An Energy think tank informing the European Commission

Policy Report
August 2015

3

Exploring the strengths and weaknesses of European innovation capacity within the Strategic Energy Technologies (SET) Plan

Lead Author: *Ilja Drmač, Dražen Jakšić, Nikola Karadža (EIHP)*

Authoring Team: *Robert Kunze, Joris Dehler (KIT); Rocco De Miglio (E4SMA); Abhishek Shivakumar, Agnese Beltramo, Mireia Romero Nevado, Manuel Welsch (KTH); Mehdi Basslim (Enerdata); Maja Lojanica (Ifri), Audrey Dobbins (USTUTT)*

Reviewer: *Fionn Rogan (UCC)*

This report is also available on our website: www.insightenergy.org

European Commission

SEVENTH FRAMEWORK PROGRAMME

The INSIGHT_E project is funded by the European Commission under the 7th Framework Program for Research and Technological Development (2007-2013). This publication reflects only the views of its authors, and the European Commission cannot be held responsible for its content.

About INSIGHT_E

INSIGHT_E is a multidisciplinary energy think tank which provides the European Commission and other energy stakeholders with advice on policy options and assesses their potential impact.

The INSIGHT_E consortium is formed by twelve complementary partners representing various sectors: academia, research centres, consultancies, one think tank, one stakeholder organization and one of the Knowledge and Innovation Community of the European Institute of Technology. Our partners are based in ten European countries. This sectoral and geographical diversity is also reflected in the thematic scope of INSIGHT_E, ranging from energy infrastructure, new energy technologies to economic analysis, geopolitics and trade, environmental and climate impact, and social and behavioral change.

To receive regular updates about INSIGHT_E programme of work and to learn more about participation opportunities, please visit the following links:

Website: www.insightenergy.org

Contact us: info@insightenergy.org

Follow us on: Facebook & LinkedIn: Insight Energy and on Twitter: INSIGHT_E@EuropeEnergy

Enerdata	*Enerdata*	ifri	*Institut Français des Relations internationales*
EIHP Energy Institute Hrvoje Pozar	*Energy Institute "Hrvoje Pozar"*	PAUL SCHERRER INSTITUT PSI	*Paul Scherrer Institute*
e4sma	*Energy Engineering Economic Environment Systems Modeling And Analysis SRL*	STAKEHOLDER FORUM	*Stakeholder Forum for a Sustainable Future*
eit KIC InnoEnergy	*KIC InnoEnergy*	IER University of Stuttgart Germany	*University of Stuttgart*
KIT Karlsruhe Institute of Technology	*Karlsruhe Institute for Technology*	UCC University College Cork, Ireland	*University College Cork*
KTH	*KTH Royal Institute of Technology*	UCL ENERGY INSTITUTE	*University College London*

Table of Contents

List of Figures

LIST OF TABLES

Abbreviations

ASTRID	Advanced Sodium Technical Reactor
CAES	Compressed Air Energy Storage
CEA	Commissariat à l'énergie atomique et aux énergies alternatives
EBR-II	Experimental Breeder Reactor-II
EC	European Commission
EPBD	Energy Performance of Buildings Directive
EPO GPI	European Patent Office: Global Patent Index
EU	European Union
EURATOM	European Atomic Energy Community
FBR	Fast Breeder Reactors
FES	Flywheel Energy Storage
FFTF	Fast Flux Test Facility
H&C	Heating and Cooling
HLW	High Level Waste
IAEA	International Atomic Energy Agency
IC	Integrated Challenge (of the SET Plan)
ICT	Information and communications technology
INPRO	International Project on Innovative Nuclear Reactors and Fuel Cycles
JAEA	Japan Atomic Energy Agency
NIST	National Institute of Standards and Technologies
NRC	National Regulatory Commission
NUMO	Nuclear Waste Management Organization of Japan
nZEBs	nearly Zero Energy Buildings
OECD	Organisation for Economic Co-operation and Development
P&T	Partitioning and Transmutation
PHS	Pumped Hydro Storage
R&D	Research and Development
R&I	Research and Innovation

RD&D	Research, Development and Demonstration
SET Plan	Strategic Energy Technology Plan
SF	Spent Fuel
UK	United Kingdom
UN	United Nations
USA	United States of America

INTRODUCTION

The purpose of this policy report is to explore the strengths and weaknesses of European innovation capacity within the Strategic Energy Technologies (SET) Plan Integrated Roadmap[1]. The SET Plan Integrated Roadmap groups energy technology priorities into 13 themes for research and innovation (R&I). **As a comprehensive European Energy R&I agenda, the thirteen themes of the Integrated Roadmap have been instrumental to determine the R&I priorities of the Energy Union[1]. The Energy Union R&I priorities have been addressed in the recent Integrated SET Plan Communication[2], which proposes ten actions to accelerate the energy system transformation that have been identified on the basis of the Integrated Roadmap. Structured around the thirteen themes of the Integrated Roadmap,** the aim of this report is to carry out an assessment of energy technology R&I in specific sectors and challenges in the EU.

This is done by benchmarking cost, performance and market-readiness levels in relation to other regions of the world using data on the key companies, industries, and research institutes in the EU that are active in a particular area. The analysis is based on available literature and databases and compares the performance of the EU's Energy R&I sector versus other key countries worldwide on the basis of the following key research questions:

1. Based on existing indicators, which indicators can be used to measure the innovation capacity performance of the community in each sector?
2. Who are the key players in the 13 theme areas set out in the Integrated Roadmap, including companies, research institutes, universities and industries?
3. How does the community in Europe benchmark against other leading competitors in the world in the 13 themes?

The SET Plan Integrated Roadmap provides the framework for the assessment of the state of play in each theme in Europe and summarises the challenges. Each Integrated Roadmap theme is discussed in a separate chapter in this policy report. A summary of the methodology employed to gather appropriate data on four key indicators to measure the innovation capacity is described in the next chapter. The four Integrated Challenges and thirteen themes of the SET Plan Integrated Roadmap are as follows:

I. **Integrated Challenge 1:** Active consumer at the centre of the energy system
   - *Theme 1:* Engaging consumers through better understanding, information and market transformation, and
   - *Theme 2:* Activating consumers through innovative technologies, products and services

II. **Integrated Challenge 2:** Demand focus – increasing energy efficiency across the energy system
   - *Theme 3:* Increasing energy efficiency in buildings
   - *Theme 4:* Increasing energy efficiency in heating and cooling
   - *Theme 5:* Increasing energy efficiency in industry and services

[1] https://setis.ec.europa.eu/SET Plan-process/integrated-roadmap-and-action-plan COM(2015)080, A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy
[2] C(2015) 6317 final, Towards an Integrated Strategic Energy Technology (SET) Plan: Accelerating the European Energy System Transformation

III. **Integrated Challenge 3:** System optimisation

- *Theme 6:* Modernising the European electricity grid and establishing synergies between the various energy networks
- *Theme 7:* Unlocking the potential of energy storage and conversion of electricity to other energy carriers
- *Theme 8:* Providing the energy system with flexibility, security and cost-effectiveness
- *Theme 9:* Development and demonstration of holistic system optimisation at local/urban level (Smart Cities and Communities)

IV. **Integrated Challenge 4:** Secure, cost-effective, clean and competitive supply

- *Theme 10:* Accelerating the development of renewable electricity and heating/cooling technologies
- *Theme 11:* Enabling carbon capture, CO_2 utilisation and storage technologies and increased efficiency of the fossil fuel-based power sector and energy intensive industry
- *Theme 12:* Supporting safe and efficient operation of nuclear systems, development of innovative reactor concepts and sustainable solutions for the management of fissile materials and radioactive waste
- *Theme 13:* Developing sustainable biofuels, fuel cells and hydrogen and alternative fuels for the European transport fuel mix

Each of the subsequent chapters follow a similar structure, starting by describing each integrated challenge and their respective themes and then provides an analysis of the strengths and weaknesses of each by drawing on publicly available data sources and stakeholder engagement. Each chapter concludes with an overview of Europe's research and innovation capacity. The report concludes with a summary of the main conclusions from each integrated challenge.

METHODOLOGY

The innovation capacity of a country or a region is not directly measurable. Through the assessment of available characteristics and information, specific indicators can be used to describe the innovation capacity. In literature[3,4], different quantitative or qualitative parameters are used. The latter are provided, for example, by expert interviews and are largely dependent on subjective perspectives which reflect the knowledge of the respective respondents of a survey. Generally, such views can be influenced by personal prejudices or idealised expectations. This is why this report relies largely on the analysis of quantitative indicators that are transparent, publicly available from reliable sources and assessable via statistical methods.

Ultimately, the evaluation of the strengths and weaknesses of the European innovation capacity in energy technologies is based on a comparison of absolute values of indicators of the EU and other relevant countries. The assessment is conducted across the Integrated Challenges and Themes according to the SET Plan Integrated Roadmap. The themes are further divided into different technology and measure categories that are presented in the beginning of each theme section.

The study does not calculate relative indicators (e.g., normalized to the GDP or the number of inhabitants). From relative indicators, only the performance or efficiency of innovation can be distilled. This study provides insight to the absolute innovation capacity of the EU in comparison with other countries or regions.

As indicators, the following four publicly available parameters were assessed:

- Number of patents
- Number of publications
- R&D expenditure
- Export/Import Volume

Aside from patents, the data for other parameters were collected over a timeframe of the last five years and therefore do not allow a detailed analysis of trends in the underlying time frame. Thus, the figures provide a snapshot and do not intend to provide a forecast for the development of the indicators. In the analysis of the patents, no restrictions were applied to the time frame. This figure can rather be interpreted as an assessment of the theoretical know-how available in a specific country and maintained over time in different ways, therefore also accounting for potential that may lie in the more distant past. In summary, although direct conclusions to the future innovation cannot be drawn, innovation capacity can be estimated.

The number of patents is a reliable and common indicator to describe the absolute innovation potential. This is also due to the requirements to be granted a patent. Those include, among others, the novelty of a product, which is more than a state of the art technology. Furthermore, this approach ensures a patent only represents a single invention or a group of inventions that represents one single product. Patents are differentiated by product patents and process patents

[3] World Economic Forum (2015): Global Competitiveness Report, http://www3.weforum.org/docs/WEF_GlobalCompetitivenessReport_2014-15.pdf

[4] Cornell University, INSEAD, and WIPO (2014): The Global Innovation Index 2014: The Human Factor In innovation, second printing. Fontainebleau, Ithaca, and Geneva.

which we will not distinguish in the current study, since both forms are relevant for the innovation capacity.

