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Trade as a measure of innovation performance: Selection and assessment of trade indicators

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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Abbreviations

CAGR	Compound Average Growth Rate
CCS/U	Carbon capture, utilisation and storage
CEII	Clean Energy Innovation Indicator
CET	Clean Energy Technology
CN Code	Combined Nomenclature Code
Eurostat RAMON	Eurostat - Reference and Management of Nomenclatures
GDP	Gross Domestic Product
HS Codes	Harmonised System Codes
JRC	Joint Research Centre
OECD	Organisation for Economic Co-operation and Development
PPP	Purchasing Power Parity
RES	Renewable Energy Sources
R & D	Research and Development
R & I	Research and Innovation
SITC	Standard International Trade Classification
Solar PV	Solar Photovoltaic
TiVA	Trade in Value Added
UN	United Nations
WEC	World Energy Council

1 Introduction

This report is an interim 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 members, which contributes to the overarching aim of assessing progress in clean energy innovation by analysing output-related indicators.

The composite indicator consists of three dimensions: scientific publications, patents and trade. This report covers the work on using **trade** as a measure of innovation performance and aims to provide details on:

1. Assessment of different trade-indicators and selection of those most suitable for inclusion in the composite indicator;

2. Insights on clean energy innovation performance from the perspective of trade flows;

3. Deliver the trade dataset for inclusion in composite indicator calculations.

The report is structured according to the above objectives. In chapter 2, we discuss the main challenges of using trade flows as a measure of innovation performance, identify the most relevant trade indicators, assess how they mitigate the key challenges, and finally select the most suitable trade indicator(s) for including in the index. Chapter 3 summarises the methodology of mapping clean energy technology (CET) products to the structure of the SET Plan Key Actions (KA). In chapter 4, we provide insights on CET innovation performance for the selected indicator(s). Annex A includes information on the dataset that will be used as input for the trade dimension of the composite indicator calculations.

2 Trade flows as indicators for measuring innovation performance

In our approach the process of innovation in clean energy technologies (CETs) can be captured in the context of a flow-concept in global markets, where the international diffusion of technological advancements has, essentially, three key stages. Scientific (basic) research forms the basis for CET innovation, a process that often results in writing research materials and publications (here captured by scientific publications). The second phase is for applied research and development activities, the success of which is often indicated by and measured in terms of classical indicators of innovation outputs (in the composite indicator: proxied by patents). Finally, diffusion of the goods resulting from the innovation process takes place internationally through trade (in the composite indicator: proxied by export).

Trade is a key attribute of the CEII composite indicator, which, as a whole, is intended to be capable of matching and weighting the indicators so that it reflects an unbiased as possible, robust and credible picture of a country's progress in innovation in CETs vis-à-vis its own historic performance and vis-à-vis other countries. Within the CEII indicator, the trade dimension essentially reflects the ability of an economy, notably resulting from innovation, to export goods and services with high levels of value added, and successfully take part in knowledge-intensive global value chains[1].

In this chapter, we first discuss the key challenges of trade-based indicators. We then present several indicators and approaches to mitigate the impacts of the main challenges. Finally, we compare and assess the results of the most relevant indicators and select the best trade indicator(s) for measuring innovation performance and for inclusion in the clean energy innovation index.

2.1 Key challenges of trade-based indicators

When dealing with trade flows data, there are several issues that need to be considered for proper interpretation of the data. Some of these are more practical challenges that can be addressed by applying a transparent and consistent approach. Others are fundamental in nature and are built around the usefulness of trade data for measuring innovation performance of national economies. This section discusses two key issues.

Practical challenges

A first practical challenge in working with trade data concerns the treatment of **re-exports** in the analysis of trade. Re-exports can introduce strong bias in favour of some countries (e.g. a very low-income country may seem to be a key exporter of airplanes only because its national airline has sold second-hand planes[2]). Fortunately, the raw data that is used to calculate the trade indicators were available in both aggregation types: including re-exports or excluding them (**net exports**). Both the export flow data from UN Comtrade international trade database and the value added in export data series from the OECD's Trade in Value Added database make a distinction between these categories - thus we could take a consistent approach in our analysis by using the trade flow data ignoring re-exports.

Fundamental issues

A more fundamental issue in building up trade indicators to assess trade in clean energy technologies is related to the choice of the **elemental level of analysis**. Essentially, there are two key approaches to take in researching trade flows: the **product approach**

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[1] Vertesy, D (2017) The Innovation Output Indicator 2017. Methodology Report, EUR 28876 EN, Publications Office of the European Union, Luxembourg, 2017, ISBN 978-92-79-76474-5, doi:10.2760/971852, JRC108942. https://publications.jrc.ec.europa.eu/repository/bitstream/JRC108942/jrc108942_ioi_2017_report_final.pdf

[2] International Trade Centre (na) Trade Competitiveness Map – Trade Performance Index. Technical notes. https://tradecompetitivenessmap.intracen.org/Documents/TradeCompMap-Trade%20Performance%20Index-Technical%20Notes-EN.pdf

or the sectoral approach. The sectoral approach builds economic indicators on an aggregation of the economic industries. In the product approach, product categories are identified and are aggregated based on a combination of final use and other product characteristics.

In economic analysis, the sectoral approach is generally used for the construction of all indicators except data on high-tech trade and patents. We consider that the product approach is more capable of capturing trends in CET-relevant trade for two reasons: it builds upon a more granular level of observations; and it is more capable of capturing the presence of technological advancements than the aggregated sector-level data, as these advancements essentially appear at the level of individual products, instead of whole economic industries producing a wide range of products. To provide a practical example of this: while the glass and glassware industry (within the complete manufacturing sector) cannot be considered an innovation- and technology-driven one as an aggregate (and thus would likely not be accounted for in terms of CET advancements), some of its products are key for the insulation of energy efficient systems and buildings, such as the product category 'Multiple-walled insulating units of glass'.

2.2 Identification of relevant indicators and approaches

Trade in CETs[3] is one of the three dimensions of the CEII. This dimension measures the diffusion of innovation in CET through trade metrics. We have developed a core list of three indicators, based on the collected and processed data:

1. **High-tech export:** High-tech exports / Total exports

2. **CET vs GDP:** Clean energy technology exports / GDP

3. **CET export value added:** Domestic value added content in Clean energy technology exports / Clean energy technology exports.

The first indicator, *High-tech export*, essentially gives a measure of the actual share of high-technology[4] products' exports in a national economy within total exports and reflects the extent to which the country is currently embedded in high-technology products' global value chains. Creating, exploiting and commercialising new technologies is vital for the competitiveness of a country in the modern economy. While this indicator alone should not be considered as predictive, interpreting it in parallel with other indicators and assuming that a country can develop the relevant domestic industries, it may also indicate the *potential* for a particular national economy to shift in the future towards high value-added production and potential export of high-tech products, including CET.

CETs and clean energy products are key drivers for the low-carbon transition, hence assessing the ability of countries' to generate competitive capabilities in the production and export of low-carbon energy technologies is also of great importance – this is the key rationale behind the second indicator (*CET export vs GDP*). In order to measure clean energy innovation performance of a country and to allow for comparison of performance between countries, the size/budget/industry structure of countries need to be controlled for; therefore, instead of investigating export value in itself, the country's export is expressed relative to GDP value.

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[3] Our definition of 'clean energy technology' (CET) has been developed in accordance with the Key Actions set out in the SET Plan: https://ec.europa.eu/energy/sites/ener/files/publication/Complete-A4-setplan.pdf as per the tender specifications.
In a nutshell, the notion refers to technologies related to the exploration, integration and operation of clean energy forms (presented in more detail later in the report).

[4] Our definition of 'high-technology' is in accordance with Eurostat's latest classification list for High-tech products aggregation, available here: Eurostat (2020a) Eurostat indicators on High-tech industry and Knowledge – intensive services - Annex 5: High-tech aggregation of products by SITC Rev.4. Available at:
https://ec.europa.eu/eurostat/cache/metadata/Annexes/htec_esms_an5.pdf
The classification includes technical products the manufacturing of which involved a high intensity of R&D.

The first and the second indicators provide an overall assessment of the relative importance of high-tech and CET product exports of a country, relative to trade volumes and economic activity (total exports and GDP), thereby also reflecting technological competitiveness of a given country in these fields. It is important to highlight that while the group of high-tech products and the CET products do have overlaps in terms of products (around one-fifth of the set of 6-digit HS codes classified as CET are also present in the high-tech definition), they are not subsets of each other, nor are they disjoint sets. In this regard, the *High-tech export* indicator, and the *CET export vs GDP* indicator both capture relevant, yet different angles of the relative export competitiveness of a country's innovative industries. It is important to note, however, that these indicators (the *High-tech export* indicator and the *CET export vs GDP* indicator) cannot account for the location of the R&D activity performed, as the export component also captures the export of manufactured products whose R&D has been performed elsewhere than the specific country.

Finally, the indicator *CET export value added* (Domestic value added content in Clean energy technology exports / Clean energy technology exports) aims to measure the extent to which the given economy provides an individual contribution to global clean energy supply chains. Trade in value added considers the value added by each country in the production of goods and services that are consumed worldwide[5]. Pioneering new products and services can provide substantial margins for first movers, thereby securing competitive advantage in the longer run; furthermore, the agglomeration effect provides the possibility of extending the first-mover advantage in a CET to a whole ecosystem of related products and services in the future.

These indicators build upon existing approaches developed for the European Innovation Scoreboard[6] and the Innovation Output Indicator[7].

It should be noted that while no indicator can be calculated for all the in-scope countries that would reflect the ratio of exports versus domestic production for all the relevant product categories, such an indicator can be calculated for EU member countries and is discussed later in more detail.

The tables (1-3) below provide summaries of the three key indicators to be used for the construction of the trade dimension of the CEII, as well as a fourth indicator that only covers 28 countries (EU-27 + the United Kingdom) due to data availability. Its inclusion in the composite index will be decided in the final calculation of the composite index.

Table 1 Indicator 1: High-tech exports as a share of total product exports

Aspect	Description
Indicator	Exports of high-technology product exports as a share of total product exports
Numerator	Value of high-technology products export, in USD and current prices; specifically, value of exports of the HS 6-digit product codes classified as high-technology in Table 3-2.
Denominator	Value of total product exports, in USD and current prices
Description	The indicator can be used to measure the technological competitiveness

[5] OECD (2020) Trade in Value Added. Available at: https://www.oecd.org/sti/ind/measuring-trade-in-value-added.htm
[6] European Commission (2019) European Innovation Scorecard – Main report. Available at: https://ec.europa.eu/docsroom/documents/38781
[7] Vertesy, D (2017) The Innovation Output Indicator 2017. Methodology Report, EUR 28876 EN, Publications Office of the European Union, Luxembourg, 2017, ISBN 978-92-79-76474-5, doi:10.2760/971852, JRC108942. https://publications.jrc.ec.europa.eu/repository/bitstream/JRC108942/jrc108942_ioi_2017_report_final.pdf

	of the observed countries, i.e. the ability to commercialise the results of research and development (R&D) and innovation in international markets. In general, this indicator could reflect a country's 'potential' with respect to advanced technologies – i.e., how well developed its high-tech trade offering is. The overall expectation is that if a country tends to perform strongly in high-tech trade, this capacity could be turned towards CET production.
Rationale / relevance	High technology products are in general characterised by high value added and high-paid employment, hence are key drivers for economic growth, productivity and welfare. In addition, trade intensity of a country in these products can be considered a proxy for the country's progress in the diffusion of pioneer technologies.
Comparability	The indicator allows for proper comparison across the selected countries (EU-27 member states and countries with Mission Innovation membership).
Data availability	UN Comtrade database. Coverage: for all requested countries, for all requested years, at HS 6-digit level.
Assessment	The indicator, in general, reflects how well developed a country's high-tech trade offering is. It can be the case, however, that a country scores high in this indicator due to its strong specialisation in a very specific set of high-tech product exports, but performs poorly in trade relevant to CET, and no robust assumption can be made with regards to turning this capacity towards clean energy production in the future. This type of bias in assessing the countries' innovation performance will have to be accounted for in designing the statistical aggregation method and the weighting of the indicator in the final CEII.

