figure 10). Four Member States (Germany, France, Netherlands and Denmark) accounted for about 80 % of the total and high-value EU inventions for the same period, with Germany in particular contributing more than half of the total. France followed with approximately one sixth of the total EU inventions, while Netherlands, Denmark, Sweden and Italy filed for around 5 % of the total each.

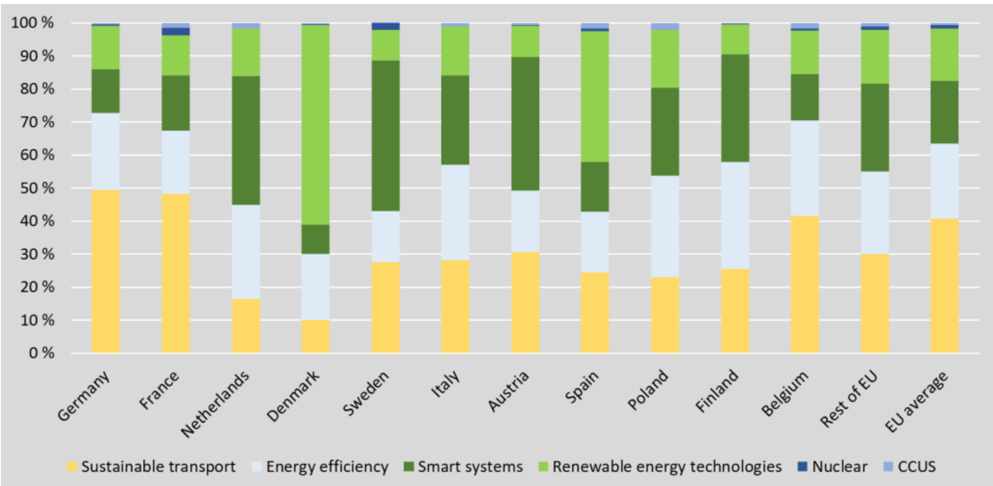
Figure 10: Number of CET inventions and share in high-value inventions per EU Member State, 2015–2018



Source: Joint Research Centre (JRC) based on European Patent Office (EPO), Patstat 2021 autumn edition.

In terms of technology areas, the portfolios of Germany and France shaped the EU portfolio since they account for 67 % of all EU high-value inventions. Nonetheless, the portfolios at the EU Member State level vary greatly (Figure 11). Among the leading Member States, Germany, France and Belgium focus more on sustainable transport compared to the EU average, while Denmark and the Netherlands have a lower than average share in this field, specialising in smart systems and renewable energy technologies respectively instead. The Netherlands are joined by Sweden, Austria and Finland in an above average performance in smart-system technologies, while Spain, like Denmark has a high share of inventions in renewable energy technologies. Finland and Poland show greater focus in energy-efficiency technologies than the EU average. Finally, CCUS accounts for 2 % of the patenting portfolio in the Netherlands, Spain, Poland and Belgium, while nuclear attracted 2 % of the patenting portfolios in France and Sweden.

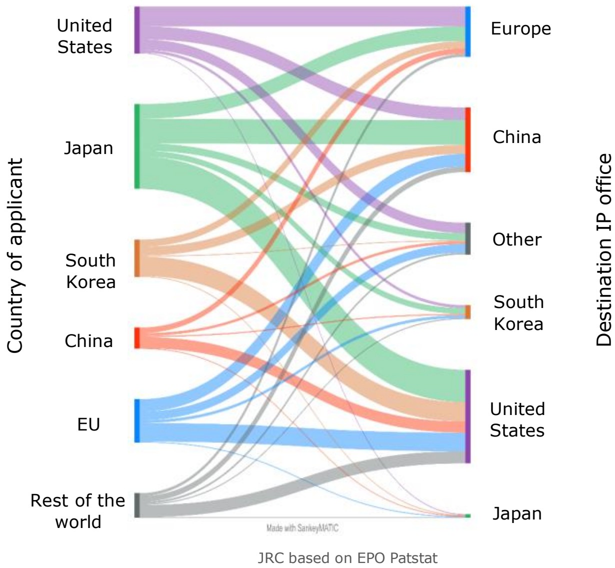
Figure 11: Share of high-value inventions related to the five CET categories in the national portfolio of the top five EU countries, 2015–2018



Source: Joint Research Centre (JRC) based on European Patent Office (EPO), Patstat 2021 autumn edition.

Figure 12 shows where applicants headquartered in major economies chose to protect their invention in clean energy technologies. The US attracted most of the international patenting activity, with more than one third of high-value inventions filing for protection in that market. China and the EU were the destination for 25 % and 20 % of the international high-value applications, respectively. Japan, a major innovator, accounting for a third of clean energy inventions protected internationally, remains rather small as a destination market for foreign applicants.

Figure 12: International protection of high-value inventions in major economies, 2015–2018



Source: Joint Research Centre (JRC) based on European Patent Office (EPO), Patstat 2021 autumn edition.

4. Export

4.1. Relevance of export indicators for clean energy innovation performance

Market competitiveness is one of the outcomes of successful innovation activities undertaken by firms, the competitiveness of which can be proxied by trends on the value of exported products or global market shares relative to main competitors. The same relationship between innovation and competitiveness applies at the macro level to national economies, which should not be intended (only) as the sum of all firms producing and exporting products but rather as a network of innovation-active stakeholders and their linkages, often referred to as national innovation systems (OECD, 1997; Sagar and Holdren, 2002).

The objective of increasing competitiveness of firms in international markets is in itself a strong factor in mobilising innovation efforts, hence indicators related to export can also provide useful insights on innovation performance. Obviously, innovation is only one of the many factors affecting market competitiveness, which can also depend on labour costs, the quality of human capital, economies of scale in production, access to raw materials, the availability of subsidies and other forms of support given by the government, etc. Some of these factors (e.g. human capital), together with process innovation, may determine greater productivity at the firm level. In consideration of the many factors that can drive export performance, a statistically solid assessment of the *net* impact of innovation on export performance at the country level would warrant solid econometric analysis relying on granular datasets encompassing all relevant variables, which are not always available at the sectoral level, including for clean energy technologies. Therefore, it should be cautioned that using **only** export performance data to draw insights on innovation performance of a given country may lead to inaccurate conclusions. Export indicators need to be put in context and at minimum be part of a system of indicators, as in the *European Innovation Scoreboard* (European Commission, 2021b) and the *Innovation Output Indicator* report of the European Commission (Bello et al., 2022).

There is evidence at both the microeconomic and the macroeconomic level that companies and countries characterised by greater innovation outputs (usually proxied by patents) also have stronger export performance, including in the green technology sector, of which clean energy technologies are a subset (Dipietro and Anoruo, 2006; Costantini and Mazzanti, 2012; Love and Roper, 2015).