The number of publications in scientific journals can also be regarded as a relevant indicator for innovation capacity. The review process undertaken before the publication of an article ensures that only new insights, methods, technologies or applications are published. Data collection for the number of publications available was made through the advanced search tool, on ScienceDirect full-text scientific database (< 2010)).

The significance of research and development expenditure might be less pronounced, because on the one hand not every research project necessarily leads to a breakthrough. On the other hand, the financial investment demonstrates the current perception of which technological fields are the most promising or where the techno-economic potential to advance is greatest. In any case, it is given that a higher expenditure on R&D will increase the technological competences and therefore can increase the likelihood of developing innovation.

The same holds for the fourth indicator that was considered, the (financial) export/import volumes. Traditionally, export success is viewed as an indicator to assess the technological competitiveness of a country. At the same time, export can be a driver for further innovation. A high export excess in international comparison can foster innovation capacity especially with regard to the adaptability of products and processes to different markets. Still, the overall economic downsides of high export excesses, especially in a region as the EU, should be noted.

The sources of information for the above indicators used include:

- European Patent Office: Global Patent Index (EPO GPI)
- Elsevier's ScienceDirect
- OECD iLibrary
- UN Comtrade Database

The indicators are aggregated for the whole of Europe and compared with the respective values for the USA, China, Japan and South Korea. This choice of countries is justified by their overall economic and technological position, but also by the availability of the necessary data. Assessable data from other countries will be summarized in "Others". Queries for the EPO GPI have been formulated according to the suggestions regarding the query syntax available in the GPI user manual[5] and in accordance with the work in a recent report by Kic-Innoenergy and Questel[6], *Top 10 Energy Innovators in 100 Energy Priorities*.

Some of the following features were used in the queries for the number of patents and publications:

- Use of synonyms
- Preparation of complex composite queries (in particular with more disjunctive operators)
- Records are not filtered by date of publication/application
- The same keywords are used for both patents as well as for the number of publications, where applicable.

[5] http://documents.epo.org/projects/babylon/eponet.nsf/0/16B7F77528515906C1257C04003AB2FA/$File/GPI_UM_V23_EN.pdf
[6] http://www.kic-innoenergy.com/top-10-energy-innovators-in-100-energy-priorities/

This is an example of the EPO GPI query:

Theme 10 Wind energy: *Accurate methodologies for wind resource assessment*

WORD = "wind" and "resources" and ("wind climate" or "potential" or "methodologie*" or "advanced" or "accurate" OR "offshore" OR "onshore" OR "assessment" OR ("electricity" and "production") OR "turbine" OR "turbines" OR "measurements" OR "speed" OR "direction" or "ultrasonic" OR "lidar" OR "sodar") and (PUC=*)

Data on research and development (R&D) expenditure are prepared according to the available data from OECD iLibrary. Only limited data is available publicly across all the themes of interest, and there are no data for China. Consequently, the only reliable number is for total spending, where applicable, and the figures are thus aggregated for the relevant themes specific to the Integrated Roadmap.

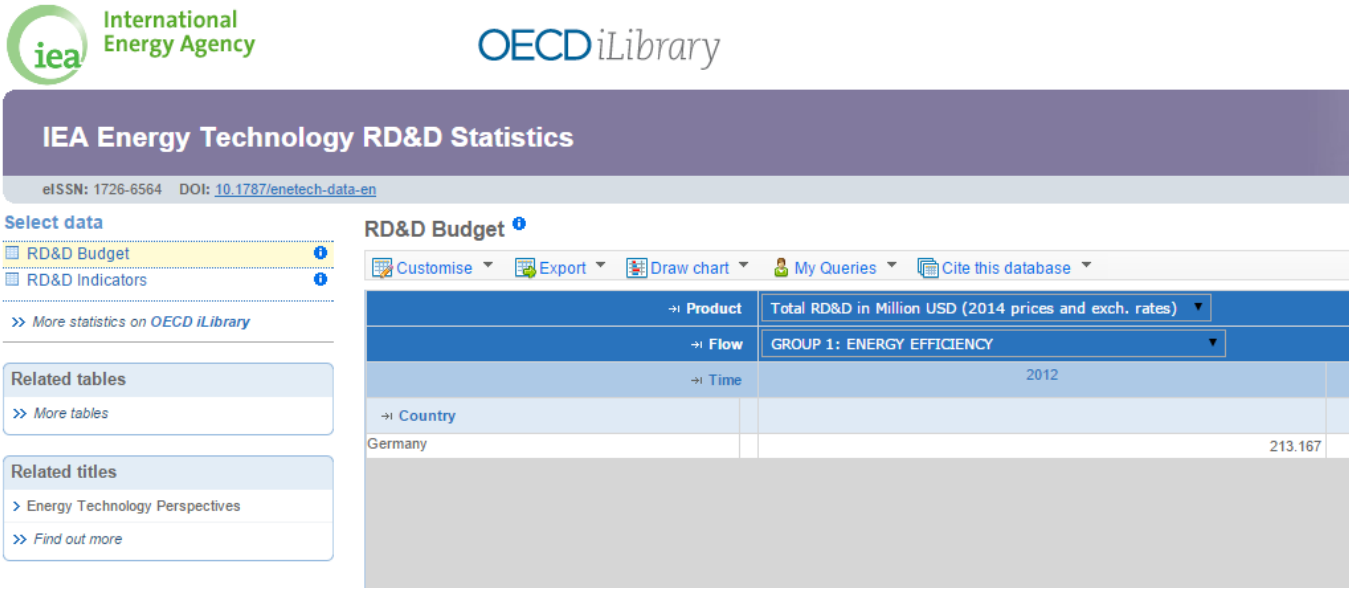


Figure 0-I Example of the search in OECD iLibrary: R&D expenditure data for Germany in 2014 in energy efficiency

Export-import data are assessed through the UN Comtrade database. Available data are organised according to a commodity code. Also for this indicator, there was only limited data available publicly to cover all applicable themes. Therefore, looking at the descriptions available in the related commodity list, the figures presented were calculated by selecting some of the defined commodities in the database which were better linked to the technologies in the 13 themes of the Integrated Roadmap. These are aggregated numbers for the entire theme and do not detail specific technologies. Much of the data available can be assigned to a number of themes.

An example of aggregated data from the UN Comtrade database for the theme, wind energy (part of theme 10):

Commodity codes:

- *8501 Electric motors and generators, except generating sets*
- *8504 Electric transformers, static converters and rectifiers*
- *8505 Electro and permanent magnets, equipment using magnets*

In addition to the quantitative analysis, a ranking based on the number of patents filed lists the industrial players of the themes in Appendix VI.A., and a summary of the stakeholder survey to experts for the different fields is available in Appendix VI.B. The final data tables are available in Appendix VI.C.

I. Integrated Challenge 1: Active consumer at the centre of the energy system

Integrated Challenge (IC) 1 of the Integrated Roadmap focuses on the consumers in the energy system by stressing the importance of people (i.e., households, public authorities, enterprises) engaging and playing an active role within the energy market. This first Integrated Challenge is divided into two themes:

- Theme 1: Engaging consumers through better understanding, information and market transformation
- Theme 2: Activating consumers through innovative technologies, products and services.

This chapter will focus on solutions that can help end-users to monitor their energy consumption and production, particularly where renewable energy sources are available. These are technologies that specifically help consumers understand possible alternatives for changing behavioural patterns and enhance flexibility on the demand side. This can significantly contribute to increasing energy efficiency and optimise the use of renewable energy, when available to the grid.

Within the context described above, it was decided to focus on smart grids and metering systems as well as automated and remote controlled appliances. These research areas were identified following definitions for "Smart Grid" and "Smart Home" given by the National Institute of Standards and Technologies (NIST)[7] under the U.S. Department of Commerce, the European Commission (EC) and the Intertek Research and Testing Centre for UK Department of Trade and Industry. Then, a list of related technologies was identified within the areas of ICT, and electric distribution technologies, which provide the services needed to allow consumers to actively manage the energy demand in optimal ways.

Summary of the situation regarding Active Consumer at the Centre of the Energy System

In total, the **EU holds average to strong positions concerning the number of publications** for the solutions analysed, but this is not translated into the number of **patents filed where Europe holds average to weak or very weak positions**. For this reason, European industries should try to strengthen their market position by investing in development of new products and innovative solutions. This would also pave the way to opening up more investment options for European customers. This could be relevant especially in relation to the implementation of European directives and plans, for instance the envisioned smart meter rollout in each Member State by 2020 defined in the Third Energy Package.

The **main competitors in patent filing** are the **USA -** for the solutions belonging to both ***Grid and Home networking systems*** **- and China -** for the solutions listed under ***Smart Homes and Buildings***.

Concerning the number of **publications**, the **EU is the leading competitor** followed by USA.

Regarding volumes of import and export associated with the technologies under consideration, **Asia - and particularly China - is the main exporter**. Europe and the USA together are instead

[7] http://www.nist.gov/

responsible for 60% of imports. This data correlates with the information collected concerning patent filings.

Analysed categories of measures

Grid networking systems	*Advanced metering infrastructure (AMI)*
	Smart metering systems
	Smart Meter device/apparatus for energy measurement
	Utility Energy System Management (UEMS)
	Demand Response (DR) Energy Management System
	Meter Data Management System (MDMS)
Home networking systems	*Home Area Network (HAN) System*
	Home energy Management System (HEMS)
	Home monitoring system
	Home communication system
	Sensor
	Thermostat
	Wireless technologies
	Home Remote Control System
	In-home displays Personal Digital Assistants (PDAs) [i.e. Smartphones]
Smart Homes and Buildings	Smart devices Smart plug Smart home/domestic appliances Smart heating system Smart cooling system Smart air conditioning system Smart lighting system

I.A.1. **Overview**

The following Figure I-I shows an overview of the geographical spread of the volume and ratio of patents, publications, exports, and imports regarding the categories of solutions analysed.

Concerning regional R&D expenditure, data is incomplete and not sufficiently detailed, as available data does not supply figures for China nor do they provide data for the specific solutions and measures listed above. Therefore, they should only be considered as rough estimations of the actual R&D expenditure.