Table 2 Indicator 2: Clean energy technology exports as a share of GDP

Aspect	Description
Indicator	Clean energy technology-related product exports as a share of GDP
Numerator	CET product exports, in USD and current prices, specifically, value of exports of the HS 6-digit product codes classified as CET in Table 3-1.
Denominator	GDP, PPP
Description	This indicator measures the export performance of a country relative to its productive capacities available (the output of which is GDP), with a special focus on CET exports (i.e., it reflects a country's ability to

	commercialise results of R&D and innovation in international markets).
Rationale / relevance	The key rationale behind this indicator is a view that CET exports are an indication of successful innovation performance in the sector. The indicator shows the size of the CET exports relative to the size of the country's economy; and through reflecting the relative importance of international trade (of clean energy technologies) in the economy of a country, it is also a proxy for the country's position in global clean energy value chains.
Comparability	The indicator allows for comparison across the selected countries (EU-27 member states and countries with Mission Innovation membership).
Data availability	CET exports: UN Comtrade database. GDP: World Bank. Coverage: for all requested countries, for all requested years, exports at HS 6-digit level.
Assessment	CET exports as a proportion of GDP provides an overall measure of innovation performance in CET fields.

Table 3 Indicator 3: Domestic value-added content of clean energy technology exports as a share of clean energy technology exports

Aspect	Description
Indicator	Domestic value-added content of energy technology-related product exports as a share of total CET product exports
Numerator	Value of domestic value added embedded in CET products exports, in USD and current prices, reflecting value added content of exports of CET products.
Denominator	Value of total CET products exports
Description	The indicator measures the domestic contribution to traded CET products, measured against the value of total CET exports.
Rationale / relevance	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.
Comparability	The indicator allows for comparison across the selected countries (EU-27 member states and countries with Mission Innovation membership).
Data availability	OECD Trade in Value Added database. Coverage: for all requested

	countries (except for the United Arab Emirates), until 2016.
Assessment	A key advantage of the data is that it does not include re-exports by design and shows to what extent actual innovative domestic value added is created in exports. While an important shortcoming of the currently available dataset is that the last year of data is 2016, according to the 2020 July communication of the OECD[8], the next updated version of TiVA indicators is expected to be released at the beginning of September 2020 and will cover the period 1995-2018.

Missing data and imputation methods

For the 'Export of High-tech products' data from UN Comtrade, a complete dataset would mean data for nine broader product groups classified as high-tech per year, and four years of observations per country, for 42 countries in total. For the 'Export of Clean energy technology products' data from UN Comtrade, a complete dataset would mean 36 HS code observations per year, and four years of observations per country, for 42 countries in total. For the 'Domestic value added in Clean energy technology product exports' data from OECD, a complete dataset would mean 36 HS code-level observations per year (value added disaggregated from the relevant industries to the product level), and four years of observations per country, for 41 countries in total. Since data is not available for the United Arab Emirates, this was proxied by that of a country with similar industry structure / trade characteristics (best available proxy in selected country group: Saudi Arabia).

Potential limitations of the applied methodology

While mapping the HS codes to trade in CETs - in our approach and within the framework of the current project - is the best available methodology, it is important to note that it may not be exhaustive and multiple end-uses give limitations to the accuracy of the mapping exercise.

Extension of the analysis using the Eurostat PRODCOM database

As an additional layer of analysis of CET trade flows, we are using industry production data from the Eurostat PRODCOM database. The following indicator has been calculated for the EU-27 countries, as well as for the United Kingdom for all the years required in the analysis:

8 OECD (2020) Trade in Value Added.
The next updated version of TiVA indicators will cover the period 1995-2018 and is expected to be released at the beginning of September 2020. This is 2-3 months later than originally planned due to unforeseen circumstances related to the COVID-19 crisis.

Indicator 4: CET export vs production: Clean energy technology exports / Clean energy technology Total Sold Production[9]

The indicator reflects to what extent domestic production of a specific CET is exported – in other words, how export-driven the production process of a country is, with respect to clean energy technologies.

The dataset only covers EU countries, therefore we see two options for the treatment of this indicator, calculated for a subset of countries, in order to add value to the analysis, while not diminishing the indicator's robustness (due to the limited coverage of countries):

- The indicator can be included in the computation of the composite indicator, but the weights used in computing the composite indicator based on sub-indicators need to be different for EU countries and for non-EU countries. This needs to be developed at the later stage of weighting and aggregation of indicators.

- The indicator is not included in the computation of the composite indicator, but is provided separately, in a format to be agreed upon later, calculated and assessed for EU countries only. Additionally, based on the assessment of this indicator, insights with regards to EU countries' industrial competitiveness will be drawn and written up in the final report as part of the analysis of CET trade dimension.

Approach to enable trade data to be used in combination with publication and patent data for composite indicator

As will be done for the publications and patent data, the data for the trade indicators will be consolidated and weighted before feeding into the CEII. The key requirement for this step is that a normalised value has to be created. The normalised value is expected to be a combination of all the proposed indicators in the trade dimension, which will allow for capturing all the trade aspects of key relevance to the SET Plan implementation, while avoiding redundancy across the underlying indicators.

9 Total Sold Production data covers the production sold outside the enterprises during the reference period. While total production would include both the production sold and the production retained for reuse by the enterprises as inputs to the manufacture of other products, which may also be informative with regards to the industrial competitiveness in international markets; since products that are not sold cannot easily be valued, only the volume of Total Sold Production can be reported and thus is available from the PRODCOM database. For further details please refer to the PRODCOM Data User Guide:
Eurostat (2017) Statistics on production of manufactured goods (PRODCOM). Available at:
https://ec.europa.eu/eurostat/documents/120432/4433294/europroms-user-guide.pdf

3 Mapping of traded goods classifications to the SET Plan structure

A concordance framework has been developed, linking the relevant clean energy technologies (CETs) to classifications often used in assessing trade in products data (the latest Harmonised System Codes, HS classification). Our mapping approach draws on discussions with the JRC team involved in the project, as well as on the review of some relevant preceding sources: JRC reports[10,11], a recent academic study[12] building on these reports and expanding on their mapping structures (mostly with regards to 'Wind' energy technology), relevant studies[13,14,15] commissioned by international organisations, as well as a proposed list of goods for inclusion under the Environmental Goods Agreement (EGA), developed by the World Energy Council (WEC)[16] in 2010.

While it should be noted that some of these studies and this latter report from the WEC are not very recent and therefore might be considered as outdated, the changes in the technologies and related products have not been that substantial that the suggestions of these sources cannot still be considered valid. However, it might be the case that some categories, which were not included in earlier works, are now included in our analysis: for example, in the previously referred WEC report, there is no mention of 'Energy Storage & Electric powertrains' as a distinct technology domain, but some of the HS codes related to 'Transformers' that in the WEC report are allocated under 'Energy efficiency in power distribution and plant-level consumption' (i.e. HS codes 8504.2X, 8504.3X) are in this report allocated to 'Energy Storage & Electric powertrains'. To end up with a comprehensive categorisation, in such cases sources needed to be synthesised: in this case, for example, HS codes 8504.2X, 8504.3X (other than 8504.31) have remained included under CET category 'Energy Storage & Electric powertrains' within SET Plan KA 'Competitive in the global battery sector (E-mobility)'; and based on another relevant study[17], out of the 8504.XX HS group only 8504.31 has been included under CET 'Wind' within the SET Plan KA 'Performant renewable technologies integrated in the system', as this is the only Transformer category that should be considered as of key relevance for 'Wind' (based on our own expert judgement).

Where needed, harmonisation of different HS code classifications was based on the concordance tables available in Eurostat's RAMON[18] metadata.

Importantly, there is no clear one-to-one mapping between the investigated SET Plan KAs and the product-level 6-digit HS codes. Certain product categories, while being highly relevant for the assessed CETs, capture trade in products which are also relevant to trade in several other non-CET product categories. The clearest example of this appears to be in the SET Plan KA '*CCS/U*' where some of the key products are likely to capture trade in natural gas and chemical industry, too, for example. Some of the codes, e.g., HS 2012 841861, 841950, or 850431) might apply to more than one CET type. However, for the sake of consistency and additivity (for the calculation of the 'total' indicator, based on the sub-indicators per different CETs and per different SET Plan KAs), in these cases the HS codes

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[10] Pasimeni, F (2017) EU energy technology trade: Import and export. EUR 28652 EN, Publications Office of the European Union, Luxembourg, 2017, ISBN 978-92-79-69670-1, doi:10.2760/607980, JRC107048.
[11] Fiorini, A et al (2017) Monitoring R&I in Low-Carbon Energy Technologies. Methodology for the R&I indicators in the States of the Energy Union Report – 2016 edition. EUR 28446 EN. doi: 10.2760/447418
[12] Read, E A (2019) The technology transfer reality behind Costa Rica's renewable Electricity. EKHS34 Master's Thesis, Lund University, School of Economics and Management, Sweden. Available at: http://lup.lub.lu.se/luur/download?func=downloadFile&recordOId=8993611&fileOId=8993612
[13] Wind, I (2010) HS Codes and the Renewable Energy Sector. International Centre for Trade and Sustainable Development. Available at: https://www.files.ethz.ch/isn/111414/2010_01_hs-codes-and-the-renewable-energy-sector.pdf
[14] Wind, I (2010) HS Codes and the Transport Sector. International Centre for Trade and Sustainable Development. Available at: https://www.files.ethz.ch/isn/139135/hs-code-study-transport.pdf
[15] Jacob, A – Møller, M K (2017), Policy landscape of trade in environmental goods and services. ARTNeT Working Paper Series No. 166, April 2017, Bangkok, ESCAP. Available at: https://www.unescap.org/sites/default/files/AWP%20No.%20166.pdf
[16] World Energy Council (2010) Proposed list of goods for inclusion under the Environmental Goods Agreement (EGA). Available at: https://www.worldenergy.org/assets/images/imported/2012/09/20100914_wec_envtl_goods_list.pdf
[17] Jacob, A – Møller, M K (2017), Policy landscape of trade in environmental goods and services. ARTNeT Working Paper Series No. 166, April 2017, Bangkok, ESCAP. Available at: https://www.unescap.org/sites/default/files/AWP%20No.%20166.pdf
[18] Eurostat (2020c) Reference And Management Of Nomenclatures. Available at: https://ec.europa.eu/eurostat/ramon/index.cfm?TargetUrl=DSP_PUB_WELC

have been exclusively allocated to one CET. This way the indicators, when aggregated up to SET Plan KA level and to 'total', show a comprehensive picture of a country's progress in CET trade and there is no risk of double-counting a specific product category under more than one CET. In these cases, i.e. where one product (as defined by one HS code) might have been relevant to more than one technology or SET Plan KA, the final allocation of the code was based on a) the reviewed literature sources (listed in the footnotes) and b) the observed relative importance of the HS code in question within all the HS codes associated with the specific CET (in terms of the share of trade value captured by the HS code in question compared to total trade value of all HS codes associated with the specific CET).