Export-performance indicators can be used to assess the impact of successful innovations on the competitiveness of firms and countries. One caveat of this assessment is that it is not always possible to properly account for all factors influencing export performance so as to 'isolate' the effect of innovation at both the micro and the macro level. In addition, export trends can only provide insights as to the **relative** innovation performance of one country or aggregate of countries relative to other countries or regions. In other words, export indicators cannot be used to complement other indicators (e.g. patents) when looking at innovation performance at the global level.

Given this broad caveat, there are some additional considerations to be made on different export indicators. Using figures on absolute exports of a given product might not account for the 'assembly effect', i.e. the fact that a given share in the export value of a given product is made of imported components and the same product (the output value) has a relatively low domestic added value ([14]). This may suggest a relatively modest role of innovation processes in the firm. Therefore, using data on 'value added in exports' as one of the indicators to gauge the effects of innovation performance on export may neutralise at least this limitation.

Along these lines, the analytical work carried out on the export of products related to CETs include indicators on both export values and domestic value added of exports of 49 product categories selected from the UN Comtrade database ([15]), encompassing the six categories listed in Section 1.2.

4.2. Analysis of export trends of products related to clean energy technologies

Estimated global exports of products related to clean energy technologies ('CET exports') of increased from USD 111 billion (EUR 100 billion) in 2015 to USD 120 billion (EUR 107 billion) in 2019 (+ 8 %) (Figure 13) ([16]). EU Member States (EU-27) and MI members accounted for about 80 % of estimated global CET export).To note, the market trend of CET exports broadly aligns with the growth of global clean energy investments, which have increased by 11 % from 2015 to 2019 (IEA, 2022).The top five exporting countries of CET-related products in 2019 were China (25 % of the estimated total CET export market), followed by Germany (12 %), the United States (7 %), Japan (6 %) and South

([14]) See footnote ([3]) for definition of gross added value and net added value.

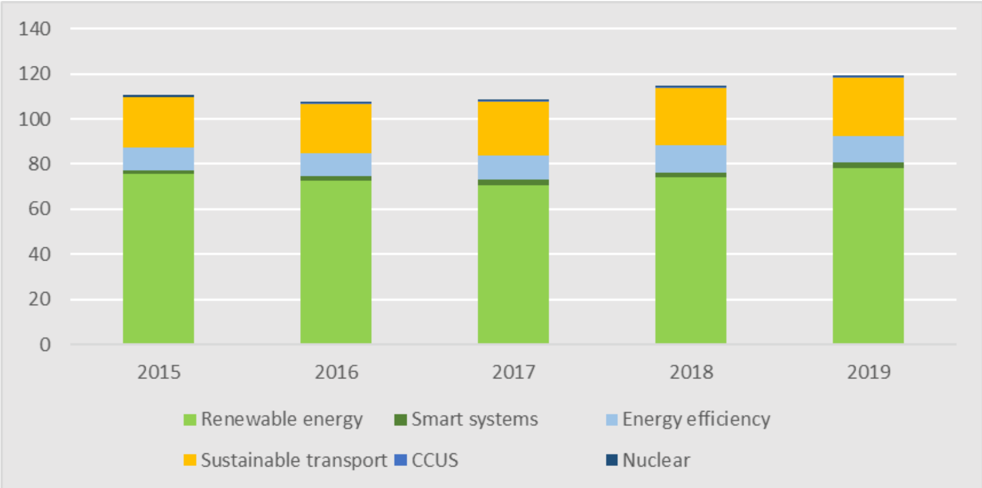
([15]) A concordance table between SET plan key actions and harmonised system (HS) codes was developed by Cambridge Econometrics (see European Commission, Directorate-General for Research and Innovation, Fazekas, D. and Molnár, B. 2022).

([16]) Exports and domestic value added of CET-related exports were estimated by authors building on the analysis included in the report from Cambridge Econometrics *Export as a measure of innovation performance in the clean energy sector* (European Commission, Directorate General for Research and Innovation, Fazekas, D. and Molnar, B., 2022). Data coverage includes MI-23 and EU-27 members, for a total of 42 countries. Coefficients estimated from expert-based assessments or desktop research were applied to account for the fact that several HS codes include products that have other applications other than low-carbon energy systems, for example, 841489, 841490, 731100, 761300 in the case of CCUS v conventional fossil-fuel applications. Further work is needed in the analysis of HS codes of products related to CETs, in particular to account for products with applications in energy efficiency investments in industry and transport.

Korea (4 %). The combined market share of the top five exporters was about 51 % in 2019, with the EU-27 exporting about 33 % and the MI-23 accounting for about 72 % of estimated global CET exports, respectively. The market shares of the five top CET exporting countries were relatively stable from 2015 to 2019. Amongst EU Members States, the countries with the highest estimated exports of CET-related products in 2019 after Germany (EUR 12.1 billion) were Denmark (EUR 4.1 billion), Italy (EUR 3.1 billion), France (EUR 2.9 billion) and the Netherlands (EUR 3 billion).

When looking at the technology breakdown of CET exports, the predominance of products related to renewable energy technologies is evident, with 66 % of the market in 2019, followed by sustainable transport (22 %) and energy efficiency (10 %). The three remaining categories, namely smart systems, nuclear and CCUS only account for less than 3 % of estimated global CET exports (Figure 13).

Figure 13: Global exports of CET-related products, 2015–2019 (*billion USD*)



Source: Author's estimates based on Cambridge Econometrics (2022) and United Nations (2022).

The picture changes significantly when scaling CET exports by gross domestic product (Figure 14) ([17]). The share of global CET exports on the world's GDP has remained stable between 2012 and 2019, with only a slight decrease from 0.11 % in 2012 to 0.09 % in 2019. The five top-performing countries with the highest ratio of estimated CET exports to their GDP in 2019 were all European: Denmark (1.22 %), Slovenia (0.88 %), Czechia (0.31 %), the Netherlands (0.30 %) and Slovakia (0.27 %). Looking at major economies, South Korea had the highest ratio (0.20 %) of CET export to GDP in 2019, followed the EU (0.19 %), China (0.13 %) and Japan (0.12 %). CET exports play a less relevant role in the economies of the United Kingdom and the United States, with estimated ratios of 0.06 % and 0.04 %, respectively.