The available data below is the average value for years 2011-2013:

- USA: 2,061.50 Mio. €/a
- Europe: 1,011.11 Mio. €/a
- Japan: 108.46 Mio. €/a
- South Korea: 81.11 Mio. €/a

The data suggests that the **EU is the second largest investor in R&D** worldwide in all the solutions to empower consumers to manage their energy consumption, **following the USA**. This can explain the results highlighted below, which show the EU and the USA holding the strongest positions regarding the number of publications. European academia and researchers seem to perform better than their USA counterparts. In fact, **Europe provides two times the number of publications than the USA**, using less than half of the money invested in the USA in the same research areas.

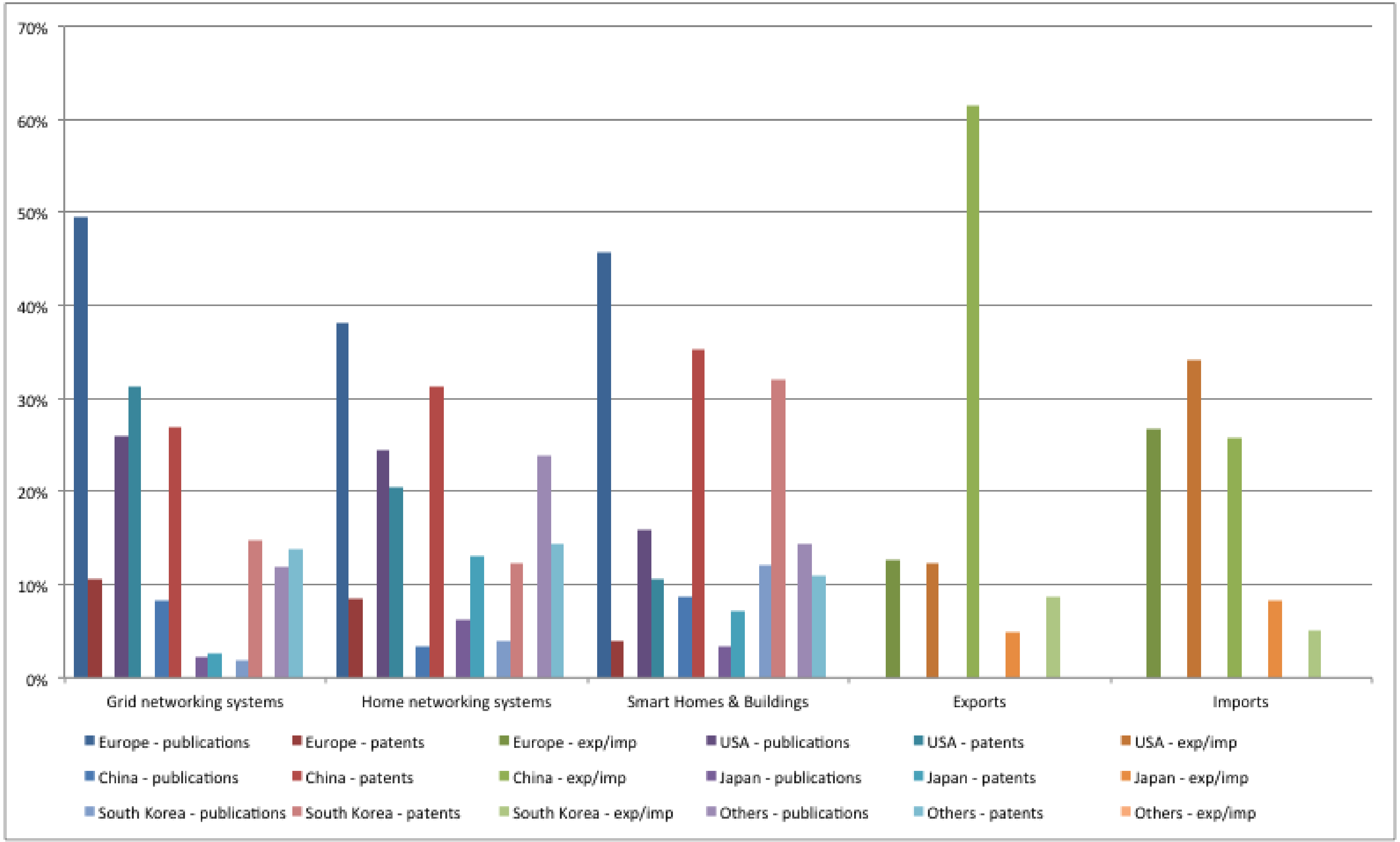


Figure I-I: Total ratio of publications, patents, exports and imports by country and category of solutions related to smart homes

The volumes of import and export presented in this report are only broad estimations. They were calculated using data from the UN Comtrade database, selecting some of the defined categories according to their descriptions available in the related commodity list

Looking at the results concerning the ***Grid networking systems***, Europe holds a strong position for number of publications, while being weak in terms of patent filing. Overall, the USA performs better holding average to strong positions in both publications and patent filings. China is the leader in the number of patent filings.

Concerning ***Home networking systems***, Europe also holds a very strong position in terms of number of publications while performing very poorly in relation to the number of patent filings, where China leads the ranking. The USA holds average to strong positions for both numbers of publications and patents.

Finally, looking at the ***Smart Homes & Buildings*** data, Europe continues leading the rank in number of publications, whereas it holds the last position for number of patents. In general, China and South Korea present the best results in this category of solutions.

Concerning the ratio of ***imports and exports*** referred to the entire range of solutions analysed, the EU holds an average position in exports while it results as one of the main importers. Globally, China is the main exporter while the USA is the first importer. Japan and South Korea in comparison hold very weak positions, even though together they contribute to make the Asian players the largest exporters on the market.

I.A.2. **Number and Ratio of Publications**

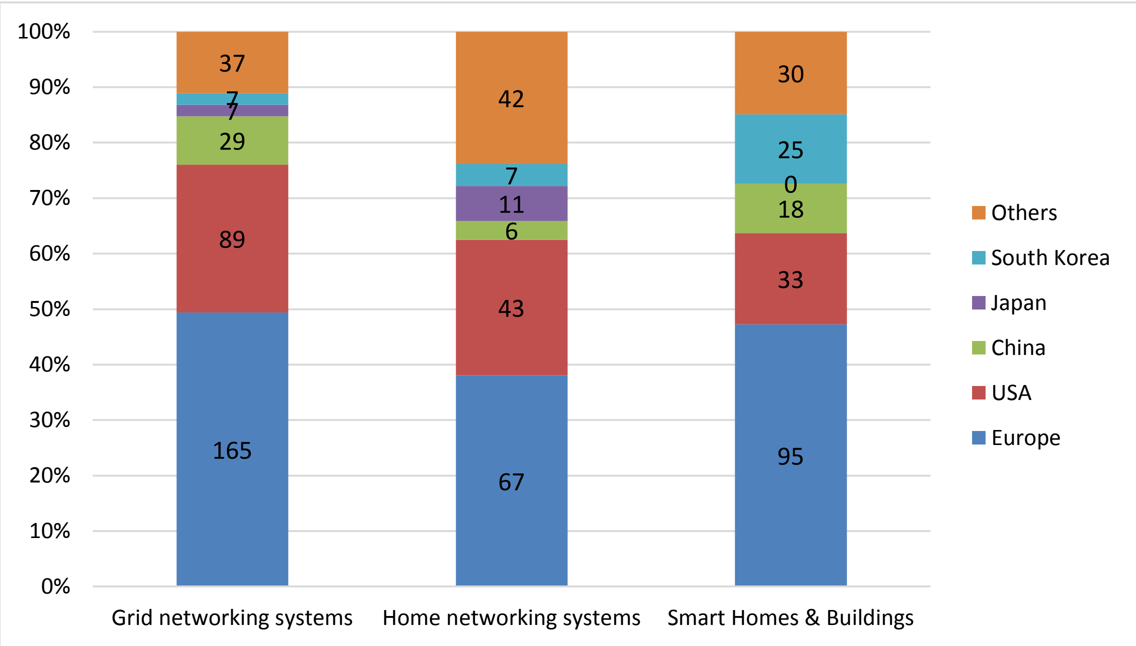
The following diagram (

Figure I-II) shows the geographic allocation of publications from academic institutions in the last 5 years for the analysed categories.

Figure I-II: Number and ratio of publications by country and category of technology

Europe leads the ranking with regards to publications in all categories of solutions analysed, and particularly within the *Grid networking systems*, thereafter closely followed by the USA. These results point to European academia as the strongest player within solutions and measures considered in relation to smart technologies for the residential sector on a global level.

Some reasons behind this result might be linked to the recent EU strategies and policies, which push



towards the full deployment of smart metering systems for both electricity and gas grids in each

Member State. The smart meter rollout plan aims to achieve a complete rollout of smart meters for electricity and 40% service to gas consumers across the European grid by 2020. Taking this into consideration, the incentive to develop in these areas is clear as the market demands knowledge and cost efficient solution in order to achieve these EU goals.