The concordance between the key topics of the Energy Union R&I and Competitiveness priorities, the SET Plan KAs, the selected CETs and the corresponding HS codes (to assess trade) is summarised in Table 4 below.

Table 4 Concordance between topics within the Energy Union R&I and Competitiveness priorities, SET key actions and HS product codes for clean energy technologies

Energy Union R&I priority	SET Plan (key actions)	Corresponding clean energy technology	HS code (6- or 4-digit)	HS code description
Number 1 in Renewables	Performant renewable technologies integrated in the system	Solar PV	854140	Diodes, transistors and similar semiconductor devices; photosensitive semiconductor devices, including photovoltaic cells, whether or not assembled in modules or made up into panels; light-emitting diodes; mounted piezoelectric crystals
			850440	Electrical transformers, static converters (for example, rectifiers) and inductors
		Solar Thermal	841919	Instantaneous or storage water heaters, non-electric (excl. instantaneous gas water heaters and boilers or water heaters for central heating)
			850239	Electric generating sets; (excluding those with spark-ignition or compression-ignition internal combustion piston engines), other than wind powered
			841950	Heat Exchanger Units
		Wind	730820	Towers and lattice masts, of Iron or Steel
			850231	Generating Sets, Electric, Wind-powered
			841381	Pumps for liquids, whether or not fitted with a measuring device; other pumps
			841290	Engines; parts, for engines and motors of heading no. 8412 (reaction engines, hydraulic power engines, pneumatic power engines)
			848210	Ball bearings
			848340	Gears and gearing; (not toothed wheels, chain sprockets and other

				transmission elements presented separately); ball or roller screws; gear boxes and other speed changers, including torque converters
			850164	Electric generators; AC generators, (alternators), of an output exceeding 750kVA
			850431	Electrical transformers; n.e.c. in item no. 8504.2, having a power handling capacity not exceeding 1kVA
			853620	Electrical apparatus; automatic circuit breakers, for a voltage not exceeding 1000 volts
		Hydropower	841011	Hydraulic Turbines, Water Wheels, of a Power Not Exceeding 1,000kw
			841012	Hydraulic Turbines and Water Wheels, Power 1,000-10,000kw
			841013	Hydraulic Turbines, Water Wheels, of a Power Exceeding 10,000kw
			841090	Parts of Hydraulic Turbines and Water Wheels, Including Regulators
		Geothermal	841861	Refrigerators, freezers and other refrigerating or freezing equipment, electric or other; heat pumps other than air conditioning machines of heading 84.15
Smart system – Smart EU energy system with consumers at the centre	New technologies & services for consumers	Smart meters	902830	Electricity meters
	Resilience & security of energy system	Clean coal & gas	840420	Condensers for Steam or Other Vapour Power Units
			841181	Other Gas Turbines of a Power Not Exceeding 5,000kw
			841182	Other Gas Turbines of a Power Exceeding 5,000kw
			841199	Parts of Other Gas Turbines
Efficient energy systems	New materials & technologies for buildings/ Energy efficiency in industry	Insulation	680610	Slag wool, rock wool and similar mineral wools (incl. Intermixtures thereof), in bulk, sheets or rolls
			680690	Other: Articles of Heat-insulating, Sound-insulating Mineral Materials
			700800	Multiple-walled insulating units of glass
			701939	Webs, Mattresses, Boards and Similar Nonwoven Products, of Glass Fibres
			680510	Abrasive powder or grain; natural or artificial, on a base of woven textile fabric only, whether or not cut to shape or sewn or otherwise made up
			680520	Abrasive powder or grain; natural or artificial, on a base of paper or paperboard only, whether or not cut to shape or sewn or otherwise made up

			680530	Abrasive powder or grain; natural or artificial, on a base of materials n.e.c. in heading no. 6805, whether or not cut to shape or sewn or otherwise made up
Sustainable transport	Renewable fuels	Biofuels	220710	Ethyl Alcohol (Alcoholic Strength 80 degrees or More)
			220720	Ethyl Alcohol, Other Spirits (Denatured)
		Fuel cells	850680	Cells and batteries; primary, (other than manganese dioxide, mercuric oxide, silver oxide, lithium or air-zinc)
			850690	Cells and batteries; primary, parts thereof
		Hydrogen technology	280410	Hydrogen
			840510	Generators; producer gas, water gas, acetylene gas and similar water process gas generators, with or without their purifiers
			840590	Generators; parts of producer gas, water gas, acetylene gas and similar water process gas generators, with or without their purifiers
			731100	Containers for compressed or liquefied gas, of iron or steel
			761300	Aluminium; containers for compressed or liquefied gas
	Competitive in the global battery sector (E-mobility)	Energy Storage & Electric powertrains	850300	Electric motors and generators; parts suitable for use solely or principally with the machines of heading no. 8501 or 8502
			850421	Electrical transformers; liquid dielectric, having a power handling capacity not exceeding 650kVA
			850422	Electrical transformers; liquid dielectric, having a power handling capacity exceeding 650kVA but not exceeding 10,000kVA
			850423	Electrical transformers; liquid dielectric, having a power handling capacity exceeding 10,000kVA
			850432	Transformers; n.e.c. in item no. 8504.2, having a power handling capacity exceeding 1kVA but not exceeding 16kVA
			850433	Transformers; n.e.c. in item no. 8504.2, having a power handling capacity exceeding 16kVA but not exceeding 500kVA
			850434	Transformers; n.e.c. in item no. 8504.2, having a power handling capacity exceeding 500kVA
			850720	Electric accumulators; lead-acid, (other than for starting piston engines), including separators, whether or not rectangular (including square)

			850650	Cells and batteries; primary, lithium
			850710	Lead-acid Accumulators, of a Kind Used for Starting Piston Engines
			850730	Nickel-cadmium Accumulators
			850740	Nickel-iron Accumulators
Carbon capture, utilisation and storage (CCS/U)	Carbon capture, utilisation and storage (CCS/U)	Carbon capture, utilisation and storage (CCS/U)[19]	730630	Tubes, Pipes And Hollow Profiles, Seamless, Of Iron (Other Than Cast Iron) Or Steel
			841490	Parts of air or other gas compressors
			841480	Air or other gas compressors CCS
			841990	Parts of apparatus for treatment of materials by temperature
			841989	Other apparatus for treatment of materials by temperature
Nuclear safety	Nuclear safety	Nuclear energy	840110	Nuclear reactors
			840120	Machinery and apparatus; for isotopic separation, and parts thereof
			840140	Nuclear reactors; parts thereof

Source: Mapping of technologies and HS product codes based on Pasimeni, F (2017), Fiorini (2017), Read, E A (2019) and the World Energy Council (2010). Mapping of R&I priorities adapted from the JRC's "Monitoring R&I in low-carbon energy technologies," 2017, allocation was applied to the extent made possible by the structure and granularity of publicly available data on product-level trade.

Classification of high-tech industries

Our definition of high-tech industries is based on that applied in Eurostat's "high-tech statistics"[20]. In their statistical methodology, there are two main approaches used to identify technology-intensity: the sectoral approach and the product approach. The sectoral approach builds on an aggregation of the manufacturing industries according to their technological intensity (R&D expenditure divided by value added). In this approach, manufacturing activities are grouped using the Statistical Classification of Economic Activities in the European Community (NACE Rev.2) at the 2- or 3-digit level to:

- 'high-technology' (e.g., Manufacture of basic pharmaceutical products and pharmaceutical preparations),
- 'medium high-technology' (e.g., Manufacture of electrical equipment),
- 'medium low-technology' (e.g., Manufacture of rubber and plastic products) and
- 'low-technology' (e.g., Manufacture of beverages)[21].

[19] The HS codes most relevant to CCS/U technology have been selected based on the proposed list of goods for inclusion under the Environmental Goods Agreement (EGA) developed by the World Energy Council in 2010. Available at: https://www.worldenergy.org/assets/images/imported/2012/09/20100914_wec_envtl_goods_list.pdf.
Out of all HS product codes marked to be partly or fully linked to CCS/U in the referred source, we have selected the five most relevant HS codes based on their share in total exports of products that are marked to be partly or fully linked to CCS/U of EU-28 countries to the world in 2016 (five most relevant products accounting for ~50% of this export). Export data taken from the UN Comtrade products export database. May be revised/extended based on the referred source.
[20] Eurostat (2020a) Eurostat indicators on High-tech industry and Knowledge – intensive services - Annex 5: High-tech aggregation of products by SITC Rev.4. https://ec.europa.eu/eurostat/cache/metadata/Annexes/htec_esms_an5.pdf
[21] Eurostat (2020d) Glossary:High-tech. Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:High-tech

In the product approach, product groups are classified as high-technology products depending on their R&D intensity (R&D expenditure divided by total sales) and are aggregated on the basis of the Standard International Trade Classification (SITC).

According to the metadata source of Eurostat referred to above, the sectoral approach is generally used for the construction of all indicators except data on high-tech trade and patents. As industrial sectors that are characterised by a limited number of high-technology products may also produce a range of low-technology products, the product approach is more capable of capturing trends in high-tech trade, as it is built up from a more granular level of observations and reflects the presence of technological advancements in trade metrics better than the aggregated sector-level data.

In accordance with Eurostat's latest classification list for High-tech products aggregation[22], high-technology trade is defined as exports and imports of a subset of products defined according to the Standard International Trade Classification (SITC – Rev. 4). The classification, presented in Table 5 below contains technical products the manufacturing of which involved a high intensity of R&D.

Table 5 High-tech aggregation of products by SITC Rev.4

Group	Code	Title[23]
Aerospace	(714-714.89-714.99)+	Lead-acid Accumulators, of a Kind Used for Starting Piston Engines
	792.1+	Helicopters
	792.2+792.3+792.4+	Aeroplanes and other aircraft, mechanically-propelled (other than helicopters)
	792.5+	Spacecraft (including satellites) and spacecraft launch vehicles
	792.91+	Propellers and rotors and parts thereof
	792.93+	Undercarriages and parts thereof
	874.11	Direction finding compasses; other navigational instruments and appliances
Computers, office machines	751.94+	Multifunction office machines, capable of connecting to a computer or a network
	751.95+	Other office machines, capable of connecting to computer or a network
	752+	Computers
	759.97	Parts and accessories of group 752
Electronics, telecommunications	763.31+	Sound recording or reproducing apparatus operated by coins, bank cards, etc
	763.8+	Video apparatus
	(764-764.93-764.99)+	Telecommunications equipment, excluding 764.93 and 764.99
	772.2+	Printed circuits

[22] Eurostat (2020a) Eurostat indicators on High-tech industry and Knowledge – intensive services - Annex 5: High-tech aggregation of products by SITC Rev.4. Available at: https://ec.europa.eu/eurostat/cache/metadata/Annexes/htec_esms_an5.pdf
[23] In some cases, the titles have been shortened. For full description see: United Nations (2020) Classifications on Economic Statistics. Available at: http://unstats.un.org/unsd/cr/registry