The estimated domestic value-added content of CET exports increased by 2 % from USD 68 billion in 2015 to USD 70 billion in 2018, contributing to about 76 % of estimated CET export at the global level ([18]). When looking at export performance through the lenses of indicators related to 'value added' (either in absolute terms or scaled by GDP), the country rankings are quite similar to those derived from export-related indicators ([19]). The five top-performing countries on 'value-added content in CET export per unit of GDP'

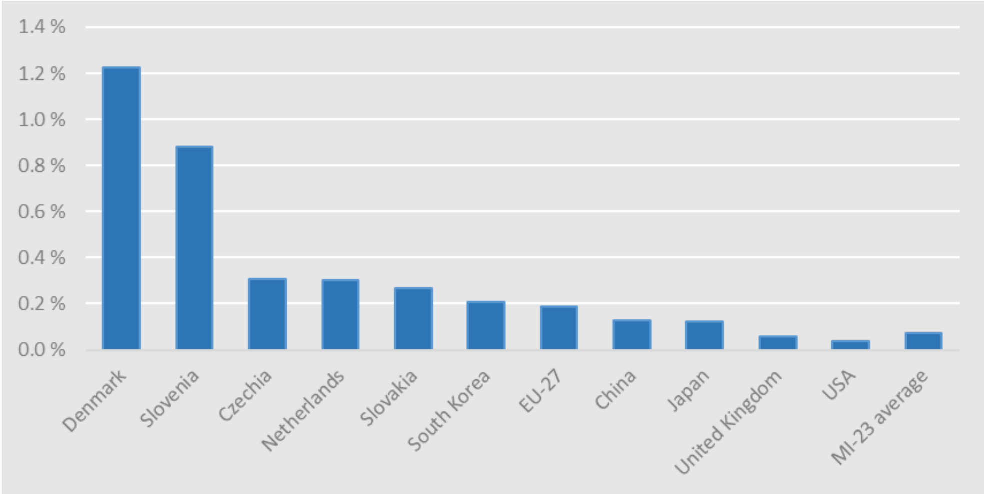
([17]) Gross domestic product figures are expressed in Purchase Power Parity, current international USD (World Bank, 2022).

([18]) Due to the 2018 spike in the USD/EUR exchange rate, the variation in the domestic value added content of global CET exports between 2015 and 2018 – expressed in USD in the UN Comtrade database - would be negative if the same exports are converted into Euros (i.e. from EUR 62 billion in 2015 to EUR 60 billion in 2018).

([19]) The ranking of the five top-performing countries and major economies in 2018 in terms of value-added content of CET exports is the same as that of CET exports.

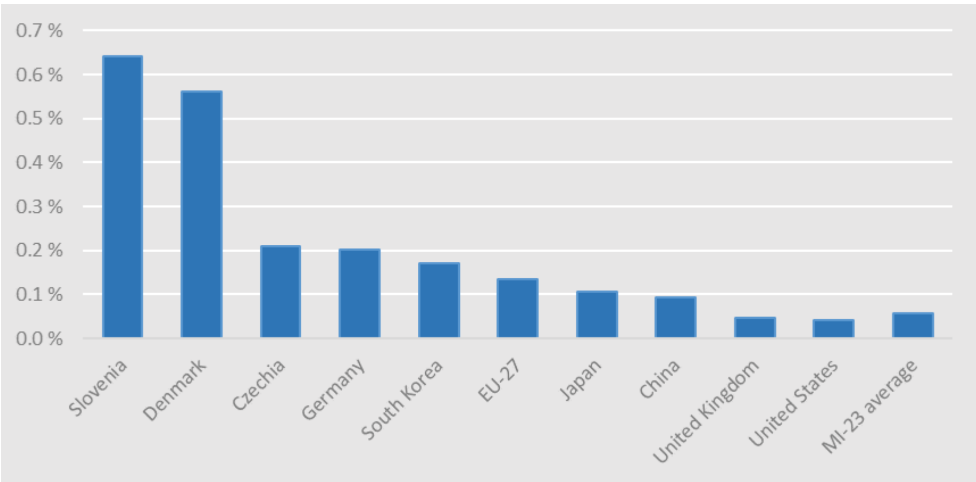
(Figure 15) in 2019 were Slovenia (0.88 %), Denmark (0.56 %), Czechia (0.22 %), Germany (0.19 %) and South Korea (0.17 %). Amongst major economies, South Korea is followed by the EU-27 (0.13 %), Japan (0.11 %), China (0.09 %), the United Kingdom (0.05 %), and the United States (0.04 %).

Figure 14: CET exports per unit of GDP, top global performers and major economies in 2019



Source: Authors' estimates based on Cambridge Econometrics (2022); United Nations (2022); the World Bank (2022).

Figure 15: Domestic value-added content of CET export per unit of GDP, top-performing countries and major economies in 2018



Source: Authors' estimates based on Cambridge Econometrics (2022); United Nations (2022); OECD (2022b); the World Bank (2022).

When comparing trends of CET exports and domestic value-added content of the same CET exports of EU Member States and MI members over a longer time frame (2012–2019), the CAGR of the latter is higher (1 %) than the CAGR value estimated for CET exports (0.6 %). A higher growth rate of the value added embedded in exports versus the growth rate of exports may suggest increasing 'self-sufficiency' of domestic CET supply chains, with a growing share of intermediate inputs either produced 'in-house' (within the firm or subsidiaries) or sourced from domestic suppliers.

Overall, the CET export trend observed over the 2012–2019 time frame points to reduced market shares of 'mature' economies, such as the EU-27 (- 3 %) and Japan (- 2 %). On the other hand, most emerging economies increased their market shares of CET-related products, in particular China (+ 5 % increase with a share of 25 % in 2019).

5. Composite indicator analysis

5.1. Tracking research and innovation performance with composite indicators

Composite indicators are constructed through the aggregation of individual indicators into a single index. The purpose of composite indicators is to 'measure multi-dimensional concepts which cannot be captured by a single indicator' (OECD and EC Joint Research Centre, 2005, p. 7). A composite indicator will seldom represent the final step of an analysis, but will more often offer an informed description of a complex concept supplying a conceptual guidance together with the aggregated data.

Composite indicators have been extensively used to measure innovation, such as in the case of the *Global Innovation Index* (WIPO, 2021), the *European Innovation Scoreboard* (EC, 2021b) and the EU Eco-Innovation Index (Al-Ajlani, et al., 2021). The Global Energy Innovation Index (Smith and Hart, 2021) is one recent example of a composite indicator used to measure innovation in the clean energy sector by combining a range of indicators encompassing 'inputs' (e.g. R & D investments), 'outputs' (e.g. patents) and outcomes (e.g. deployment of clean energy technologies).

The Clean Energy Innovation Index (CEII) concept was developed in 2018 by the European Commission Directorate General for Research and Innovation and the Joint Research Centre with the aim of tracking research and innovation performance in the clean energy sector based on three dimensions:

- scientific productivity, as measured by scientific publications;
- inventive activity or innovation outputs, based on patents;
- commercialisation of innovative products or innovation outcomes, as measured by domestic value added in export.

The rationale behind the creation of the Clean Energy Innovation Index is to gain insights as to the performance of research and innovation policies and programmes in the clean energy sector across the three fundamental stages defined above.

The CEII is built on the following dimensional indexes, calculated from indicators constructed with data related to clean energy technologies.