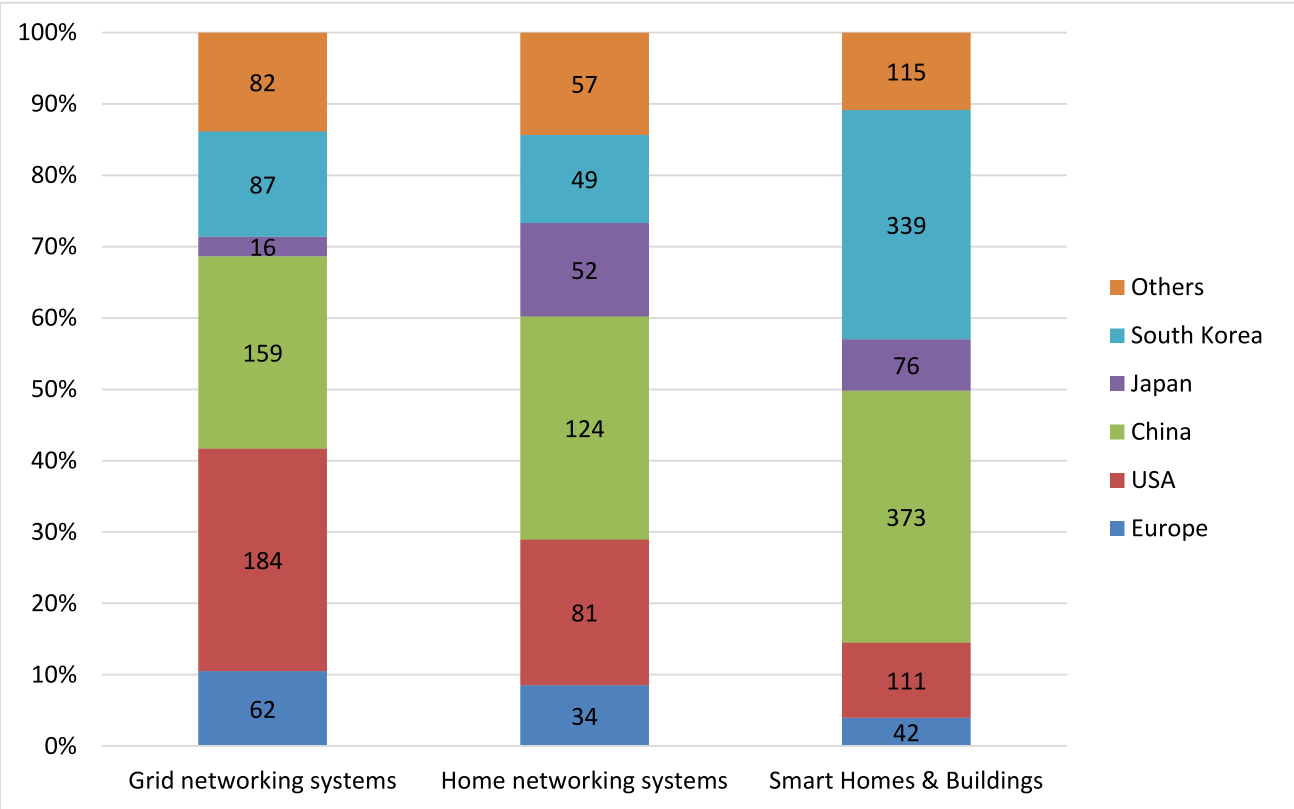
The Energy Performance of Buildings Directive (EPBD) Directive (2010/31/EU) aims for the implementation of nearly Zero Energy Buildings (nZEBs) solutions. Here, smart heating and cooling systems as well as automated domestic appliances can be considered as options.

I.A.3. **Number and Ratio of Patents**

The following diagram, Figure I-III, show the geographic allocation of patents for the analysed categories of solutions presented in this chapter.

Figure I-III: Number and ratio of patents by country and category of technology

Europe holds very weak positions in all of the categories analysed. China appears to be the leading country, presenting the highest number of patents for most of the solutions investigated. The USA also holds the second strong position with patents for the majority of the solutions analysed while they hold the leading position within the *Grid networking systems*.



Finally, South Korea presents a relevant number of patents, particularly for the solutions related to *Smart Home & Buildings.* Globally, the predominance of Asian countries is noticeable. **China, Japan and South Korea are responsible for at least half of the patents** in almost all the solutions analysed, and particularly in those listed under *Smart Homes & Buildings*.

I.A.4. **Volume and Ratio of Import and Export**

The following diagram (Figure I-IV) gives an estimation of the average volume and ratio of import and export in year 2013 for all the solutions analysed. European imports are almost double the amount of its exports. The current EU strategies and policies give an impulse for the European industries to strengthen their market position. Investing particularly in the development of smart technologies, appliances and meters would make it possible for European customers to support the EU economy while achieving the targets set by EU legislation.

Looking at the overall picture, **the volume of exports is much higher for the Asian players than for Europe and the USA**. At the same time, the latter two countries are the biggest importers of goods with 60% of the imported goods worldwide.

These results follow the trend already highlighted in relation to patent filings, where China holds strong positions in all the fields. However, China also records a significant volume of imports that could contradict in some ways the previous conclusion and should be further investigated.

Figure I-IV: Volume and ratio of import and export by country (Mio. US$)

I.A.5. **Conclusions on Strengths and Weaknesses of the EU**

Erreur ! Source du renvoi introuvable. below gives an overview of the geographical allocation of strengths and weaknesses regarding patents (●) and publications (○) and industrial key players (◇).

In terms of patent filings, Europe holds average or low positions. In particular, it looks very weak in relation to the solutions belonging to *Smart Home and Buildings*. Globally, the USA and China hold the strongest positions for number of patents. South Korea also performs well, especially for the solutions considered under the *Grid networking systems*.

Regarding the number of publications, however, the EU holds a very strong position leading the ranking in most of the cases, followed by the USA. Finally, regarding the industrial key players, Europe holds weak to very weak positions. South Korea and the USA lead the lists in all the cases, thus also providing a good explanation for their predominance in terms of patent filings.

Table I-I: Strengths and Weaknesses by country and category of measures listed in Themes 1 and 2

Category		Europe		USA		China		Japan		S. Korea		Others	
Grid networking systems	Advanced metering infrastructure (AMI)	●● ○○○		●●●● ○○○		● ○		○		●●●●		●● ○○○○	
	Smart metering systems	●● ○○○ ○		●●		○						●●●●	
	Smart Meter device/apparatus for energy measurement	●● ○○○ ○		●● ○○		● ○		● ○		●●●●		●● ○○	
	Utility Energy System Management (UEMS)	●● ○○○ ○	◇	●● ○○	◇◇ ◇◇	●●●●	◇				◇◇ ◇	● ○○○	
	Demand Response (DR) Energy Management System	● ○○○ ○		●●●● ○○○		●● ○						●● ○	
	Meter Data Management System (MDMS)	●		●●● ○○○○				●		●●●●		●● ○○○○	
Home networking systems	Home Area Network (HAN) System	●●● ○		●●●● ○○		●				●●●●		●●● ○○○○	
	Home energy Management System (HEMS)	● ○○○		●●●● ○○		●		●●●● ○○○○		● ○		● ○○	
	Home monitoring system	○○○ ○		● ○		●●●● ○		●				● ○○	
	Home communication system	● ○○○ ○	◇	● ○	◇◇ ◇◇	●●●			◇◇	○	◇◇	●● ○○○○	
	Sensor	○○○ ○		○○		●●● ○		○				● ○○	
	Thermostat	○○○		●●● ○○○○						○			
	Wireless technologies	○○○		● ○○		●●●● ○		○		○		● ○○	

Category		Europe		USA		China		Japan		S. Korea		Others	
		○											
	Home Remote Control system	○○		●		●●●		●●●●				○○○○	
	In-home displays	● ○○○ ○		●●●● ○○○				●●		●●●		●● ○○	
	Personal Digital Assistant (PDA) [i.e., Smartphones]			○○○○								●●●●	
Smart Homes & Build-ings	Smart devices	○○○ ○		●●●		●●●● ○				○○		● ○○○○	
	Smart plug	●●● ○○○ ○		●●●		● ○				●●●● ○○		○○	
	Smart home/domestic appliances	○○○ ○		● ○		●●●● ○○○		● ○○		●●●● ○○		● ○○○	
	Smart heating system	● ○○○ ○		○	◇	●●●●			◇	●●● ○	◇◇ ◇◇	●	
	Smart cooling system	○○○ ○		● ○○○		● ○				●●●● ○		●●	
	Smart air conditioning system	○○○ ○		● ○		●●●● ○				●● ○		●● ○○○	
	Smart lighting system	○○		●● ○○○○		●●●●				● ○○		● ○○○○	

Some indications can be provided in order to target future investment and point towards those technologies that could provide more benefits for faster development of smart grids and efficient energy management solutions. According to the results of the stakeholder engagement (see Appendix VI.B), the residential sector continues to be the one that requires the most development. In particular, many of the stakeholders involved mentioned the importance of targeted services, investments, subsidies, tariffs, market mechanisms that help people to get more benefits and incentives, instead of specific technologies. Nonetheless, electric cars, battery storage solutions and "smart devices" or "in-home displays" and "Personal Digital Assistants (PDAs)", as listed in Theme 1, were also mentioned. Standards for communication and better planning of new smart grids and networking system, together with subsidies for smart meters are the main addition to those mentioned in terms of trending or upcoming technologies.

Finally, most of the stakeholders suggest that for the future establishment and implementation of smart grids it is important to develop new energy simulation software that takes residential sector consumer behaviour and interaction with the grid into consideration. This has the potential to allow better management and balancing of the entire energy grid, and better integration and management of small local Renewable Energy (RE) power plants.

II. Integrated challenge 2: Demand focus – increasing energy efficiency across the energy system

The implementation of energy efficiency measures and the application of locally available renewable energies on the demand side as a driver for the whole energy supply system is one of the most important starting points to reach climate targets, as well as targets related to protection of the local environment, to reinforcement of the economy and to security of energy supply in the European Union. The technical potential of energy efficiency technologies already available in the market usually exceeds their economic potential. Improving available technologies and developing new efficient technologies for the industrial value chain as well as for satisfying the energy demand of the population can be a crucial contribution to increasing the economic potential of those technologies, to the preserving resources and increasing the overall energy productivity.

This chapter will address energy efficiency technologies especially for the building and household sector (Theme 3), technologies for heating and cooling supply in buildings and in industry (Theme 4) and further efficiency technologies that are applied specifically in industry (Theme 5).

Summary of the situation regarding Demand and Energy Efficiency solutions

All in all, **Europe's academic players hold strong positions** in almost all categories analysed. An analysis of the number of publications reveals that Europe has the highest share of publications with regard to energy efficiency solutions. A more differentiated conclusion is to be drawn for patents: apart from some specialized technologies for the heating and cooling supply (Theme 4), technologies for heat storage (Theme 3) and building envelopes, **EU applicants only hold an average to low share of patents** for the respective technologies. **Except for lighting technologies and energy efficiency measures in industries (Theme 5), EU is a net exporter.** However, a closer look at the shares of exports in Theme 5 reveals that EU is the largest exporting region. Due to the aggregation of figures for exports and imports, not all the measures discussed could be covered.

II.A. **Theme 3: Energy efficiency in buildings**

Analysed categories and subcategories

Thermal storages	Sensible liquid/solid
	Latent inorganic/organic
	Sorption/Chemical
Building envelope	Insulation
	Windows
Lighting	Halogen lamp Fluorescent / energy saving lamp Discharge lamp Light Emitting Diode (LED)
Building Ventilation	Ventilation systems Heat recovery systems
Building monitoring and control systems	Heating Ventilating and Air Conditioning Systems (HVAC) Lighting control systems Other monitoring and management systems

II.A.1. **Overview**

Figure II-I shows an overview of the geographical spread of the volume and ratio of patents, publications, exports and imports regarding analysed categories in theme 3, which will be presented in the following paragraphs in more detail. The figures of export/import represent only categories of *Building envelope* and *Lighting*.