	772.61+	Electrical boards and consoles < 1000V
	773.18+	Optical fibre cables
	776.25+	Microwave tubes
	776.27+	Other valves and tubes
	776.3+	Semiconductor devices
	776.4+	Electronic integrated circuits
	776.8+	Piezoelectric crystals
	898.44+	Optical media
	898.46	Semiconductor media
Pharmacy	541.3+	Antibiotics
	541.5+	Hormones and their derivatives
	541.6+	Glycosides, glands, antisera, vaccines
	542.1+	Medicaments containing antibiotics or derivatives thereof
	542.2	Medicaments containing hormones or other products of subgroup 541.5
Scientific instruments	774+	Electrodiagnostic apparatus for medicine or surgery and radiological apparatus
	871+	Optical instruments and apparatus
	872.11+	Dental drill engines
	(874-874.11-874.2)+	Measuring instruments and apparatus, excluding 874.11, 874.2
	881.11+	Photographic cameras
	881.21+	Cinematographic cameras
	884.11+	Contact lenses
	884.19+	Optical fibres other than those of heading 773.1
	(899.6-899.65-899.69)	Orthopaedic appliances, excluding 899.65, 899.69
Electrical machinery	778.6-778.61-778.66- 778.69)+	Electrical capacitors, fixed, variable or adjustable, excluding 778.61, 778.66, 778.69
	778.7+	Electrical machines, having individual functions
	778.84	Electric sound or visual signalling apparatus
Chemistry	522.22+	Selenium, tellurium, phosphorus, arsenic and boron
	522.23+	Silicon

	522.29+	Calcium, strontium and barium
	522.69+	Other inorganic bases
	525+	Radioactive materials
	531+	Synthetic organic colouring matter and colour lakes
	574.33+	Polyethylene terephthalate
	591	Insecticides, disinfectants
Non-electrical machinery	714.89+	Other gas turbines
	714.99+	Part of gas turbines
	718.7+	Nuclear reactors and parts thereof, fuel elements, etc
	728.47+	Machinery and apparatus for isotopic separation
	731.1+	Machine-tools working by laser or other light or photon beam, etc
	731.31+	Horizontal lathes, numerically controlled
	731.35+	Other lathes, numerically controlled
	731.42+	Other drilling machines, numerically controlled
	731.44+	Other boring-milling machines, numerically controlled
	731.51+	Milling machines, knee-type, numerically controlled
	731.53+	Other milling machines, numerically controlled
	731.61+	Flat-surface grinding machines, numerically controlled
	731.63+	Other grinding machines, numerically controlled
	731.65+	Sharpening machines, numerically controlled
	733.12+	Bending, folding, straightening or flattening machines, numerically controlled
	733.14+	Shearing machines, numerically controlled
	733.16+	Punching machines, numerically controlled
	735.9+	Parts and accessories of 731 and 733
	737.33+	Machines and apparatus for resistance welding of metal, fully or partly automatic
	737.35	Machines and apparatus for arc welding of metal, fully or partly automatic
Armament	891	Arms and ammunition

Source: Eurostat (2020a)[24]

[24] Eurostat (2020a) Eurostat indicators on High-tech industry and Knowledge – intensive services - Annex 5: High-tech aggregation of products by SITC Rev.4. https://ec.europa.eu/eurostat/cache/metadata/Annexes/htec_esms_an5.pdf

Concordance between traded goods categories (by HS codes) and SITC Rev.4 classification

As high-technology trade is defined as exports and imports of products according to the Standard International Trade Classification (SITC – Rev. 4), while the initial dataset on international trade (UN Comtrade data) sorts traded goods data according to Harmonised System Codes (HS classification), it is necessary to map the above SITC commodities to HS codes to the relevant industries. The relevant correspondence table for this conversion can be found on the Eurostat RAMON[25] site. Initially, traded goods data for the more recent years is provided in the HS 2017 classification version, while earlier years are reported in HS 2012 classification, thus in order to have a single set of HS codes to use for the analysis, everything has been mapped to HS 2017 classification.

Concordance between traded goods categories (by CN codes) and HS classification

Production of manufactured goods data available from the PRODCOM database26 uses the CN-code classification by NACE Rev. 2 categories. To allow for linking it to the identified clean energy technologies, another correspondence table was developed by Cambridge Econometrics that allows for a matching of CN product codes to HS product codes and finally, to clean energy technologies.
The correspondence tables used for these conversions can be found in the accompanying dataset including all the indicators (Synthesised Trade Analysis_Input data_Graphs_20201111.xlsx).

[25] Eurostat (2020c) RAMON – Reference and Management of Nomenclatures. Available at: https://ec.europa.eu/eurostat/ramon/relations/index.cfm?TargetUrl=LST_REL&StrLanguageCode=EN&IntCurrentPage=1
[26] Eurostat (2020b) Statistics on the production of manufactured goods (prodcom). Available at: https://ec.europa.eu/eurostat/web/prodcom/data/database

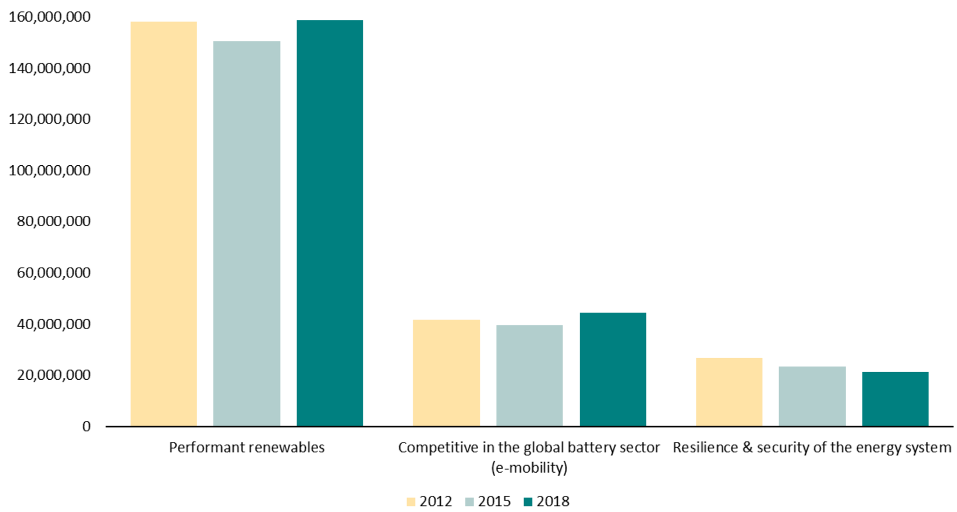
4 Clean energy innovation performance through the lens of trade indicators

This chapter provides a high-level analysis of the main developments regarding international trade in clean energy technologies (CETs). First, aggregate performance of the investigated countries (and groups of countries such as the EU) for all SET Plan KAs is assessed for the relevant indicators. Second, the country performance is assessed across various renewable technologies that are sub-categories of SET Plan KA "Performant renewable technologies". Finally, the performance of world players across the years is investigated in more detail, with a focus on exploring trends in specialisation per country.

4.1 Main developments of CET exports by SET Plan Key Action

Export volumes of CET products of in-scope countries have been largely stagnant between 2012 and 2018; the total CET export volume increased from 0.302 B USD in 2012 to 0.304 B USD in 2018, with a CAGR (compound average growth rate) of 0.1%. Figure 1 presents total export volumes across the top three largest SET Plan KA categories. The top five largest CET product exporters, in volume terms and as of 2018 were (larger to smaller): China, Germany, US, Japan and Italy. Based on 2018 data, out of all the in-scope countries, Mission Innovation members, as a group (23 countries out of 42 in total), accounted for as much as 87% of total CET exports.

Figure 1 Clean energy technology export volumes across the top 3 largest SET Plan Key Actions, in-scope countries total (1000 USD)

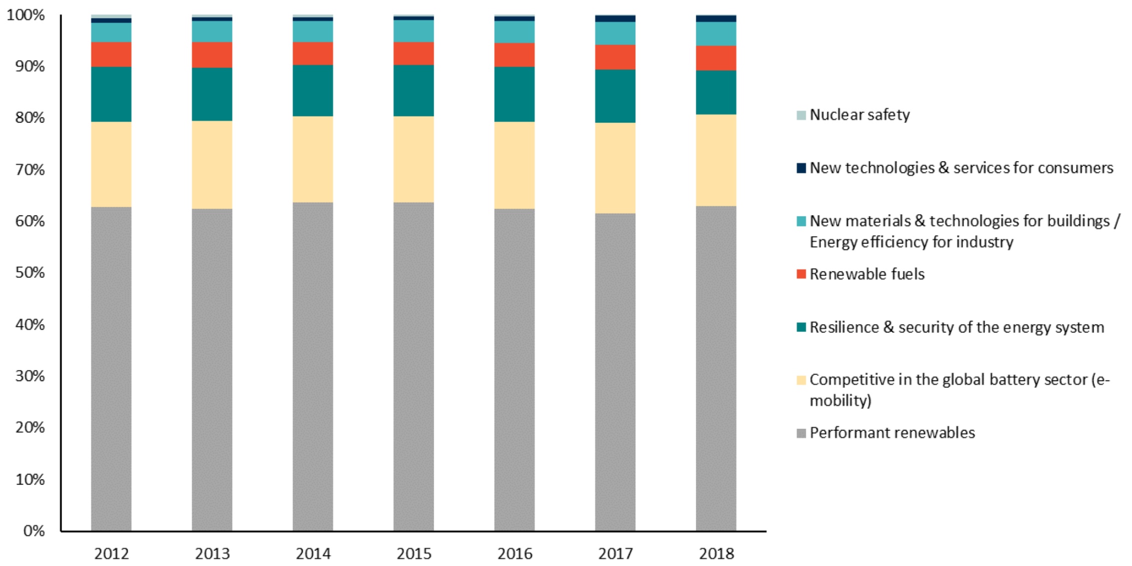


Data Source: United Nations (2020)[27]

Figure 4-2 presents the distribution of CET products exports across all SET Plan KAs. The chart illustrates the relative sectoral importance in the dimension of traded goods in in-scope countries (EU member states and non-EU Mission Innovation members aggregated).

[27] United Nations (2020) UN Comtrade Database. Available at: https://comtrade.un.org/

Figure 2 Clean energy technology product exports by SET Plan Key Actions (% of total)



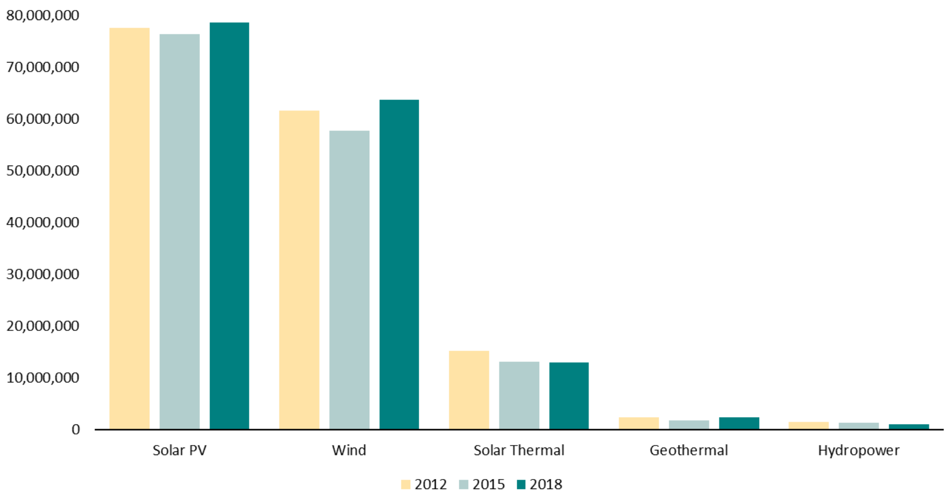
Data Source: United Nations (2020)

A key insight from Figure 2 is that '*Performant renewables*' (including Solar PV and Solar Thermal, Wind, Hydro and Geothermal) accounts for over 50 percent of traded CET-related products in all SET Plan KA categories in total, across all the years investigated. The second most traded category is goods related to the SET Plan KA '*Competitive in the global battery sector (e-mobility)'* (e.g. electric motors, electrical transformers, accumulators), followed by product exports related to '*Resilience and security of the energy system*' (e.g. condensers for steam, certain gas turbine categories).