- Bibliometric index, constructed with the two indicators (a) number of scientific publications per capita and (b) share of highly cited publications on total publications.
- Patents index, constructed with two indicators (a) number of inventions scaled by GDP and (b) number of high-quality inventions scaled per unit of GDP.
- Export index, constructed from the indicator 'domestic value-added content of export' scaled by GDP.

As said at the beginning of this section, a composite indicator is not a simple collection of elements, it has to offer a clear conceptualisation and operationalisation of a complex concept. The interaction of conceptual and statistical steps are required for this goal to be achieved. The methodology followed for the CEII is based on the most recent recommendations of the JRC's Competence Centre on Composite Indicators and Scoreboards, which are described in the user guide ([20]) developed in 2020. This guide broadly follows the methodological steps outlined in the *Handbook on Constructing Composite Indicators* (OECD and EC Joint Research Centre, 2005). The steps suggested by the JRC-COIN guide range from the conceptual definition of the framework and selection of indicators to the analysis of the relations between the

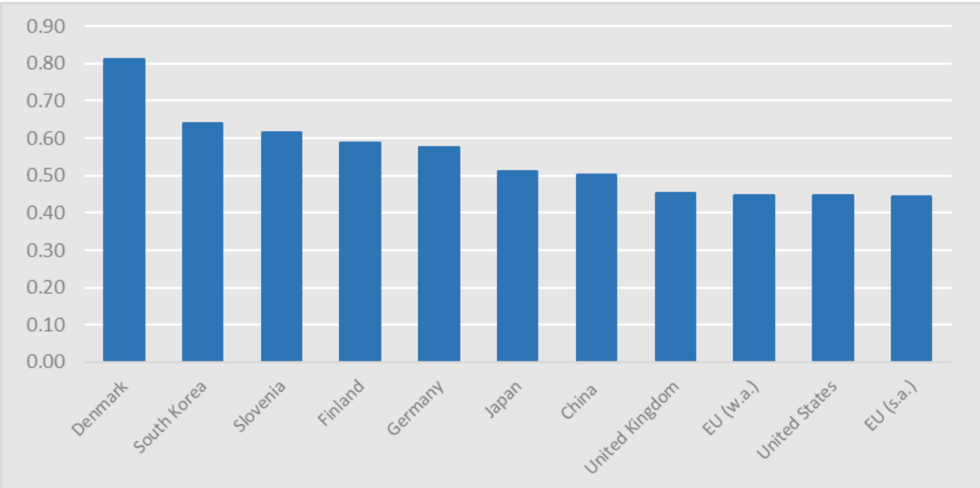
([20]) https://composite-indicators.jrc.ec.europa.eu/?q=10-step-guide; https://knowledge4policy.ec.europa.eu/publication/your-10-step-pocket-guide-composite-indicators-scoreboards_en elementary and aggregated elements selected for the specific composite indicator to check the statistical coherence of those relations. The steps also include the management of missing data, outliers and normalisation of data, and the analysis of the sensitivity of the index to the assumptions made in its construction. This procedure has the aim of producing a transparent and reliable composite indicator that can serve as a tool to provide insights for measuring clean energy innovation ([21]).

5.2. Results of CEII analysis on research and innovation performance

The five countries with the highest CEII values in 2018 are Denmark (0.81), followed by South Korea (0.64), Slovenia (0.61), Finland (0.59) and Germany (0.58). Amongst main major economies outside of the EU, South Korea (0.64) is followed by, Japan (0.51), China (0.50), the United Kingdom (0.45) and the United States (0.45). As a term of comparison, the CEII value for the EU in 2018 is 0.44 if using simple average of EU Member State values, while it slightly increases to 0.45 if using a population-weighted average. The MI-23 have a CEII value of 0.43 in 2018 (Figure 16).

Looking at the performance of EU members, in addition to the four EU members (Denmark, Slovenia, Finland and Germany) that are amongst the top five global performers, there are also three EU Members States (Luxembourg, Sweden and the Netherlands with CEII values between 0.57 and 0.52) scoring above Japan (0.51), which is the second highest performer amongst major economies. Austria (0.50), Belgium (0.48) and Estonia (0.46) have CEII scores above the EU (weighted) average, whilst France (0.44) and Italy (0.43) position themselves slightly below the EU (simple) average (0.44) (Figure 17).

Figure 16: Clean Energy Innovation Index, top global performers and major economies, 2018

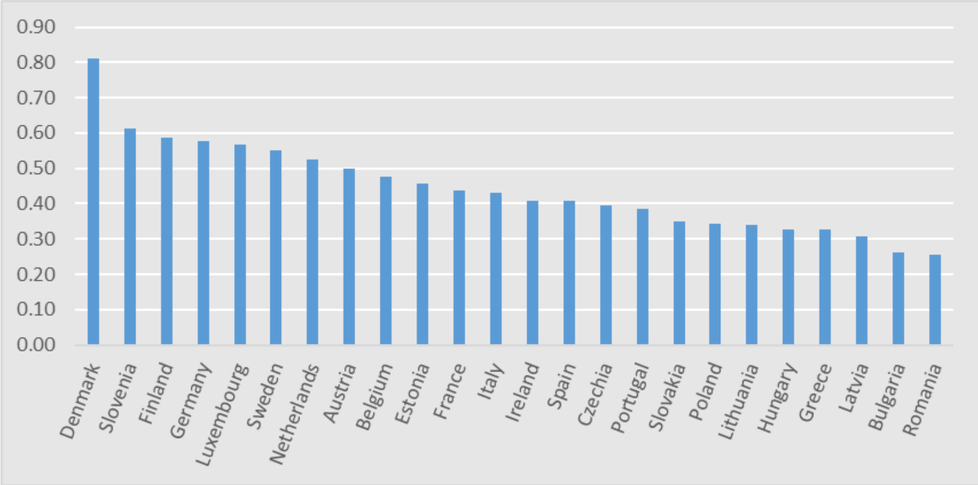


Source: Author’s estimates based on Trinomics (2022).

NB: (a) w.a.: population-weighted average; s.a.: simple average. (b) average EU values for year 2017 do not include values for Croatia, Malta and the United Kingdom.

([21]) For more information on the methodology followed to construct the CEII, See EC Directorate General for Research and Innovation et al. (2021; 2022c).

Figure 17: Clean Energy Innovation Index of EU Member States, 2018



Source: Author's estimates based on Trinomics (2022).

NB: (a) w.a.: population-weighted average; s.a.: simple average. (b) Average EU values for year 2017 do not include values for Croatia, Malta and the United Kingdom.

The computed CEII values for 2015–2018 show an increase in clean energy research and innovation performance for 16 countries out of the 38 for which it was possible to compute the index ([22]). The largest percentage increases between 2015 and 2018 are those of Luxembourg (+ 26 %), followed by Slovenia (+ 18 %) and Hungary (+ 18 %). Amongst major economies, China has the best performance (+ 9 %), whereas South Korea (-0.4% %), the United Kingdom (- 1 %), Japan (-2 %), and the United States (-5 %) all had a decrease in their CEII scores between 2015 and 2018 (Table A-7).