Concerning regional R&D expenditure, insufficiently detailed data could not be collected for categories corresponding to the SET Plan outlined for theme 3. Only aggregated figures were available for the overall themes 3 and 4, which is why we will present this data in this section. Due to the gaps in the existing data and the overlap with integrated heating and cooling supply of theme 4 as well as other household appliances, the figures should be regarded as a rough estimate of the actual R&D expenditure for the categories in theme 3 and 4. However, the figures reflect the status of energy efficiency in buildings to some extent in the covered regions. The basis for the following estimated expenditure is the available information on R&D spending in the years 2011 to 2013:

- Europe: 168 Mio. €/a
- USA: 69 Mio. €/a
- Japan: 56 Mio. €/a
- South Korea: 29 Mio. €/a

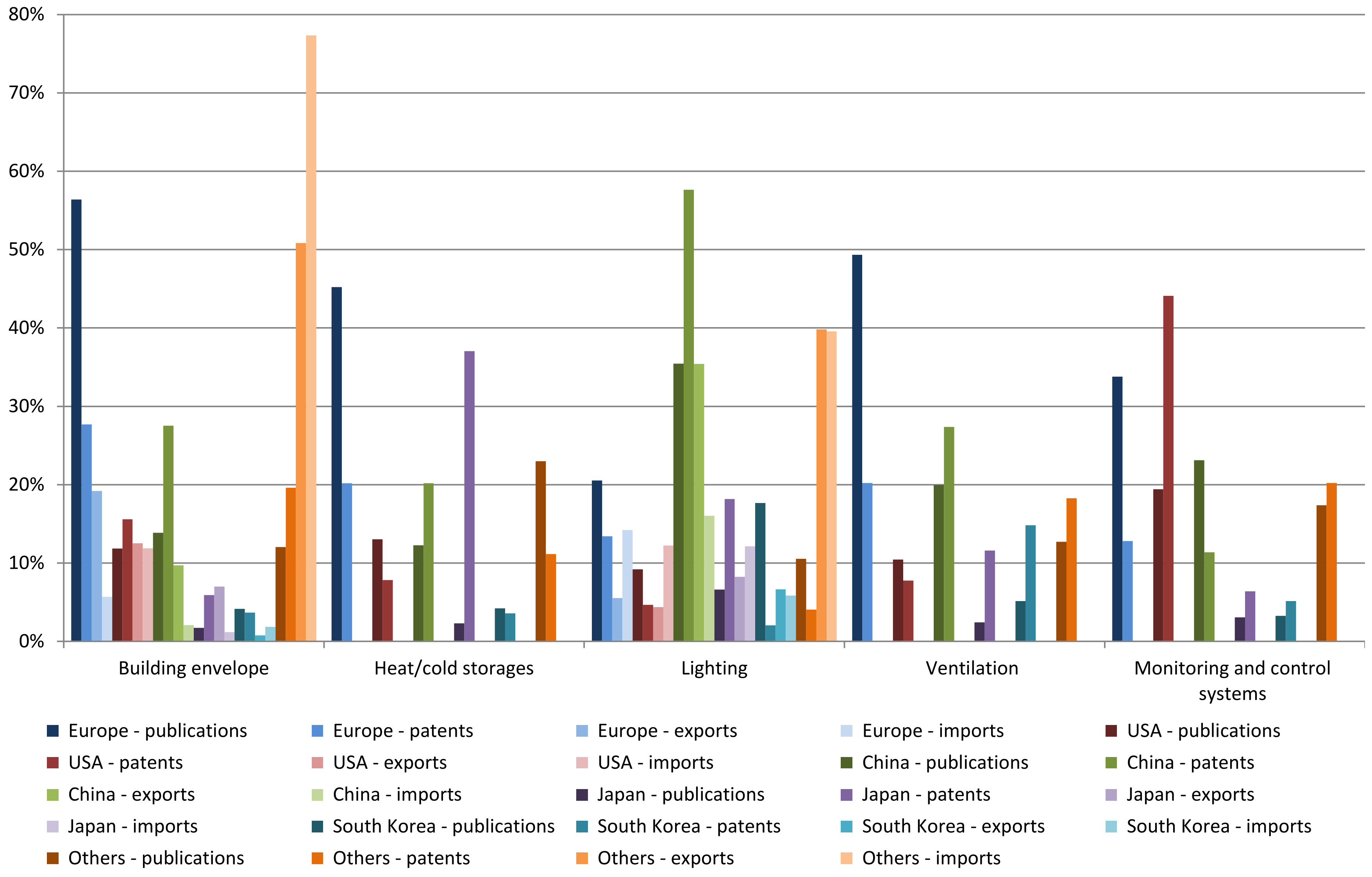


Figure II-I: Overview of the geographical allocation of the volume and ratio of publications, patents, exports and imports.

Looking into the **category of *Building envelope*** we notice the strong engagement of European academic players, contributing over 50% of the total publications counted. The impression of a high innovative potential is also supported from the gathered data on **patent statistics: Europe has the largest share** (28%) while being followed closely by Chinese players. **Also export statistics are in favour of Europe** (523 Mio. € for insulation materials/systems and windows). This correlates with the support of energy efficiency measures, the high requirements to newly constructed buildings and the high living standard in the EU.

Heat and Cold storage shows a somewhat different picture. While EU has the most academic contributions in terms of publications, **Japanese industrial players hold the major share of patents** for thermal storage. Chinese players contribute a similar share of patents.

In the case of ***Lighting technologies***, China leads in terms of publications as well as patents. These large shares are reflected in their position as the chief exporter of lighting technologies (18.4 billion €). There is no doubt that **China is the strongest player** in this particular field. Combined with the shares from other Asian countries, the shares of western economies look small.

In ***Monitoring and control systems***, European institutions publish the most papers, while US companies file the most patents. In both regions, the population has high expectations for room temperature and air quality.

In ***Air ventilation technologies***, EU players published almost half of the journal papers that were counted in the study, while players from China filed the most patents.

II.A.2. **Number and Ratio of Publications**

The following diagram Figure II-II shows the geographic distribution of publications from academic institutions in the last 5 years for the analysed categories for building energy efficiency. **Academic players from the EU dominate in almost every area**. European research institutes appear especially engaged in the categories heat/cold storage (in particular sorption storage) and building envelope (in particular for insulation measures) in comparison with the other analysed regions. Another strong research focus of players from the EU is building ventilation including heat recovery systems. China is contributing a large amount of publications with an emphasis on lighting technologies – especially for LED. LED technologies contribute the largest development and market potential of all lighting technologies. The lighting market shows a strong upcoming shift to LED from conventional lighting technologies[8]. Furthermore, European academic players put significant emphasis through the large number of publications **in the subcategory "LED",** but the collated publications from China, Japan and South Korea clearly show the **Asian dominance in research activities** in this technology.

Academic players from the USA as the third largest fraction of the publications **have a strong focus on ICT related topics**, such as the monitoring and control systems for buildings. The European players also contribute a large amount of publications to this topic, especially due to the high requirements and standards to room temperatures and air quality in those regions. Air conditioning appliances are deployed mainly in commercial buildings in Europe. In the USA, air conditioning is applied in addition to residential buildings because of the widespread lightweight

[8] McKinsey & Company (2012): Lighting the way: Perspectives on the global lighting market.

construction. In Europe, particularly in the northern countries, air conditioning systems do not have a market penetration.

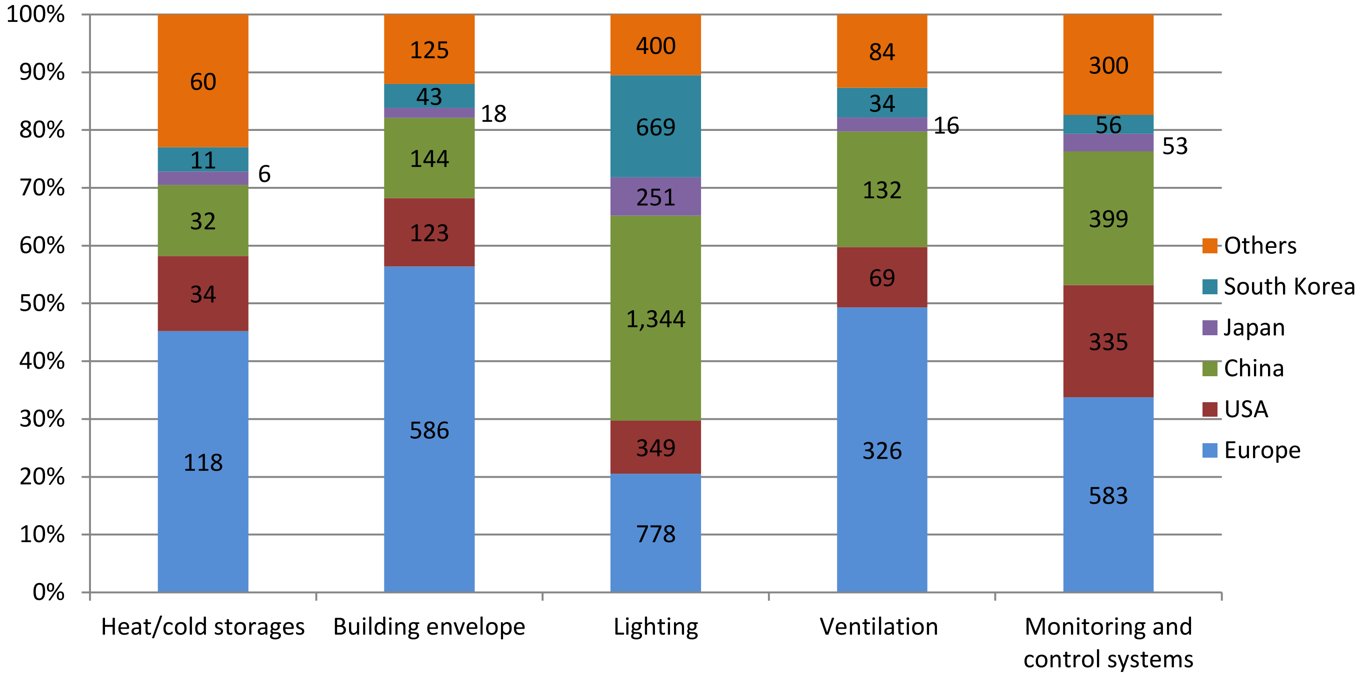


Figure II-II: Number and ratio of publications by country and category of technologies listed in Theme 3

The amount of Chinese publications in the subcategory "HVAC" shows that the relevance of building climate is also increasing in China. Given the rapid increase of the construction of new buildings, the demand for air conditioning and air quality in buildings is reaching new heights, which were rather irrelevant in the Chinese building stock until recently[9].