Exports of renewable energy technology products have largely stagnated across the time period covered: from 0.158 B USD in 2012 to 0.159 B USD in 2018.

Figure 3 shows absolute export values, outlining the overall development and size of the market (in monetary terms) across the five identified renewable technologies within SET Plan KA 'Performant renewables'.

Figure 3 Clean energy technology export volumes across various renewables-related categories, in-scope countries total (1000 USD)



Data Source: United Nations (2020)

4.2 Main developments and trend in the domestic value added content of exports

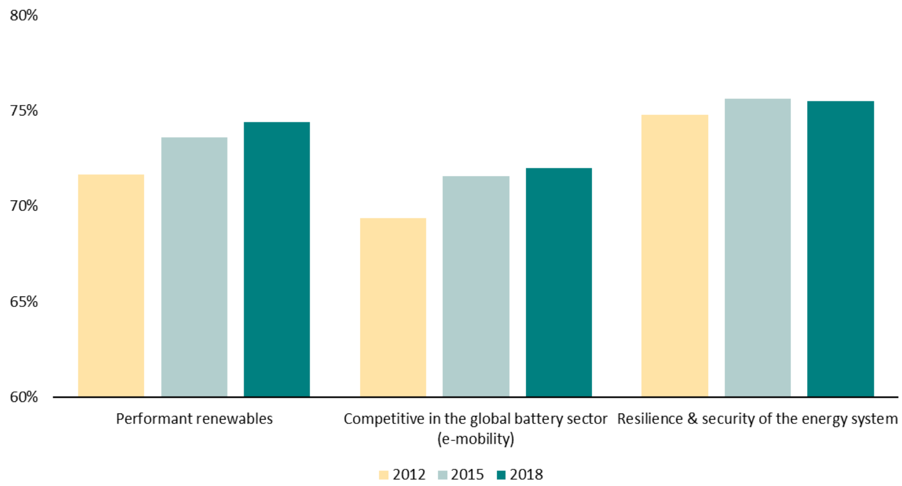
Domestic value added content of exports – Headline results

Perhaps the most important trade indicator, in terms of its ability to capture and illustrate advancements in CET innovation performance, is the '**CET value added**' indicator, capturing domestic value added content of CET exports (in percentage terms) as a share of total exports. Figure 4 below gives an overview of the shares for in-scope countries total (EU member states and countries with Mission Innovation membership) of domestic value added content of exports on total CET exports, across the most traded SET Plan KAs (with context provided by trends on exports shown in Figure 1). Figure 5 illustrates domestic value added percentage across the Renewable Energy Source (RES) categories. The distribution of domestic value added (as a share of exports) across the SET Plan KAs is very similar to that of exports.

Figure 4 and Figure 5 show that the domestic value added content of exports (in percentage terms) has been increasing for both the largest SET Plan KA categories, and for the relevant RES export product categories between 2012 and 2018. The increase is the steepest for products related to Renewables and E-mobility technologies. This trend suggests that global supply chains of CETs have become more complex and on average countries have become more integrated in supply chains (i.e., data suggests that countries are on average adding more value domestically to their exports in 2018 than they did in 2012 – this also includes cases where exported goods are used as intermediate inputs for production in another country, e.g. PV cells for PV modules).

While this increase in value added takes place in an overall smaller export market in the case of E-mobility, value added for Renewable technologies takes place in an initially large market (with total export size of above 150 billion USD for in-scope countries in total).

Figure 4 Domestic value added percentage of clean energy technology exports by SET Plan Key Actions (%)

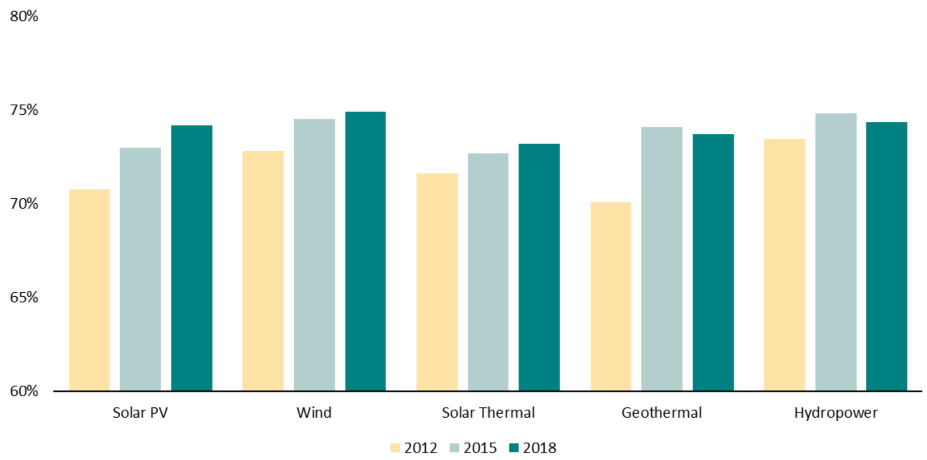


Data Source: United Nations (2020); OECD (2020)[28]

Within the SET Plan KA 'Performant renewables', domestic value added content of exports (in percentage terms) has been increasing the most for products related to Solar PV, Wind and Geothermal technologies between 2012-2018. While total export volume is rather insignificant for Geothermal, in the case of Solar PV and Wind technologies, domestic value added content is increasing in a growing export market for in-scope countries.

[28] OECD (2020) Trade in Value Added. Available at: https://www.oecd.org/sti/ind/measuring-trade-in-value-added.htm

Figure 5 Domestic value added percentage of renewables-related exports (%)

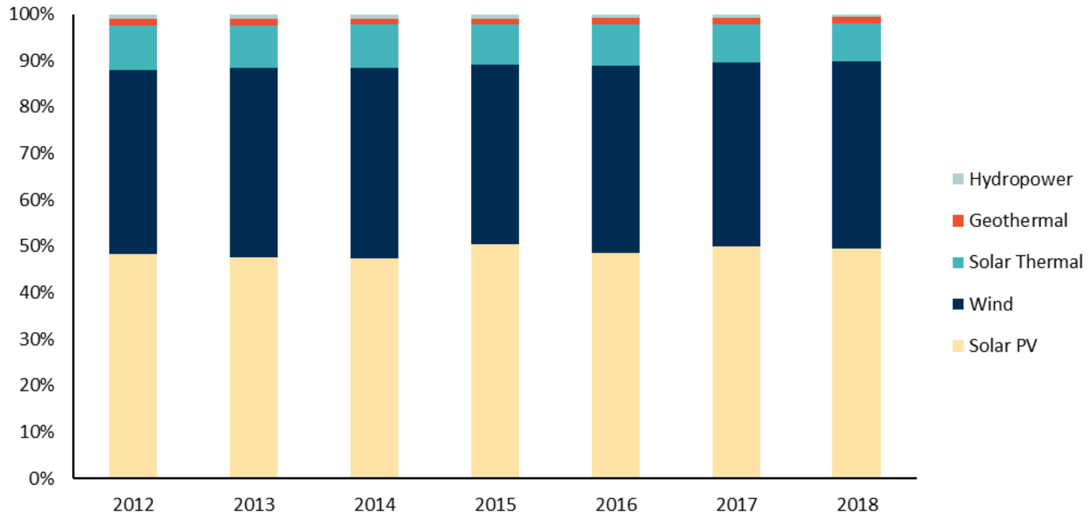


Data Source: United Nations (2020); OECD (2020)

The following chart (Figure 6) further zooms in compared to previous charts, and presents the domestic value added content of exports across five identified categories within 'Performant renewables' SET Plan KA: Solar PV, Solar Thermal, Geothermal, Hydropower and Wind. The chart illustrates the relative importance of different renewable technologies in traded goods across the years.

Of the five 'Performant renewables' identified in traded goods categories, Solar PV and Wind are the two most important with regards to their share of domestic value added content in total product exports, accounting for around 50 percent and 35 percent of total exports respectively, the ratios being relatively unchanged across the years 2012-2018. Domestically sold production of the same renewable-related trade products for EU-27 countries has been decreasing across the same time period (from 50 000 M EUR to 41 000 M EUR). This is largely explained by much less available product-level trade data for the later years (2016-2018) than for the years 2012-2015.

Figure 6 Domestic value added of clean energy technology exports across "Performant renewable technologies integrated in the system" (% of total)



Data Source: United Nations (2020); OECD (2020)

4.3 Analysis of trends for the European Union (EU-27)

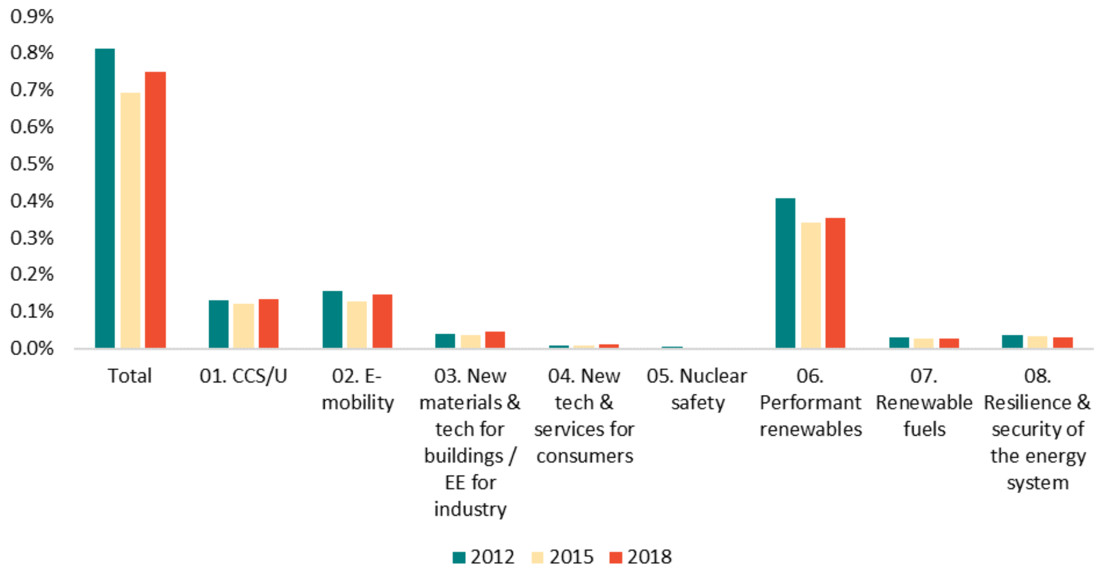
A few important insights can be made with regards to EU-27 countries' average performance over the period 2012-2018 in the four indicators assessed.

First, changes in the distribution of CET domestic sold production across SET Plan KAs in in-scope countries (EU-27 members and the UK) suggest that there is a tendency for some of the categories to gain relative importance vis-á-vis other categories, primarily at the expense of goods belonging to Performant renewables. However, it also needs to be stressed that the methodology applied (i.e., assessing CET trade based on product-level export data) implies that some of the product categories, while being highly relevant to CETs, capture trade in products which are also relevant to trade in other energy technologies applying to fossil fuels. The clearest example of this appears to be in CCS/U where the relatively high performance is likely to relate to trade in the natural gas and chemical industry, etc. However, the existence of exports in this sector may suggest the capacity to take advantage of any future growth in CCS/U. In order to present an accurate picture of the technologies vis-á-vis each other and to allow for proper comparison, CCS/U figures have been excluded from the charts presented here (they are included in the full Trade dataset).

EU-27 countries, on average, have increased their High-tech exports / Total exports (%) ratio over the period covered: from an average 9.9% in 2012 to 10.9% in 2018, with the underlying high-tech export volume increasing by 20% in the same period. The countries with the largest percentage point increase in their High-tech exports / Total exports ratio are Ireland (21.1% in 2012 and 32.9% in 2018) and Latvia (6% in 2012 and 12.5% in 2018).