6. Analysis of the European Union's R & I performance trends in the clean energy sector

The EU-27 produced a total of 30 160 publications related to CETs in 2020 (16 % of total), ranking second in the world after China and ahead of other major economies. CET-related publications from Member States increased by 10 % from 2015 to 2020. By comparison, scientific production related to clean energy technologies increased by 91 % in China, 136 % in India and 21 % in South Korea while it declined by 7 % in the United States and 10 % in Japan. As a result, the EU share on global CET-related publications decreased from 22 % in 2015 to 16 % in 2020, versus an increase from 26 % to 32 % for China over the same period.

A more accurate metric to gauge relative performance on the scientific production related to CETs is the number of scientific publications per capita. In 2020, the EU ranked third with 67 publications per 1 000 000 people, after South Korea (135) and the United Kingdom (72) and before the United States (47), China (42), Japan (37) and India (12). The ranking of the EU relative to other major economies in 2020 is the same as in 2015.

([22]) CEII values for Croatia, Cyprus Indonesia and Malta were not computed due to missing data points in publications or patents. Most of the countries reporting a negative variation in CEII values between 2015 and 2018 had an absolute increase in the primary indicators (e.g. number of publications, number of inventions, value added in CET exports) used to compute the sectoral indexes. However, these primary innovation-related indicators increased at a slower pace relative to GDP and population, which were used to scale the former into ratios (e.g. number of publications per 1 000 000 of population, number of inventions by GDP). These ratios were in turn transformed and normalised to compute the sectoral indexes which fed into the CEII, resulting in a negative variation of the latter even in a few cases were the primary indicators observed an increase between 2015 and 2018.

When looking at the quality of CET-related publications, the EU ranks fourth amongst major economies with a 13 % share of highly cited publications in 2018, preceded by the United Kingdom (19 %), the United States (19 %) and China (18 %). While the ranking in 2020 is the same as in 2015, the share of highly cited publications of all major economies except China (+ 3 % increase) slightly decreased between 2015 and 2020. Despite the relatively low performance of the EU on this indicator in comparison with other major economies, there are four EU Member States (Luxembourg, Denmark, the Netherlands and Greece) ranking amongst the top 10 global performers in 2018.

With about 9 000 inventions related to CETs in 2018 (8 % of the world's total of about 109 000 inventions), the EU ranks fourth amongst major economies after China (with about 62 000 inventions and a 57 % share on the world's total), Japan (14 %), South Korea (10 %) and before the United States (7 %). All major economies except Japan reported an increase in the number of CET-related inventions between 2015 and 2018, with the largest increments being those of China (+ 100 %) the EU (+ 20 %) and South Korea (+ 17 %). The already significant volume of domestic filings in China in 2015 and their sharp increase explains the decreasing shares on global CET-related inventions of all other major economies between 2015 and 2018 (with the EU decreasing from 10 % to 8 %). The ranking of major economies in 2018 on CET-related inventions did not change with respect to 2015.

In 2018, seven out of the ten top CEII performers (at the country level) were EU members, showing a strong and established European capacity in terms of clean energy innovation performance as measured through the lenses of the Clean Energy Innovation Index. With a score of 0.45 (population-weighted average of 24 EU-member CEII values) in 2018, the EU is hovering above the average (0.41) of the 38 countries for which the CEII was calculated. Amongst major economies, the EU is preceded by South Korea (0.64), Japan (0.51), and China (0.50), while being on par with the United Kingdom (0.45) and the United States (0.45). While the EU was already lagging behind China in 2015 (with a CEII value of 0.45 compared to 0.46 of China), the CEII value of China increased by four points between 2015 and 2018, incrementing its lead over the EU and also overtaking the United States in CEII ranking in 2018.

The European Union was the largest exporter of CET-related products in 2019, with an estimated trade value of USD 39 billion (EUR 35 billion) and a share of33 % on global CET export. The second largest CET exporter in 2019 was China, with a share of 25 %, followed by the United States (7 %), Japan (6 %) and South Korea (4 %) (the ranking of the EU v other major economies in 2019 did not change with respect to 2015). Three Member States (Denmark, Germany and Italy) accounted for more than15 % of global CET-related export in 2019, with Germany contributing 30 % of the EU's CET export. Export of CET-related products from EU Member States increased by 11 % from 2015 to 2019. However, in 2015 there was a significant drop (-10 %) in EU CET exports relative to the 2014 levels. In fact, if the time frame were extended to 2012, EU CET exports between 2012 and 2019 would decrease by - 1 %. The share of CET export on EU-27 GDP in 2019 is 0.19 %, the second highest amongst major economies. The EU-27 is preceded by South Korea (0.20 %) and is followed by China (0.13 %) and Japan (0.12 %).

Overall, between 2015 and 2017 the European Union has had an average research and innovation performance in the clean energy sector, as measured through the lenses of the Clean Energy Innovation Index and in relation to the values of MI members and EU Member States. With a score of 0.50 (population-weighted average of EU-27 CEII values) in 2017, the EU is hovering above the average (0.45) of the 40 countries for which the CEII was calculated. The EU ranks fourth amongst major economies, behind South Korea (0.65), the United Kingdom (0.53) and Japan (0.51), and on par with the United States (0.50). Though the EU still outperformed China (CEII value of 0.47) in 2017, the latter had a much higher CEII growth rate than the EU (+ 8 % versus +2 %) between 2015 and 2017. This means that if the relative growth-rate pattern observed between 2015 and 2017 by major economies on CET-related scientific publications, inventions and export has continued in the following years, China may have already outperformed (in terms of R & I performance in the clean energy sector) both the EU and the US at the time of this writing (September 2022).

7. Concluding remarks

New and extensive data on scientific publications, inventions and the export of clean energy technologies provided new insights as to the R & I performance of 42 countries, representing more than 80 % of selected R & I outputs and outcomes at the global level between 2015 and 2020.

Overall, the increasing trend in scientific publications on clean energy technologies observed between 2015 and 2020 (+ 50 %) is encouraging, however the latest available data show a slight decrease in 2020 relative to 2019 (a variation which warrants further investigation). Policymakers need to ensure that greater scientific production – as reflected by increasing scientific publications – is efficiently and effectively transferred into the applied research and development phases of the technology cycle. This can be done, for example, through the ex post evaluation analysis of R & D programmes designed to link scientific performance and innovation outputs. This kind of analysis can be greatly enhanced by the much larger amounts of data and more powerful digital tools than are available today, relative to only a few years ago.