II.A.3. Number and Ratio of Patents

Patent filings regarding energy efficiency technologies and measures in the building sector show a different picture than publications by academic players in this field. The following diagram (Figure II-III) shows the geographic distribution of patents issues for the analysed categories in theme 3.

In the category of ***Thermal energy storage*, Japan is leading the ranking with number of patents**, but Chinese players also have a significant share. Only for *Sorption based storage technologies*, EU has the lead for patent filings despite the low absolute number. Europe is holding onto the lead in terms of patents in *Building envelopes*, followed very closely by China, who contributed the most patents for windows and glazing.

The field of lighting technologies has by far the most patents of the entire Theme 3. The geographical distribution shows a similar picture to the academic publications. The field is dominated by Chinese patents. Only for halogen lamps do Japanese and European players enter the field with

[9] CPI, Amecke et al. (2013): Buildings Energy Efficiency in China, Germany, and the United States.

strong activity. **Holding 95% of patents for LED, China contributes the most to the development of a technology of the future.**

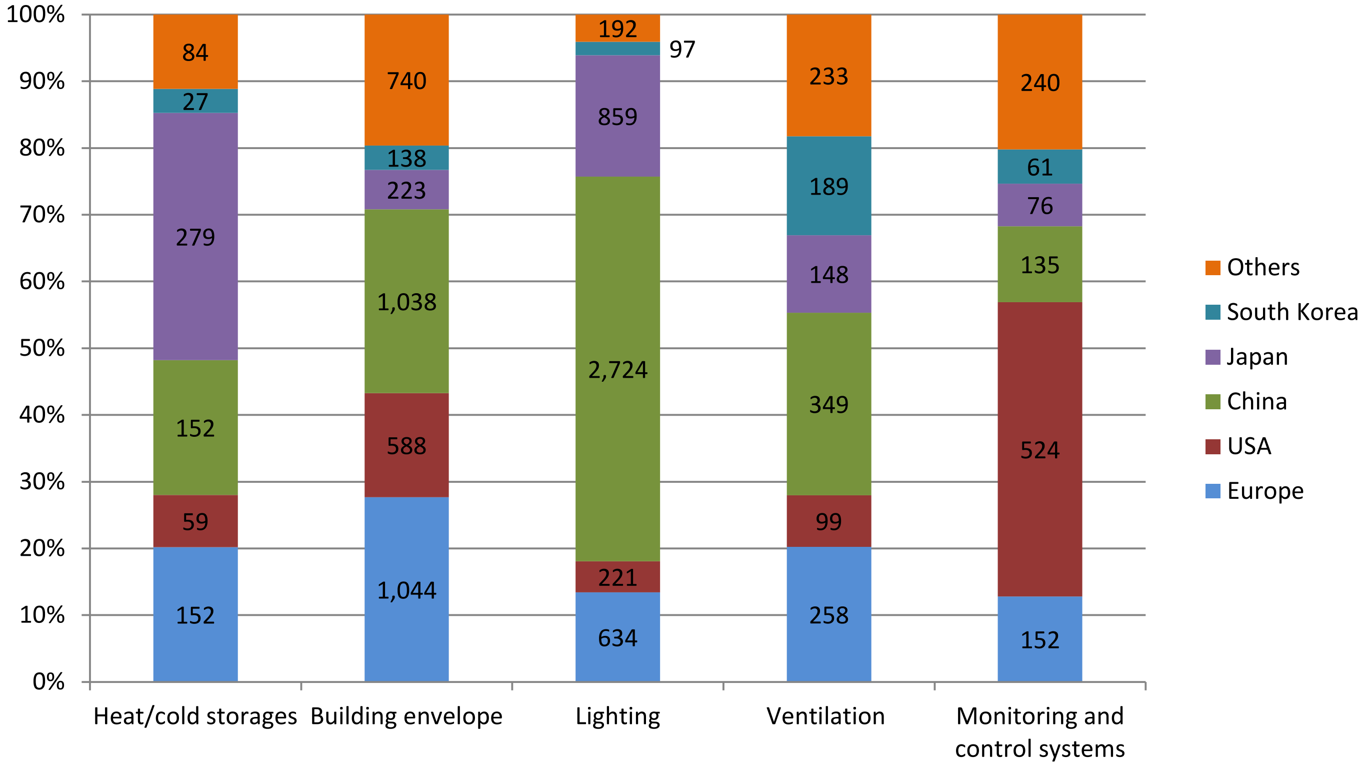


Figure II-III: Number and ratio of patents by country and category of technologies listed in Theme 3

The field of ***Building ventilation*** shows a more balanced picture. The ranking is **led by Europe for heat recovery systems**. Given the high energy demand for domestic heating, particularly in northern European countries, this technology is a major mark for reaching the EU requirements for the energy efficiency of buildings. **Innovation in monitoring and control systems is driven by players from the USA**. This finding represents the high relevance of integrated systems for controlling the indoor climate (heating and cooling) and air quality appliances in buildings in this region.

II.A.4. **Volume and Ratio of Import and Export**

The following diagram (**Erreur ! Source du renvoi introuvable.**) shows the average volume and ratio of exports and import in the year 2013 for the categories *Building envelope* and *Lighting*. **The dominance of Asian players in the field of lighting technologies is once again shown in terms of exports**. The high share of exports, particularly in LED technologies, resembles the size of the share of LEDs in the domestic markets in Asia. In 2011, the market share of LEDs in the general lighting market in Asia and China was 11-12%, while Europe only reached 9%. This makes Asia an early adopter of LED technologies. Given the size of the markets, this accounts for a large portion of the worldwide lighting market. Estimates show that this development will continue into the future. Particularly after the Fukushima incident, market shares of LEDs rose in Japan due to a higher awareness for energy efficiency. The general lighting market is fragmented in most countries due to local (national) product requirements. This is less so the case for LED fixtures[10].

Market analysis data for building materials, such as glazing and insulation materials, are either not freely available or hard to come by. An IEA expert's survey on market saturation reveals that the EU has mature or established markets for most of the glazing and envelope technologies analysed as does the USA. China is still an emerging market for most technologies, while Japan and Korea have established markets for many of these technologies[11].

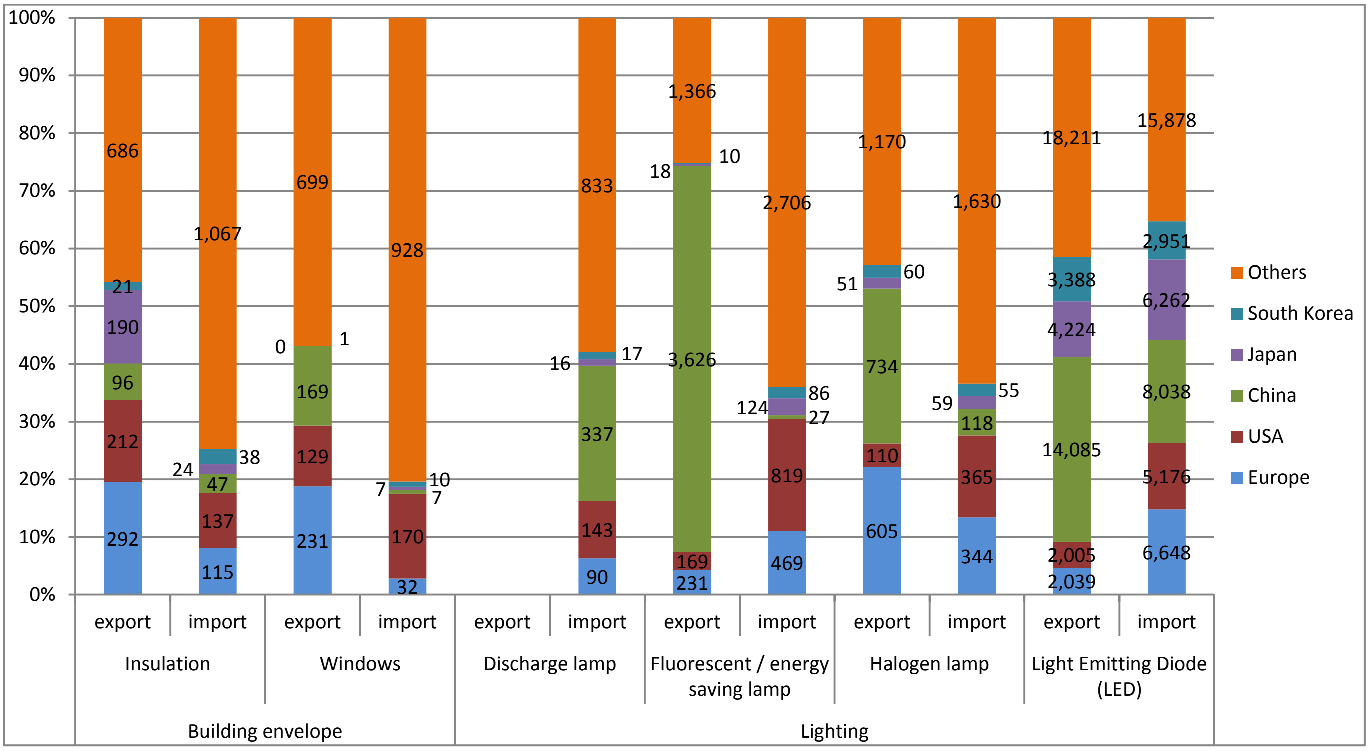


Figure II-IV: Volume and ratio of import and export (Mio. €) by country within categories *Building envelope* and *Lighting*

II.A.5. **Conclusions on Strengths and Weaknesses of the EU**

The following Table II-I gives an overview about geographical strengths and weaknesses regarding patents (•), publications (◦) and industrial key players (⋄) for theme 3.