With regards to the ratio of CET exports to GDP, the average for EU-27 countries has slightly decreased (see Figure 7): from 0.8% in 2012 to 0.75% in 2018. The EU-27 average has largely stagnated for all specific SET Plan KAs, with minor changes over the period. Ratios related to the SET Plan KAs 'CCS/U', 'New materials & technologies for buildings / Energy efficiency for industry', and 'New technologies & services for consumers' slightly increased over the period.

Figure 7 Exports / GDP ratio, SET Plan Key Actions total and per SET Plan Key Action, EU-27 average



Data Source: United Nations (2020); World Bank (2020)[29]

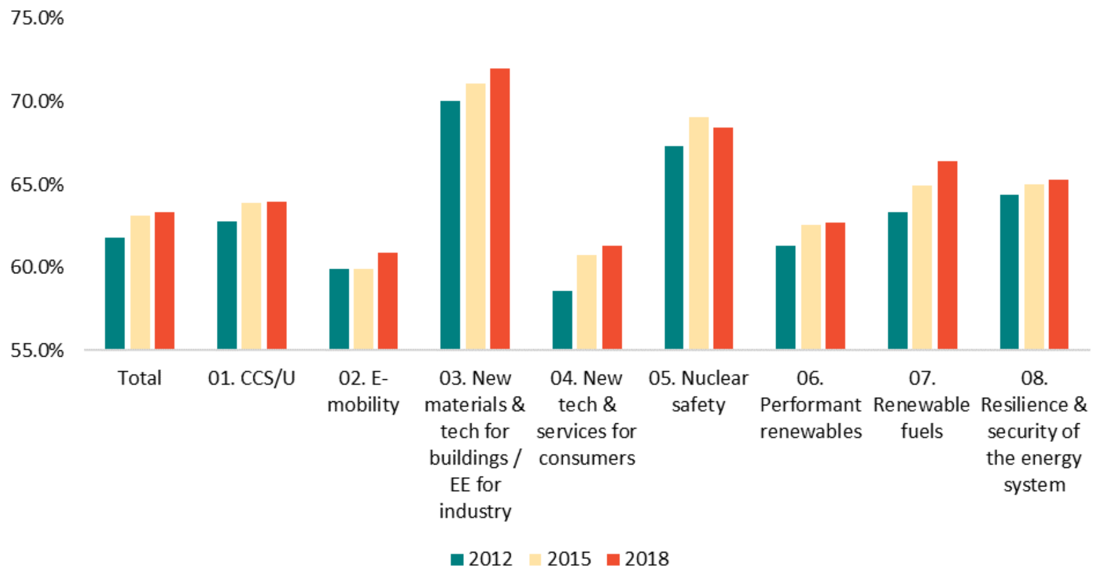
[29] World Bank (2020) World Development Indicators - GDP. Available at: https://databank.worldbank.org/source/world-development-indicators

Certain countries managed to increase their respective ratios (in terms of CET exports to GDP) relatively more: e.g. in Poland, the ratio changed from 0.4% to 0.6%, and in Slovakia the ratio changed from 1.4% to 1.6% between 2012 and 2018.

In contrast, the domestic value added percentage of CET exports increased for the EU-27 countries, on average (see Figure 8 below): from ~61% to ~63% between 2012 and 2018. The positive trend in this indicator is largely driven by some leading EU-27 countries, e.g. the ratio in Ireland increased from 56% in 2012 to above 64% in 2018, and increased from 64% in 2012 to 69% in 2018 in Denmark.

When zooming in to specific SET Plan KAs, those in which the EU-27, on average, has made the biggest percentage point increase are: 'New technologies & services for consumers' (increased from 58.6% in 2012 to 61.3% in 2018) and 'Renewable fuels' (increased from 63.3% in 2012 to 66.4% in 2018).

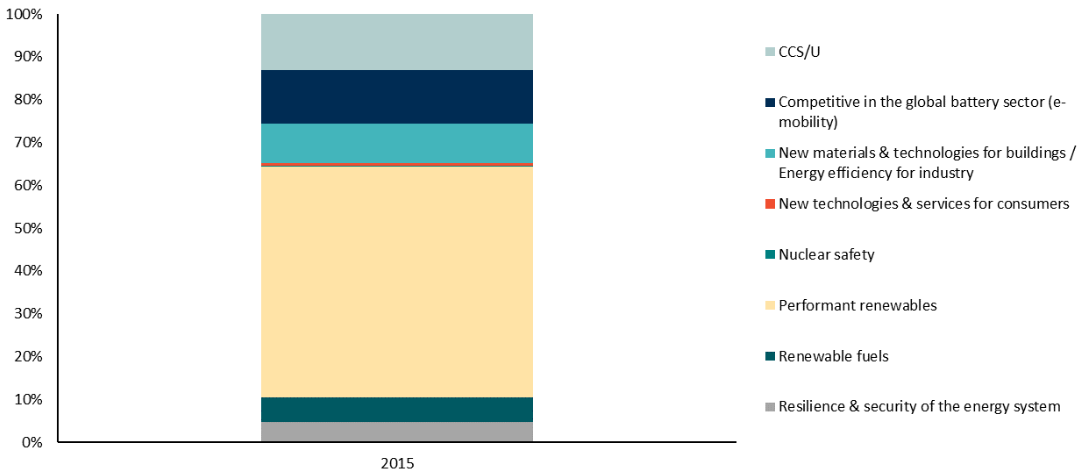
Figure 8 Domestic value added in clean energy technology exports (%) for SET Plan Key Actions total and per SET Plan Action, EU-27 average



Data Source: United Nations (2020); OECD (2020)

With regards to the fourth indicator, the ratio of exports versus domestic sold production of CETs, there are significant data gaps in the raw data (built up from product-level data) for the years 2012-2014 and for the years 2016-2018, therefore only the year 2015 can be referred to when assessing the performance of EU-27 countries (Figure 9). Furthermore, the export data used for this indicator by design includes re-exports, which means that in most countries, its value is substantially larger than that of domestic sold production (often several times the value of production). Therefore, it is not recommended to assess EU-27 average performance in this indicator; yet looking at the production data alone offers a few insights: in 2015 '*Performant renewables*' (including Solar, Wind, Hydro and Geothermal) accounted for over 50 percent of the total 96 000 M EUR sold production across all SET Plan KAs, followed by '*E-mobility*' (e.g. electric motors, electrical transformers, accumulators).

Figure 9 Clean energy technology domestic sold production by SET Plan Key Actions, % of total, 2015



Data Source: Eurostat (2020b)[30]

4.4 Key developments by countries: world players and top EU-27 countries

The following sections illustrate the development of countries classified as 'world players' (China, Japan, South Korea, United States and EU-27) in the four indicators of interest over the period covered. For all the indicators, the performance of the 'top EU-27 players' (based on their average performance value across the years) is also presented. In order to control for the extreme differences in scale (which would otherwise not allow for a proper comparison of countries' performance) the group of the 'top EU players' have been selected from a subset of countries, including the sufficiently large EU countries only (in terms of total export volume). The following countries fall in the bottom 20% in terms of 2018 export volumes, and have not been considered for the major EU countries subset: Croatia, Cyprus, Estonia, Latvia, Luxembourg, Malta.

4.4.1 Indicator 1. High-tech exports / Total exports[31]

In terms of high-tech product exports[32], South Korea has clearly made great progress to become the top amongst world player countries (with a share of high-tech product exports of total exports above 30%), followed by China, Japan, and the US (Figure 10). The top EU-27 country on this measure is Ireland (also above 30% - most likely due to the tax regime providing advantageous conditions for IT companies and products in Ireland[33]), followed by France and Czechia (both scoring higher than Japan or the US from the world players) (Figure 11).

While the overall high-tech export volume of Czechia is about a quarter of the size of the exports of France, its high-tech to total export ratio is very similar, largely driven by a high share of products related to 'Electronics' and 'Telecommunication' within total exports. Central- and Eastern European countries' economies can be seen as becoming more and more export-oriented across the years, with increasing export volumes in both high-technology products and CET exports. The performance of Czechia in this indicator

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[30] Eurostat (2020b) Statistics on the production of manufactured goods (prodcom). Available at: https://ec.europa.eu/eurostat/web/prodcom/data/database

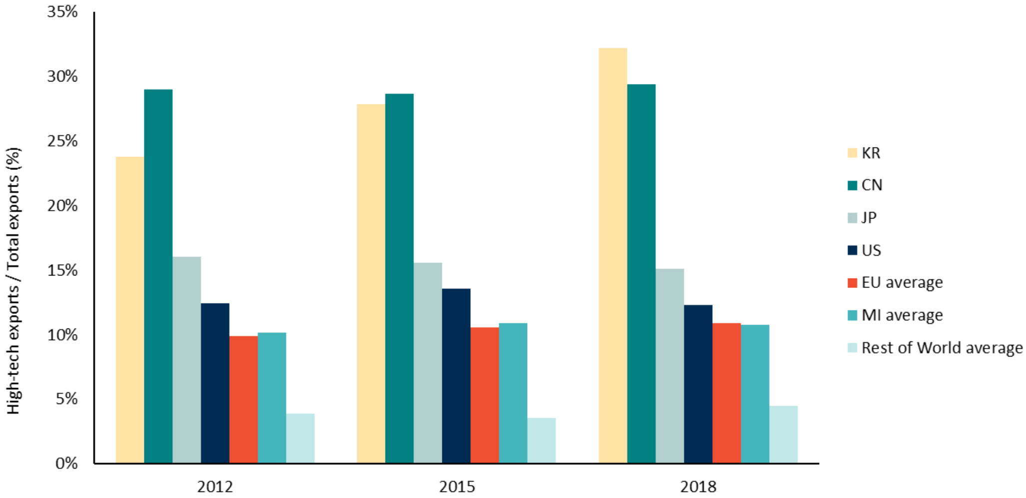
[31] It is to be noted that both high-tech exports and total exports cover total world exports, that is, intra- and extra-EU trade are also accounted for in the calculation of the indicator - to be considered when assessing the performance of countries (Figure 1-13).

[32] According to 2018 data, the top eight countries in terms of *High-tech export absolute volumes* are (larger to smaller): China, Germany, US, South Korea, France, Japan, the Netherlands and the UK. Countries with the lowest absolute volumes are (smaller to larger): Cyprus, Saudi Arabia, Chile, Luxembourg, Malta, Croatia, Latvia and Greece. The ranking order has essentially been unchanged between 2012-2018, but the growth rates are substantial with 20% total export volume growth from 2012 to 2018 (in-scope countries total), and certain countries growing even more (e.g. the UAE 2018 export volume is seven times its 2012 export volume; also Latvia, Poland, Ireland and South Korea all demonstrate strong volume growth over the period).