From 2015 to 2018, the number of inventions in clean energy technologies increased by nearly 50 % globally. While greater inventive activity does not necessarily translate into accelerated development of market-viable technologies, patenting trends can still provide a useful proxy to policymakers to gauge the extent to which research and innovation efforts are effective in producing outputs. However, it should be reiterated that the path from invention to the successful commercialisation of a new or improved technology can take years and requires a complex set of conditions at the macro level, including access to finance (e.g. venture capital), expectations on stable policy and regulatory frameworks, financial and non-financial support measures for firms targeting the progression from medium to high technology readiness levels, etc.

The estimated value added of CET export of the EU-27 and MI members increased by 3 % from 2015 to 2018, with significant differences in performance amongst major economies. For example, Japan increased its domestic value-added content of CET export by 10 % from 2015 to 2018, while South Korea and the United States had growth rates below 5%. As already mentioned, innovation is only one of the factors driving export performance. Export data, particularly when put in the right context (e.g. a scoreboard of innovators and quantitative analyses building on it), can provide useful insights into the impacts of national or regional research and innovation policies. For example, there may be countries which have increased their efforts (both financial and regulatory) to support innovation and competitiveness in the clean energy sector but are not translating the benefits of such efforts into greater export competitiveness of domestic firms or self-sufficiency of the more innovation-intensive segments of national energy value chains (e.g. manufacturing) over the medium to long run. This should call for the attention of policymakers and the fine-tuning of innovation and competitiveness policies.

The overall research and innovation performance of the EU and the MI-23 measured through the lenses of the CEII framework shows a mixed picture during the 2015–2018 time frame. Research and innovation performance in the clean energy sector shows promising progress when measured from the angle of absolute variations in primary indicators related to publications, patents and value added in CET export. However, when such indicators are scaled by population and GDP and subsequently transformed to compute the Clean Energy Innovation Index, only 18 countries out of the 38 for which CEII values were calculated reported an increment between 2015 and 2018. China, which in 2018 had the highest number of publications, inventions and value added generated in the export of CET-related technologies, had a significant performance in clean energy innovation by increasing its CEII values by about 10% between 2015 and 2018.

Finally, it should be cautioned that innovation outcomes have significant time lag before they materialise after the initial R & I investment. Once the proper time lag is accounted for, an assessment of the whole architecture of policies impacting industrial competitiveness would be needed in order to understand which policy levers are working and which are not from a systemic perspective.

In conclusion, new data and analyses have the potential to increase both the effectiveness and efficiency of research and innovation policies in the clean energy sector. Greater cooperation at the international level on data and indicators, for example in the context of the Mission Innovation initiative, can contribute to more impactful clean energy R & I policies. With new data available, novel analyses may be possible with the objective of gaining insights on the relationship between R & I inputs and outputs and their outcomes. Such insights can provide the right kind of information for policymakers to fine-tune R & D policies and programmes to deliver new and more affordable clean energy technologies at the pace needed to achieve climate neutrality early enough to avert significant negative impacts from climate change and with net economic benefits to society.

Annex

Table A-1: Number of scientific publications related to CETs by country, 2015–2020

Country	2015	2016	2017	2018	2019	2020
Australia	2 236	2 338	2 496	2 729	3 001	2 804
Austria	621	685	666	641	732	588
Belgium	816	740	811	786	802	705
Brazil	2 201	2 219	2 689	2 876	3 399	3 052
Bulgaria	90	142	168	209	292	256
Canada	2 684	3 034	2 892	3 172	3 278	3 043
Chile	210	249	269	296	329	302
China	31 435	36 040	41 617	49 061	58 864	60 151
Croatia	176	184	201	250	234	259
Cyprus	70	88	95	114	142	131
Czechia	679	671	798	792	880	696
Denmark	1 021	1 058	1 073	1 130	1 196	1 158
Estonia	118	116	123	125	152	174
Finland	769	731	718	766	810	735
France	3 195	3 159	3 332	3 272	3 217	2 921
Germany	5 727	5 821	6 240	6 248	6 188	5 772
Greece	630	742	757	759	850	847
Hungary	218	228	287	308	315	312
India	6 936	9 110	11 316	15 278	16 484	16 397
Indonesia	418	638	1 293	2 246	2 711	2 664
Ireland	367	401	411	415	474	409
Italy	4 174	3 924	4 455	4 362	4 793	4 567
Japan	5 279	5 176	5 631	5 454	5 481	4 732
Korea, Rep. of	5 803	5 873	6 112	6 616	7 181	7 000
Latvia	203	178	237	186	199	158
Lithuania	148	147	168	173	149	206
Luxembourg	44	68	61	48	60	54

Malta	12	24	17	20	18	24
Mexico	647	681	827	909	1 064	1 053
Netherlands	1 136	1 146	1 250	1 206	1 223	1 240
Norway	644	728	823	774	896	880
Poland	1 192	1 400	1 668	1 853	1 866	1 883
Portugal	932	896	939	987	1 206	1 189
Romania	691	727	1 033	905	1 202	751
Saudi Arabia	561	669	772	958	1 179	1 492
Slovakia	241	232	277	271	379	242
Slovenia	168	171	182	177	243	194
Spain	2 693	2 836	2 894	3 119	3 179	3 375
Sweden	1 248	1 303	1 408	1 341	1 384	1 314
United Arab Emirates	285	331	407	412	545	500
United Kingdom	4 352	4 516	5 017	4 784	5 268	4 906
United States	16 963	16 753	17 575	17 572	17 662	15 717
Rest of the world	14 990	18 229	21 998	24 848	30 225	30 512
World total	123 023	134 402	152 003	168 448	189 752	185 365
MI-23	98 261	105 851	118 471	131 691	146 340	142 488
EU-27	27 379	27 818	30 269	30 463	32 185	30 160

Source: Science Metrix (2022).

Table A-2 Share of highly cited publications in the total of publications related to clean energy technologies by country, 2015–2018