In publications, the EU holds strong positions in all categories. This result corresponds to the estimated R&D expenditure figures given in the overview of theme 3. This portrayal shows that the implementation of the ambitious EU targets regarding energy efficiency in buildings clearly provides the impetus for European academic research. Only for the subcategories of *LED* and *Energy saving lamps* does the EU hold an average position.

[10] McKinsey & Company (2012): Lighting the way: Perspectives on the global lighting market.
[11] IEA (2013): Technology Roadmap - Energy efficient building envelopes.

In terms of patent filings, the EU holds weak to average positions while hosting the most top 10 key players in industries (ranked by number of patents) in the fields of *Thermal storage* and *Ventilation systems*. EU is a strong driver of innovation in terms of patents in the technological fields of *Insulation*, *Sorption based thermal storage* and *Heat recovery systems*.

This picture is also reflected in the stakeholder survey conducted (see Appendix VI.B), were the EU's involvement in advancing energy efficiency in buildings ranked high, but the capacity to advance innovation in the field is rated as being moderate.

Table II-I: Strengths and Weaknesses by country and category measures listed in Theme 3

<table>
<tr><th colspan="2">Category</th><th colspan="2">Europe</th><th colspan="2">USA</th><th colspan="2">China</th><th colspan="2">Japan</th><th colspan="2">S. Korea</th><th colspan="2">Others</th></tr>
<tr><td rowspan="3">Thermal storages</td><td>Sensible liquid/solid</td><td>●
○○○○</td><td rowspan="3">◇◇◇
◇◇</td><td>●
○○</td><td rowspan="3">◇</td><td>●●
○○</td><td rowspan="3">◇</td><td>●●●●</td><td rowspan="3">◇◇</td><td></td><td rowspan="3"></td><td>●
○○</td><td rowspan="3">◇</td></tr>
<tr><td>Latent inorganic/organic</td><td>●●
○○○</td><td>●</td><td>●</td><td>●●●</td><td>●</td><td>●
○○○○</td></tr>
<tr><td>Sorption/Chemical</td><td>●●●
○○○○</td><td>●●
○</td><td>●●●
○</td><td>●●</td><td>●
○</td><td>●●
○○</td></tr>
<tr><td rowspan="2">Building envelope</td><td>Insulation</td><td>●●●
○○○○</td><td rowspan="2">◇◇◇</td><td>●●</td><td rowspan="2">◇◇◇
◇</td><td>●●
○</td><td rowspan="2">◇◇</td><td>●</td><td rowspan="2"></td><td>●</td><td rowspan="2"></td><td>●●
○</td><td rowspan="2"></td></tr>
<tr><td>Windows</td><td>●
○○○○</td><td>●
○○</td><td>●●●
○○</td><td>●</td><td>●
○</td><td>●
○</td></tr>
<tr><td rowspan="2">Ventilation</td><td>Ventilation system</td><td>●
○○○○</td><td rowspan="2">◇◇◇
◇◇</td><td>●
○</td><td rowspan="2"></td><td>●●●
○○</td><td rowspan="2">◇</td><td>●●</td><td rowspan="2">◇◇</td><td>●●</td><td rowspan="2">◇</td><td>●●
○</td><td rowspan="2">◇</td></tr>
<tr><td>Heat recovery systems</td><td>●●●
○○○○</td><td>●
○</td><td>●●
○○</td><td>●</td><td>●●
○</td><td>●
○○</td></tr>
<tr><td rowspan="4">Lighting</td><td>Halogen lamp</td><td>●●
○○○</td><td rowspan="4">◇◇</td><td>●
○</td><td rowspan="4"></td><td>●●
○○</td><td rowspan="4">◇</td><td>●●●
○</td><td rowspan="4">◇◇◇
◇◇◇
◇</td><td>●
○</td><td rowspan="4"></td><td>●
○○</td><td rowspan="4"></td></tr>
<tr><td>Fluorescent /
energy saving lamp</td><td>○○</td><td>○○</td><td>●●●●
○○○</td><td>○○</td><td>○</td><td>○○</td></tr>
<tr><td>Discharge lamp</td><td>●
○○○○</td><td></td><td>●●●●
○○</td><td>●</td><td></td><td></td></tr>
<tr><td>LED</td><td>○○</td><td>○</td><td>●●●●
○○○</td><td>○</td><td>○○</td><td>○</td></tr>
<tr><td rowspan="3">Monitoring and control systems</td><td>HVAC</td><td>●
○○○</td><td rowspan="3">◇</td><td>●●●●
○○</td><td rowspan="3">◇◇◇
◇◇◇
◇◇</td><td>○○</td><td rowspan="3"></td><td>○</td><td rowspan="3">◇</td><td>○</td><td rowspan="3"></td><td>●●
○○</td><td rowspan="3"></td></tr>
<tr><td>Lighting control systems</td><td>●
○○○</td><td>●●●
○○</td><td>●●
○○</td><td>●●
○</td><td>●●
○</td><td>●●
○</td></tr>
<tr><td>Other control systems</td><td>○○○</td><td>○○</td><td>●●●●
○○</td><td>●○</td><td>○</td><td>○</td></tr>
</table>

II.B. Theme 4: Energy efficiency in heating and cooling

The heating and cooling sector constitutes around half of the EU final energy consumption.[12] Improving the energy efficiency in the sector is one of the goals of the Energy Efficiency Directive (27/2012/EU) in transitioning the EU towards a decarbonised energy system. To achieve this, it is necessary to advance research in a combination of heating and cooling supply technologies.

Analysed categories of technology

Heating supply technologies	Condensing boiler
	Low temperature boiler
	Wood pellet boiler
	Compression heat pump
	Absorption heat pump
	Adsorption heat pump
	Solar heat systems (plate / tube collector)
	Magnetic heating
	Cogeneration/Combined heat power (CHP)
	Trigeneration/Combined heat cooling power (CCHP)
Cooling supply technologies	Air-coolers
	Thermoacoustic refrigeration

II.B.1. Overview

This theme will assess the advancement across these various heating and cooling supply technologies within EU, US, China, Japan, and South Korea in terms of publications, patents, exports/imports and R&D investment. The R&D data for this theme overlaps with that of the theme on Energy Efficiency in Buildings, and therefore has been discussed in the previous chapter. The following graph shows an overview of the geographical spread of the volume and ratio of patents, publications, exports and imports.

[12] http://www.rhc-platform.org/

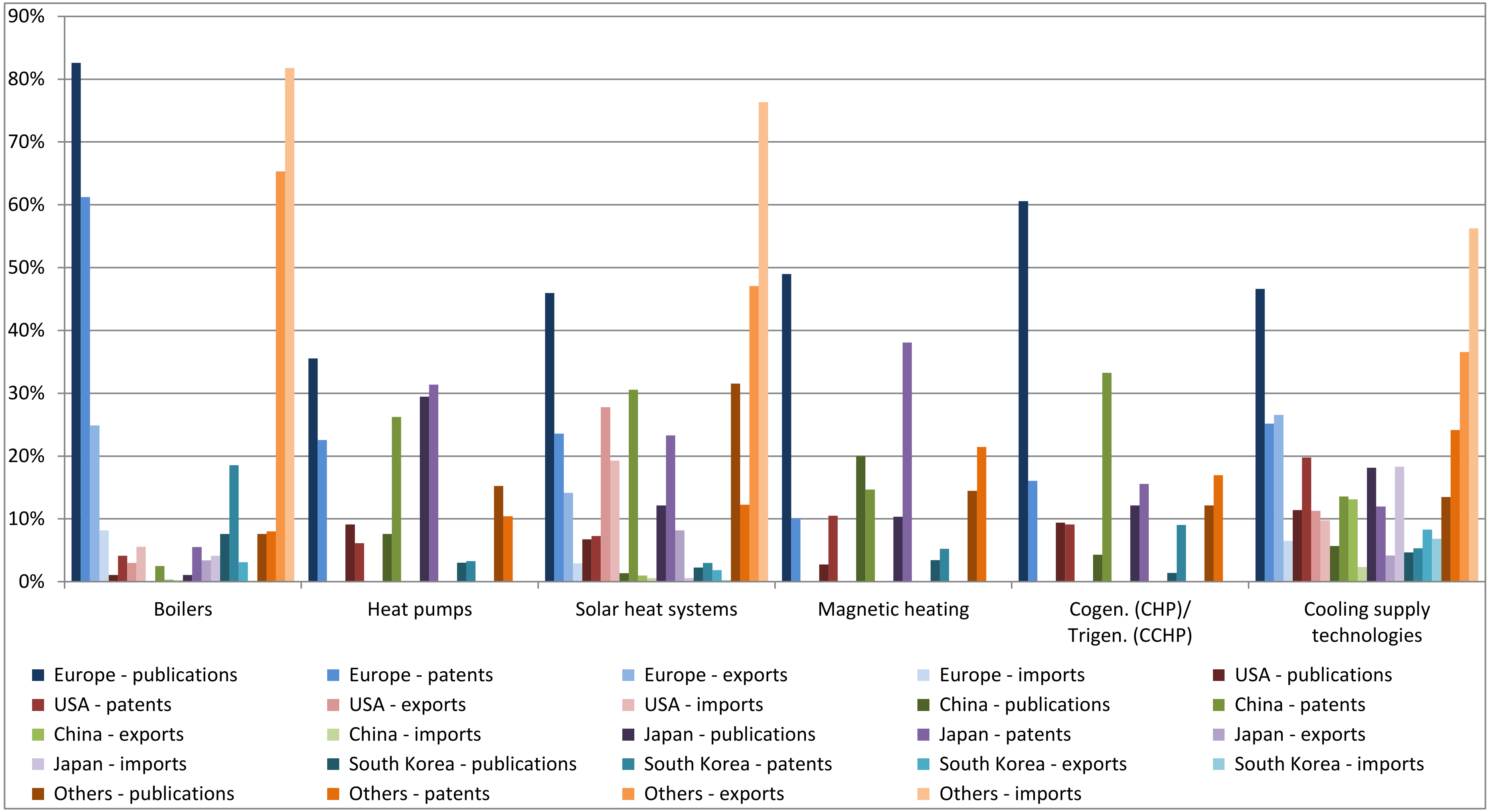


Figure II-V: Total ratio of publications, patents, exports and imports by country for Theme 4

II.B.2. Number and Ratio of Publications

The **EU's position in the heating and cooling supply technologies is well advanced in terms of publications.** The data reflecting the ratio of publications indicates that the EU leads across the board on nine out of the twelve specified fields. The academic players that follow are those of China, the US and in some fields such as magnetic heating, Japan. The particularly **high number of publications attributed to EU academic institutions to cogeneration/CHP technology** could be explained by the extensive use of CHP in district heating across EU Member States. More than 50% of the EU district heating market is concentrated in Northern Europe (Germany, Denmark, Poland, Czech Republic and Finland)[13]. While the use varies across Europe, in 2001, the use of CHP in district heating systems in France was at 22% while in Netherlands the number reached 92%. However in the US, it accounted for less than 4%[14].