[33] See e.g.: Keane, J (2020) Ireland stands by its iconic 12.5% tax rate as OECD races for reforms. CNBC online. Available at: https://www.cnbc.com/2020/11/03/ireland-stands-by-its-corporate-tax-rate-as-oecd-races-for-reforms-.html

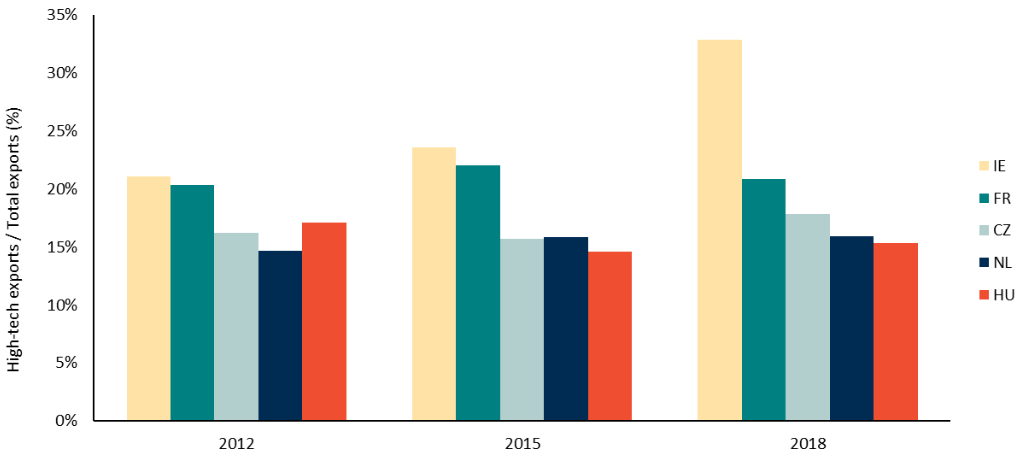
provides a good example of typical trends. Overall, EU member countries have relatively low high-tech export ratios, with the average being around 10% of total exports, while countries in the Rest of the World score relatively lower across all years, stagnating at around 4-5% of total exports. All in-scope countries, on average, score 10.7% in this indicator in the year 2018.

Figure 10 High-tech exports / Total exports (%) across world players, EU-27 average, Mission Innovation countries' average and Rest of the World average



Data Source: United Nations (2020)

Figure 11 High-tech exports / Total exports (%) across top five EU-27 countries



Data Source: United Nations (2020)

4.4.2 Indicator 2. Clean energy technology exports / GDP

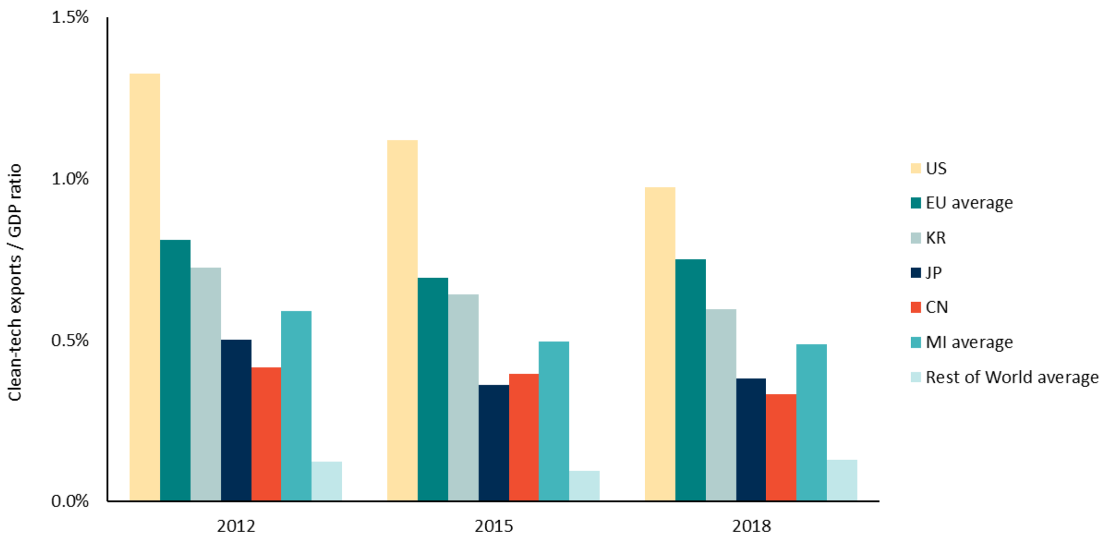
This indicator (ratio of CET exports[34] vs GDP) reflects the relative significance of CET exports in a specific country's economy, measured against its GDP (thereby reflecting the country's "economic scale", which is likely to be correlated with the RD&I "resources"

[34] According to 2018 data, the top eight countries in terms of *CET export absolute volumes* are (larger to smaller): China, Germany, US, Japan, Italy, South Korea, France and the Netherlands. Countries with the lowest absolute volumes are (smaller to larger): Cyprus, Malta, Chile, Latvia, Luxembourg, Saudi Arabia, Greece and Lithuania. The ranking order has essentially been unchanged between 2012-2018, similar to total export volumes (in-scope countries total), while some countries demonstrate strong volume growth over the period, e.g.: the 2018 UAE export volume is five times its 2012 volume, while Poland, Romania and Portugal are also seen to have increased their absolute volumes considerably (30-50% between 2012 and 2018).

(RD&I investments, research personnel, subsidies) deployed to commercialise results of R&D and innovation in international markets).

Amongst "world players", in 2018 the US had the highest value of CET exports to GDP (about 1%), followed by the EU (0.8%), South Korea (0.6%), Japan (0.4%) and China (0.3%). Figure 12 below suggest that while most of the world players (e.g. the US or South Korea) tend to show declining tendency in their CET export vs. GDP ratio across the period investigated (2012-2018), the performance of EU countries on average has partially recovered from 2015 to 2018, reaching around 0.8% by 2018, following a decline between 2012 and 2015. The EU-27 average outperforms Mission Innovation members' average in all the years; while the Rest of the World countries, on average, have a relatively low score in this dimension.

Figure 12 Clean energy technology exports / GDP ratio across world players, EU-27 average and Mission Innovation countries' average

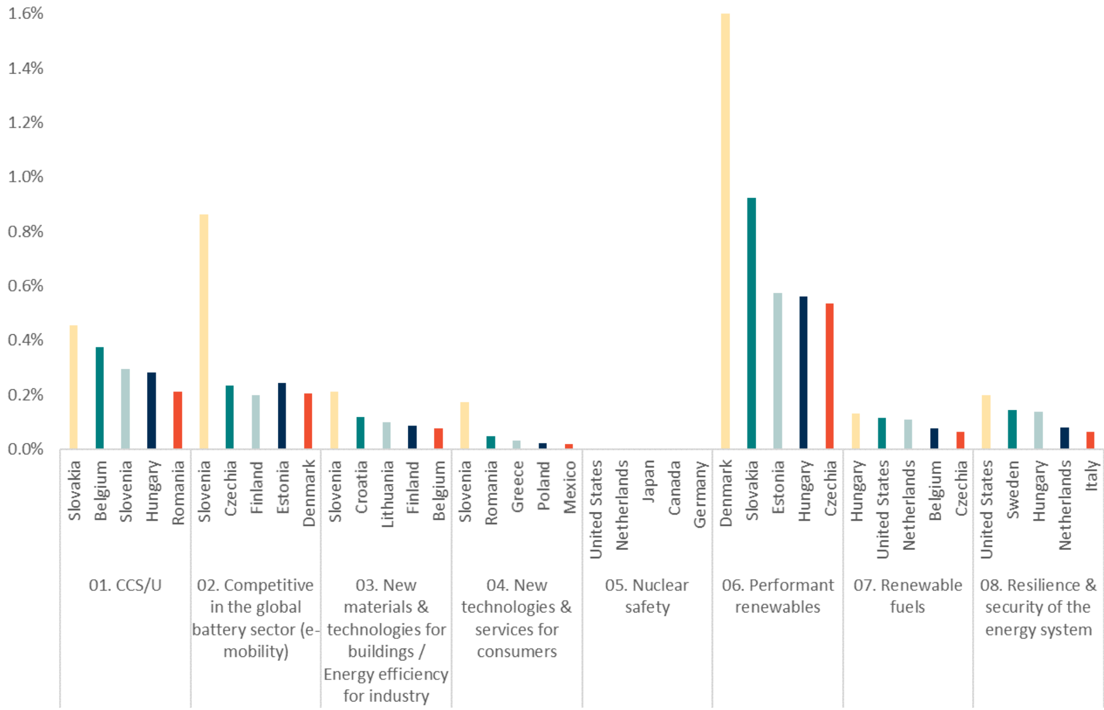


Data Source: United Nations (2020); World Bank (2020)

Country ranking per SET Plan Key Action

Figure 13 below presents the top five country scores in terms of export / GDP ratio for each of the identified SET Plan KAs, based on 2018 data (SET Plan KAs displayed in alphabetic order). The chart shows that the percentages fall between 0 to 1.6%. To note, out of the 40 countries ranked in Figure 13 across the 8 Set Plan KAs, 35 are EU members. With regards to specific SET Plan KAs, individual countries have the lowest, essentially zero percentages related to Nuclear Safety product exports, while Performant renewables prove to be the most relevant SET Plan KA category in terms of product exports compared to country GDP. An important insight from the chart is that Central- and Eastern European (CEE) countries (e.g. Slovakia, Hungary, Czechia, Slovenia) tend to appear in relation to almost all SET Plan KAs – which illustrates that these countries are often relatively small, export-oriented countries where the contribution of export to GDP is substantial, and the countries are considered to be strongly integrated in global supply chains. These countries also tend to have relatively high scores in indicator 1, in High-tech export to Total export ratio, too (10-18%). At the same time, larger countries are not well represented in these rankings per SET Plan KA.

Figure 13 Exports / GDP ratio per SET Plan Key Actions, top five countries, 2018



Data Source: United Nations (2020); World Bank (2020)

Performance of EU-27 countries

The top EU-27 countries score between 1 and 2 in this indicator, the top players being Slovenia, Denmark and Slovakia in the year 2018. Exports of Denmark and Slovakia are largely driven by Performant renewable products (and within that, mostly Wind in the case of Denmark and Wind and Solar PV in the case of Slovakia), while Slovenia's CET exports are dominated by products related to E-mobility. Data Source*: United Nations (2020); World Bank (2020)*

presents the ranking of EU-27 countries in this indicator across the years (ordered by 2018 values).

Table 6 Clean energy technology exports / GDP ratio in EU-27 countries, 2012 to 2018

Country	2012	2015	2018
Slovenia	2.1%	1.8%	2.2%
Denmark	2.2%	2.2%	2.0%
Slovakia	1.4%	1.2%	1.6%
Hungary	1.6%	1.3%	1.4%
Czechia	1.3%	1.0%	1.2%
Netherlands	1.1%	0.9%	1.0%
Belgium	1.4%	0.9%	1.0%
Finland	1.0%	1.0%	0.9%
Austria	1.0%	0.9%	0.9%
Germany	1.1%	0.8%	0.9%
Sweden	1.0%	0.8%	0.8%
Italy	0.7%	0.7%	0.7%
Poland	0.4%	0.5%	0.6%
Bulgaria	0.5%	0.4%	0.5%

Country	2012	2015	2018
Portugal	0.4%	0.4%	0.5%
Romania	0.4%	0.4%	0.5%
Lithuania	0.3%	0.4%	0.4%
France	0.5%	0.4%	0.4%
Spain	0.4%	0.3%	0.4%
Latvia	0.2%	0.2%	0.2%
Ireland	0.3%	0.3%	0.1%
Greece	0.1%	0.1%	0.1%