Country	2015	2016	2017	2018
Australia	21.42 %	22.24 %	23.85 %	22.70 %
Austria	12.47 %	11.84 %	11.73 %	10.23 %
Belgium	22.25 %	18.24 %	17.97 %	15.63 %
Brazil	7.70 %	7.92 %	7.89 %	9.09 %
Bulgaria	2.71 %	6.39 %	4.76 %	0.90 %
Canada	18.47 %	19.23 %	16.72 %	16.69 %
Chile	12.47 %	13.66 %	10.85 %	8.53 %
China	14.47 %	15.05 %	16.03 %	17.78 %
Croatia	6.26 %	9.38 %	8.14 %	7.30 %
Cyprus	6.20 %	11.14 %	14.84 %	11.32 %
Czechia	5.66 %	5.53 %	4.71 %	5.39 %
Denmark	22.62 %	23.72 %	21.63 %	21.94 %
Estonia	12.61 %	10.23 %	15.58 %	16.31 %
Finland	10.30 %	13.82 %	14.01 %	14.96 %
France	12.45 %	13.14 %	12.47 %	11.20 %
Germany	16.32 %	14.79 %	14.38 %	13.83 %
Greece	17.72 %	18.11 %	20.11 %	16.65 %
Hungary	3.26 %	6.17 %	6.80 %	6.93 %
India	11.83 %	12.45 %	11.04 %	10.58 %
Indonesia	4.28 %	2.24 %	4.14 %	3.74 %
Ireland	17.14 %	22.62 %	16.67 %	13.25 %
Italy	16.13 %	15.77 %	17.84 %	15.38 %
Japan	10.40 %	9.45 %	8.20 %	8.12 %
Korea, Rep. Of	12.32 %	11.69 %	12.05 %	11.41 %
Latvia	6.46 %	5.10 %	2.97 %	5.28 %
Lithuania	5.65 %	6.04 %	4.47 %	8.01 %
Luxembourg	11.78 %	18.90 %	17.67 %	32.16 %
Malta	n.a.	n.a.	n.a.	n.a.

Mexico	6.43 %	5.36 %	7.28 %	6.40 %
Netherlands	20.17 %	19.84 %	18.47 %	19.44 %
Norway	19.51 %	15.03 %	12.90 %	15.04 %
Poland	5.69 %	5.42 %	6.48 %	5.47 %
Portugal	15.08 %	14.16 %	16.07 %	12.10 %
Romania	6.90 %	6.25 %	7.08 %	7.01 %
Saudi Arabia	22.18 %	20.50 %	19.75 %	21.09 %
Slovakia	2.93 %	4.42 %	3.66 %	3.60 %
Slovenia	8.62 %	9.30 %	7.55 %	9.78 %
Spain	16.81 %	15.98 %	13.71 %	13.62 %
Sweden	14.99 %	16.99 %	15.79 %	15.03 %
United Arab Emirates	18.91 %	21.14 %	18.16 %	15.42 %
United Kingdom	20.10 %	21.22 %	20.74 %	18.85 %
United States	21.57 %	21.57 %	19.59 %	18.72 %
World total	15.10 %	15.10 %	14.90 %	15.00 %
MI-23	15.51 %	15.65 %	15.51 %	15.81 %
EU-27	14.70 %	14.56 %	14.25 %	13.27 %

Source: Science Metrix (2022).

Table A-3: Number of inventions related to clean energy technologies by country, 2015–2018

Country	2015	2016	2017	2018*
Australia	130	160	144	152
Austria	203	186	236	237
Belgium	122	150	150	166
Brazil	109	123	142	135
Bulgaria	8	6	4	7
Canada	269	302	307	313
Chile	17	13	18	13
China	30 668	44 503	54 970	61 818
Croatia	1	1	0	1
Cyprus	3	0	3	5
Czechia	26	32	25	34
Denmark	259	346	399	445
Estonia	3	7	7	4
Finland	150	159	183	180
France	1 308	1 182	1 334	1 439
Germany	3 810	4 265	4 841	5 023
Greece	4	11	7	5
Hungary	13	11	12	16
India	98	98	85	87
Indonesia	2	0	0	0
Ireland	50	44	57	61
Italy	283	304	272	311
Japan	15 093	15 219	14 915	14 925
Korea, Rep. of	9 359	10 791	10 568	10 943
Latvia	13	9	5	3
Lithuania	3	2	1	5
Luxembourg	30	19	20	23
Malta	3	13	3	1
Mexico	60	63	57	25

Netherlands	420	404	410	359
Norway	50	66	64	72
Poland	185	171	148	173
Portugal	23	29	13	13
Romania	44	34	46	39
Saudi Arabia	76	65	103	88
Slovakia	11	4	6	16
Slovenia	4	8	8	15
Spain	178	176	186	168
Sweden	303	298	286	308
United Arab Emirates	3	4	16	6
United Kingdom	633	569	639	760
United States	7387	7747	8160	7658
Rest of the world	2450	2549	2416	2519
World total	73 865	90 146	101 263	108 568
MI-23	71 423	87 612	98 859	106 059
EU-27	7 461	7 874	8 660	9 056

Source: European Commission Joint Research Centre (2022).
*2018 dataset not as complete

Table A-4 Number of high-value inventions related to CETs by country, 2015-2018

Country	2015	2016	2017	2018*
Australia	86	85	91	92
Austria	136	139	173	174
Belgium	95	110	117	115
Brazil	23	25	14	30
Bulgaria	5	3	2	3
Canada	184	213	227	220
Chile	12	7	12	8
China	1 664	2 482	3 038	3 416
Croatia	0	1	0	1
Cyprus	1	0	1	3
Czechia	10	13	12	10
Denmark	199	268	317	319
Estonia	2	3	6	2
Finland	108	117	126	129
France	915	831	913	948
Germany	2 030	2 320	2 733	2 745
Greece	1	5	2	4
Hungary	6	7	5	13
India	52	60	35	38
Indonesia	1	0	0	0
Ireland	42	30	37	46
Italy	192	229	202	209
Japan	5 526	5 871	6 092	5 646
Korea, Rep. of	2 660	3 046	3 034	3 012
Latvia	2	0	2	1
Lithuania	1	2	1	2
Luxembourg	28	17	14	18
Malta	3	12	2	1
Mexico	15	12	8	3

Netherlands	314	301	289	237
Norway	39	46	44	61
Poland	34	13	29	19
Portugal	17	19	8	7
Romania	0	1	2	1
Saudi Arabia	45	32	68	36
Slovakia	2	4	3	4
Slovenia	2	6	6	13
Spain	109	104	113	108
Sweden	248	249	240	216
United Arab Emirates	1	1	6	3
United Kingdom	474	418	518	586
United States	4 276	4 554	4 710	4 317
Rest of the world	985	1 074	1 089	1 088
World total	20 546	22 733	24 341	23 901
MI-23	19 563	21 663	23 260	22 816
EU-27	4 502	4 805	5 354	5 346

Source: European Commission Joint Research Centre (2022).
*2018 dataset not as complete

Table A-5 Estimated exports of products related to CETs by country, 2015–2019 (*million USD*)

Country	2015	2016	2017	2018	2019
Australia	156	123	123	143	128
Austria	1 109	1 109	1 157	1 165	1 085
Belgium	790	820	811	1032	908
Brazil	423	378	338	370	427
Bulgaria	207	197	217	251	256
Canada	1 169	1 116	1 180	1 126	1 060
Chile	16	24	20	18	22
China	26 386	22 915	22 839	25 557	29 810
Croatia	138	155	248	214	209
Cyprus	2	2	1	1	2
Czechia	1 182	1 251	1 316	1 434	1 396
Denmark	4 020	4 301	3 252	2 865	4 179
Estonia	94	93	98	99	93
Finland	535	477	541	571	493
France	2 617	2 570	2 698	2 989	2 950
Germany	11 496	11 432	10 981	12 217	12 139
Greece	212	261	322	262	321
Hungary	550	582	649	726	714
India	804	778	963	1131	1384
Indonesia	567	577	639	682	656
Ireland	111	128	140	144	129
Italy	2 832	2 843	3 050	3 233	3 147
Japan	6 265	6 474	6 743	7 064	6 654
Korea, Rep. of	5 045	5 377	5 295	5 205	4 561
Latvia	45	39	36	39	36