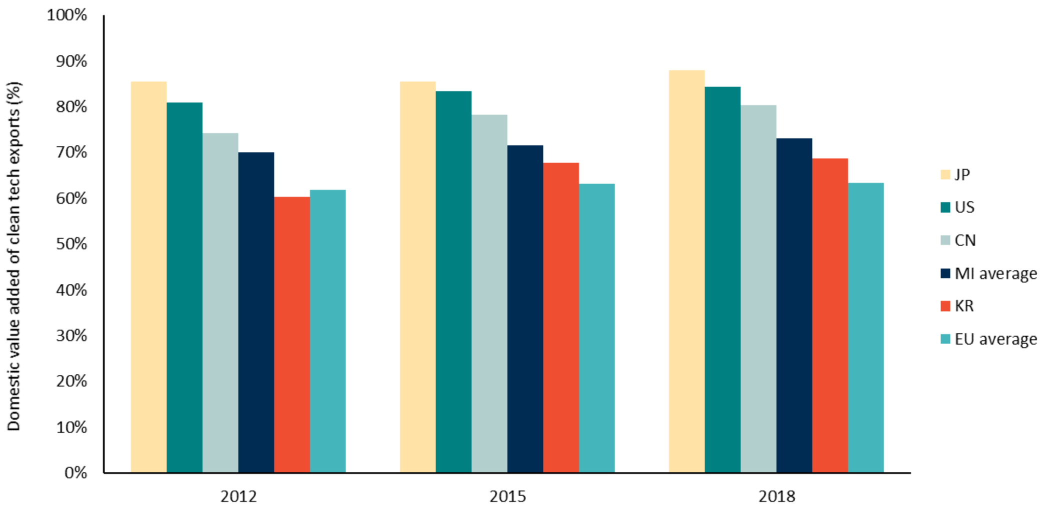
Data Source: United Nations (2020); World Bank (2020)

4.4.3 Indicator 3. Domestic value added content in Clean energy technology exports / Clean energy technology exports

Domestic value added content of the exported products classified as CET-related products[35], aggregated, is relatively high, but largely stagnating for world-player countries across the years; but while the top performer (Japan) achieves around 90%, it is much smaller and 'only' around 60% for the EU-27 average (Figure 14). In the case of Japan, the high score is largely driven by the high share of 'Machinery and equipment' products, the domestic value added content of which, in the case of Japan is around 87-89% in all the years. Several potential explanations can be made to explain this performance, e.g. the domestic labour market (including regulations) may provide Japan with a competitive advantage compared to neighbouring countries, or Japan may have a much more effective industrial strategy aimed at maximising local content of exported products. As a result, Japan's integrated supply chain that allows the country to excel in terms of local value added for this broad product category. The same metric for the US is only around 80% in 2018, and is lower for the top EU countries (e.g. 72% in France and 78% in Germany).

Figure 14 Domestic value added in clean energy technology exports (%) across world players, EU-27 average and Mission Innovation countries' average[36]

[35] According to 2018 data, the top eight countries in terms of *CET value added in export, absolute volumes* is the same set of countries as in the case of *CET export volumes* (top countries, larger to smaller): China, Germany, US, Japan, Italy, South Korea, France and the Netherlands. The ranking order has essentially been unchanged between 2012-2018, the only change in the top countries has been in that in 2012 UK was included as the eight, in volume terms, and not the Netherlands.
[36] Unlike in the case of Indicator 1 and 2, Rest of the World average has not been calculated for Indicator 3 for two reasons. First and most importantly, the OECD's Trade in Value Added dataset covers only 64 selected economies (while the data sources for Indicator 1 and 2 cover a much broader set of countries), thus the Rest of the World average could not be calculated in a consistent way across indicators, and therefore would not provide a proper comparison to in-scope countries in the dimension of Indicator 3, either. Second, domestic value added content of exports indicator needs to be calculated on a country-by-country basis, followed by process of aggregation and calculation of average values for each years, the calculation of which for the Rest of the World category is out of the scope of the current study.



Data Source: United Nations (2020); OECD (2020)

For some of the key EU countries, the domestic value added share of exports is the highest for the product category 'Other non-metallic mineral products', which primarily includes products related to the SET Plan KA 'New materials & technologies for buildings' and 'Energy efficiency for industry' (above 80%) – suggesting that leading EU countries' economies tend to focus on having higher domestic value added in these product categories.

Compared to world players, there is much less volatility amongst the top countries of the EU-27 and the United Kingdom: Germany, Romania, United Kingdom, France and Spain (in descending order by 2018 indicator value) all score between 70-75% in all the years (Figure 15). Out of these countries, France and the United Kingdom also perform amongst the top countries of the EU-27 and the United Kingdom in terms of high-tech export ratio (Indicator 1), thereby reflecting an overall more sophisticated and developed export market with large domestic value added at the same time.

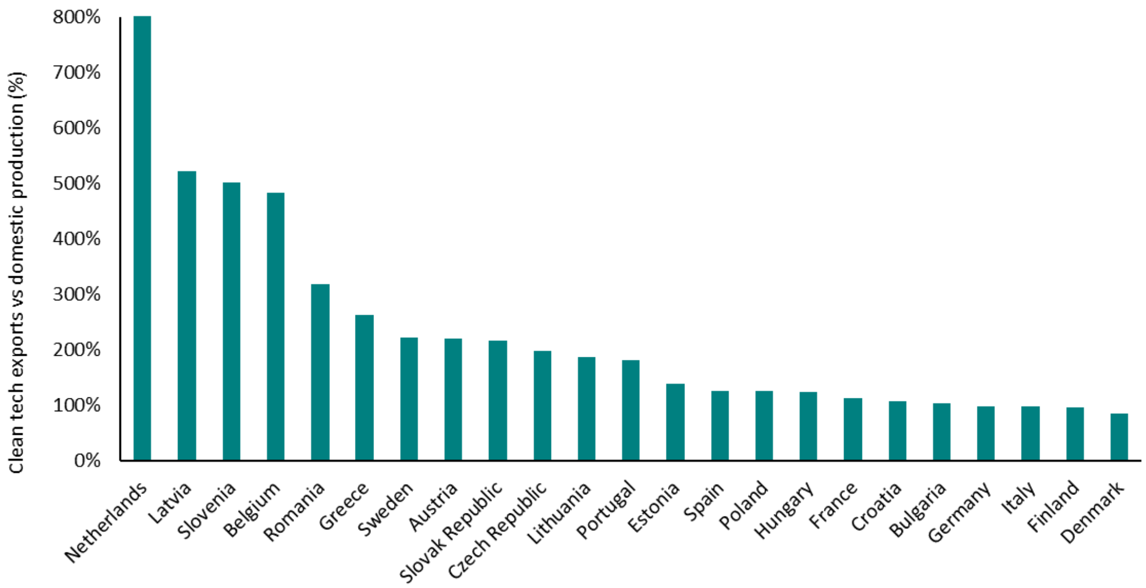
Figure 15 Domestic value added in clean energy technology exports (%) across top five EU-27 countries

Data Source: United Nations (2020); OECD (2020)

4.4.4 Indicator 4. CET export vs production: Clean energy technology exports / Clean energy technology domestic sold production (%)

Indicator 4 was calculated to reflect the share of CET exports vis-á-vis domestically sold production. For the sake of consistency, the indicator was calculated using data on export and on domestically sold production from the same data source, the PRODCOM dataset (described in more detail above). As the export data used in the PRODCOM dataset includes re-exports, in most countries, its value is substantially larger than that of domestic sold production (often several times the value of production). There are significant data gaps in the raw data (built up from product-level data) for the years 2012-2014 and for the years 2016-2018. For this reason, only the year 2015 is suggested to be referred to when comparing country performance, and the indicator is not suggested for inclusion in the CEII, as it only provides additional insight in terms of individual countries' performance in CET innovation. Figure 16 below presents data for EU-27 countries, for the year 2015, excluding countries for which the export and/or production dataset was incomplete even for the year 2015 (Ireland, Cyprus, Luxembourg, Malta). There is clearly a volume size difference between the best and worst performing countries; and while the aggregate indicator captures country performance in one figure, it is often the case that individual SET Plan KA categories within a given country have different export / production ratios than the aggregate category. For example, the indicator for the Netherlands is primarily driven by large 'Performant renewables' and 'E-mobility' product export volumes. At the same time, while the local production of 'Renewable fuels' is the second most important production category, it does not shape the indicator to a large extent due to relatively low export volumes. The performance of the Netherlands is likely to be primarily explained by the phenomena of the 'Rotterdam effect'[37], that is, by quasi-transit trade, in which goods arriving to the Netherlands as extra-EU imports and dispatched from the Netherlands to other EU member states (the actual destination) are accounted for as exports made by the Netherlands. The phenomena of quasi-transit is known to have a greater impact on imports, but exports are also affected, as Figure 16 below illustrates.

Figure 16 Clean energy technology exports vs domestic sold production (%) across EU-27 countries, 2015



Data Source: United Nations (2020); Eurostat (2020b)

[37] European Commission (2020e) International Trade in Goods: Frequently Asked Questions. Available at: https://ec.europa.eu/eurostat/web/international-trade-in-goods/faq

5 Conclusions and Recommendations

In the first part of this report, we identified three potentially suitable indicators for inclusion in the Clean Energy Innovation Index (CEII), to capture the perspective of trade in clean energy technology (CET): *High-tech export* (High-tech exports / Total exports), *CET export vs GDP* (Clean energy technology exports / GDP) and *CET export value added* (Domestic value added content in Clean energy technology exports / Clean energy technology exports). A more detailed assessment was performed for these three indicators, which aimed to better understand the merits of including each in the CEII and to provide insight into innovation performance from the perspective of trade.

The assessment of the three indicators revealed that there are five world players in terms of CET export volume as a percentage of total country GDP. For all SET plan key actions in aggregate, these are (starting from the largest ratio): the US, EU, Korea, Japan and China. Together, these countries/regions account for more than 88% of all exports within the scope of SET plan key actions.

The following four SET plan key actions account for the majority (~90%) of CET export volumes:

- Performant renewables.
- CCS/U.
- Competitive in the global battery sector (e-mobility).
- Resilience & security of the energy system.

It should be stressed that the methodology applied (i.e., assessing CET trade based on product-level export data) implies that some of the product categories, while being highly relevant to CETs, capture trade in products which are also relevant to other energy technologies. The clearest example of this appears to be CCS/U, where the relatively high share in CET exports is likely to relate to trade in products related to the natural gas and chemical industry, etc. Nevertheless, the existence of exports in this sector suggests the capacity to take advantage of any future growth in CCS/U. If the CCS/U-related product export volumes are excluded the other three SET plan actions account for around 92% of total CET export volumes in each year.

The *CET export value added* indicator provides additional insights on who the most specialised players are, in terms of domestic value added to exports. Based on 2018 ratios, Japan has the highest domestic value added percentage in all the three of the most important SET plan actions: renewables (88%), batteries (86%) and energy system security (89%). Japan is closely followed by the US in the renewables and the battery categories. Several potential explanations can be made to explain this performance, e.g. the domestic labour market (including regulations) may provide Japan with a competitive advantage compared to neighbouring countries, or Japan may have a much more effective industrial strategy allowing it to maximise the local content of exported products. For EU countries, the same ratio is lower, with an EU-27 average of around 60%. This means that EU exports of CETs have, on average, a higher percentage of imported intermediate products or other inputs.

Overall, we conclude that all three indicators (*High-tech export*, CET *exports*, and CET *export value added*) provide different and complementary insights and therefore have added value. However, as the first indicator (*High-tech export*), is only available at the country level, but cannot be further computed by the specific Set Plan KAs, it is only included in the dashboard supporting the CEII, and we recommend that only the other two indicators are included in the CEII.

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The Clean Energy Innovation Index (CEII) is a composite index designed to track progress in achieving the SET Plan key actions, as measured through the lens of scientific publications, patents and trade. This report focuses on the trade aspect of the CEII. The report provides details on the assessment of different trade-indicators and selection of those most suitable ones for inclusion in the composite indicator; insights on CET innovation performance from the perspective of trade flows; and details on the trade dataset for inclusion in composite indicator calculations.

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