Lithuania	134	135	152	179	192
Luxembourg	45	56	64	91	66
Malta	4	5	5	5	5
Mexico	2 978	2 964	2 614	2 812	2 970
Netherlands	2 070	2 024	2 296	2 361	3 095
Norway	124	90	261	114	93
Poland	1 752	1 618	1 921	2 287	2 364
Portugal	409	481	514	624	532
Romania	304	345	424	549	592
Saudi Arabia	135	155	120	94	62
Slovakia	439	467	479	536	464
Slovenia	521	582	685	772	747
Spain	2 930	2 639	2 761	2 785	2 309
Sweden	701	656	712	840	709
United Arab Emirates	458	458	620	739	729
United Kingdom	1615	1501	1674	1819	1830
United States	8 672	7 927	8 066	8 689	8 376
Rest of the World	21 425	22 228	22 677	21 982	21 992
World Total	111 484	108 353	109 698	115 818	119 885
MI-23	78 708	82 921	80 191	76 270	76 181
EU-27	39 019	39 694	35 247	35 267	35 528

Source: Authors' estimates based on Cambridge Econometrics (2022); United Nations (2022); the World Bank (2022).

Table A-6 Estimated domestic value added in exported products related to CETs by country, 2015-2018 (*million USD*)

Country	2015	2016	2017	2018
Australia	155	131	120	131
Austria	710	716	743	748
Belgium	518	520	513	638
Brazil	329	319	279	295
Bulgaria	125	129	142	162
Canada	817	783	831	791
Chile	100	172	124	180
China	20 615	17 982	17 748	19 968
Croatia	92	111	170	148
Cyprus	16	13	14	16
Czechia	688	751	915	913
Denmark	2 784	3 010	2 102	1 868
Estonia	56	62	60	69
Finland	428	367	419	433
France	1 957	2 016	2 030	2 205
Germany	8 814	8 789	8 328	9 268
Greece	157	196	229	189
Hungary	296	310	334	373
India	612	598	735	862
Indonesia	425	450	492	500
Ireland	102	112	120	175
Italy	2 140	2 181	2 279	2 333
Japan	5 193	5 588	5 707	5 674
Korea, Rep. of	3 599	3 865	3 814	3 791
Latvia	31	28	25	28

Lithuania	93	92	99	111
Luxembourg	23	27	33	55
Malta	12	9	12	13
Mexico	1 584	1 558	1 440	1 530
Netherlands	1 157	1 187	1 281	1 340
Norway	83	60	185	73
Poland	1 144	1 091	1 249	1 491
Portugal	271	324	345	435
Romania	217	249	297	365
Saudi Arabia	100	118	93	75
Slovakia	230	237	226	271
Slovenia	363	404	463	519
Spain	2 108	1 901	1 926	1 931
Sweden	503	462	502	582
United Arab Emirates	100	98	131	161
United Kingdom	1 395	1 265	1 342	1 449
United States	8 155	7 672	7 787	8 337
MI-23	62 107	59 890	63 243	61 752
EU-27	28 183	27 781	28 241	25 037

Source: Authors' estimates based on Cambridge Econometrics (2022); United Nations (2022); OECD (2022b); the World Bank (2022).

Table A-7: Clean Energy Innovation Index scores by country, 2015-2018.

Country	2015	2016	2017	2018
Australia	0.412	0.417	0.424	0.422
Austria	0.516	0.509	0.515	0.499
Belgium	0.507	0.482	0.482	0.477
Brazil	0.170	0.177	0.169	0.189
Bulgaria	0.266	0.273	0.251	0.261
Canada	0.439	0.449	0.432	0.431
Chile	0.248	0.254	0.245	0.225
China	0.458	0.470	0.483	0.501
Czechia	0.385	0.393	0.397	0.395
Denmark	0.880	0.901	0.826	0.810
Estonia	0.437	0.452	0.488	0.456
Finland	0.573	0.573	0.580	0.588
France	0.448	0.443	0.443	0.437
Germany	0.589	0.578	0.576	0.577
Greece	0.289	0.363	0.349	0.326
Hungary	0.278	0.293	0.298	0.327
India	0.151	0.156	0.138	0.142
Ireland	0.417	0.439	0.414	0.407
Italy	0.437	0.430	0.442	0.429
Japan	0.518	0.519	0.515	0.510
Korea, Rep. of	0.644	0.647	0.645	0.641
Latvia	0.390	0.273	0.340	0.309
Lithuania	0.300	0.301	0.266	0.339
Luxembourg	0.449	0.492	0.477	0.567
Mexico	0.198	0.183	0.180	0.144
Netherlands	0.544	0.537	0.532	0.524
Norway	0.455	0.442	0.468	0.446
Poland	0.342	0.316	0.344	0.343

Portugal	0.420	0.425	0.399	0.386
Romania	0.219	0.236	0.274	0.255
Saudi Arabia	0.287	0.276	0.297	0.287
Slovakia	0.311	0.311	0.313	0.349
Slovenia	0.521	0.568	0.568	0.614
Spain	0.441	0.424	0.411	0.407
Sweden	0.555	0.559	0.556	0.551
United Arab Emirates	0.197	0.220	0.278	0.230
United Kingdom	0.455	0.450	0.459	0.453
United States	0.468	0.466	0.456	0.446
MI-23 * (simple average)	0.438	0.439	0.439	0.431
EU ** (simple average)	0.425	0.428	0.426	0.429
EU ** (weighted average)	0.453	0.448	0.45	0.446

(*) Not including Indonesia for which no data on inventions was available.

(**) EU members as of 1st of February 2020, not including Croatia, Cyprus and Malta for which values could not be computed due to missing data points.

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The report assesses research and innovation performance in the clean energy sector of European Union (EU) Member States and Mission Innovation (MI) members from 2015 to 2020. Time trends, country rankings and the sectoral breakdown of indicators related to scientific publications, patents and export are assessed with the aim of providing insights to policymakers on the effectiveness of research and innovation policies in the clean energy sector. The report builds on data produced and analysis carried out in the context of the Clean Energy Innovation Index project, coordinated by the Clean Energy Transitions Unit of the European Commission's Directorate-General for Research and Innovation. The project was launched with the aim of supporting MI's work on data and indicators and the research, innovation and competitiveness pillar of the Energy Union.

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