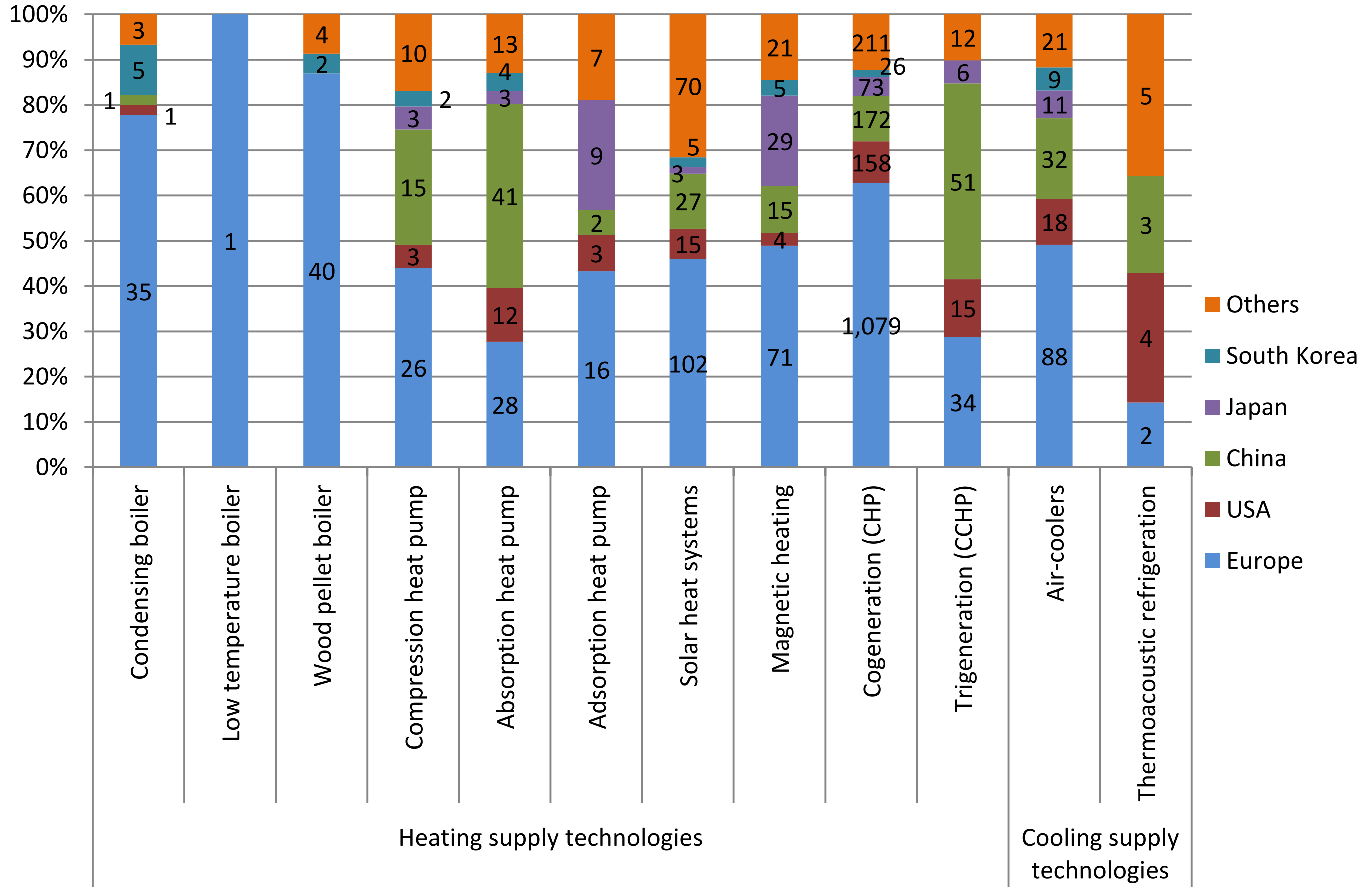


Figure II-VI: Number and ratio of publications by country and category of technologies listed in Theme 4

Within the EU, the Member States that account for the highest percentage of publications for cogeneration and CHP technologies include: Italy (39%), Germany (23%), Sweden (18%), Spain

[13] http://www.cogeneurope.eu/district-heating_270.html
[14] Gochenour, C. (2001). "*District energy trends, issues, and opportunities: the role of the World Bank* (Vol. 23)", World Bank Publications. P. 43

(17%), France (13%), Netherlands (13%), Denmark (12%) and Finland (11%). The high number of academic players from these countries may be explained by the overall strength of their scientific publication output. Within OECD countries, based on the data collected from 2003-2011, the UK and Germany ranked third and fourth in terms of number of scientific publications. France came in sixth, followed by Italy (8th) and Spain (9th). However, in terms of the percentage of top cited publications, Netherlands, Sweden and Denmark ranked among the highest.[15]

II.B.3. Number and Ratio of Patents

In the analysis of global **patent filings** for heating supply technologies, the **European Union emerged as the leader in three of the associated technologies, i.e., condensing boiler, low temperature boiler and adsorption pump.** Japan leads in terms of patents issued under the cogeneration and solar heat systems categories. China's contribution to the remaining technologies was the largest, with the exception being wood pellet boiler technology, led by South Korea. In terms of patents for cooling supply technologies, the US ranked the highest followed by the EU in the air-cooler category, while China dominated the patent holdings in thermoacoustic refrigeration. Compared to the research data, where EU is the leading source of publications **for cogeneration technologies, Japan holds the largest number of patents** in the same category. In this case, Japan may be the key innovator, while the EU has the largest application of this technology and research behind it.

[15] OECD (2013), *OECD Science, Technology and Industry Scoreboard 2013: Innovation for Growth*, OECD Publishing, Paris. p. 134

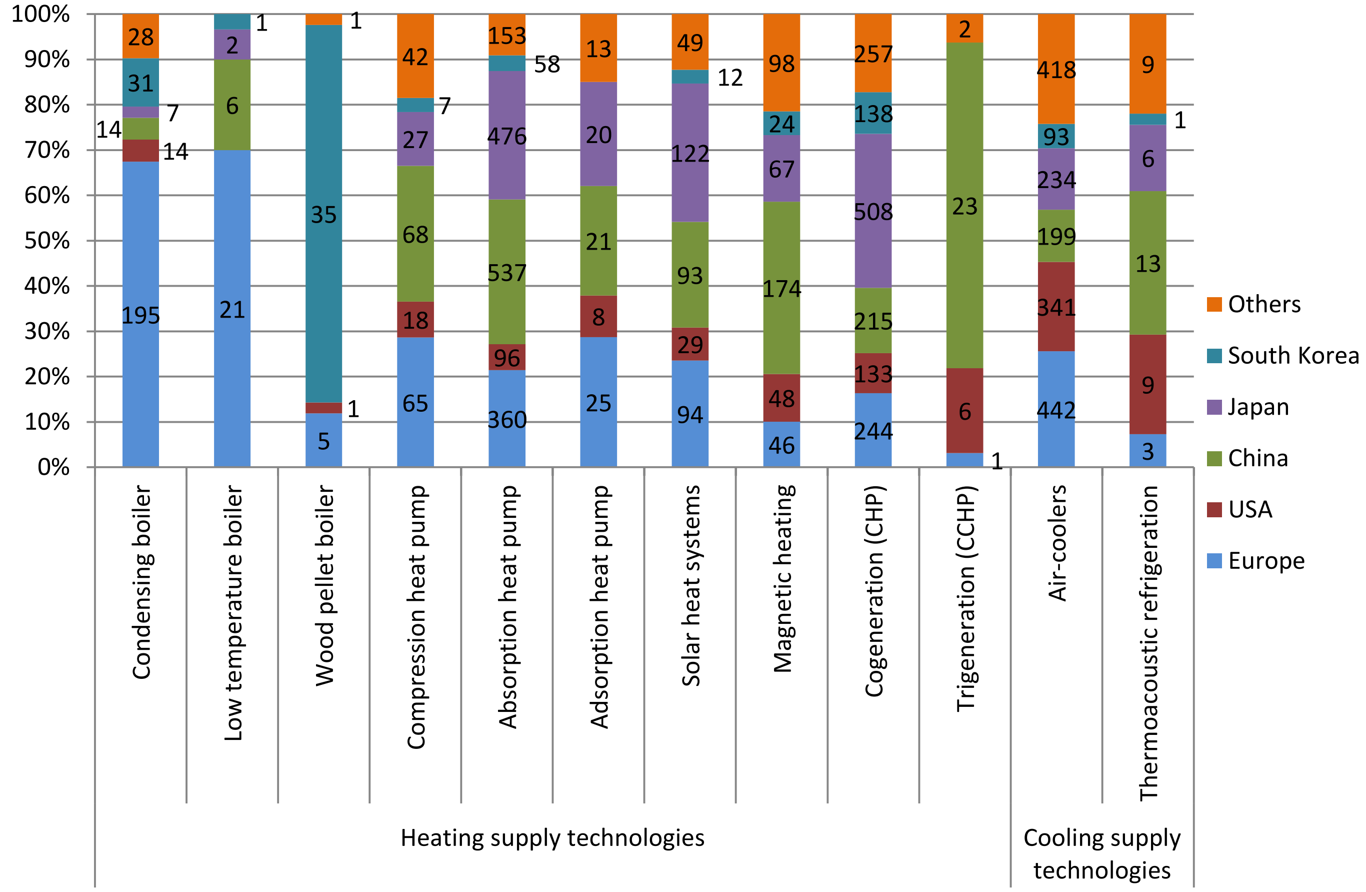


Figure II-VII: Number and ratio of patents by country and technology listed in Theme 4

II.B.4. **Volume and Ratio of Import and Export**

The EU's share of exports surpasses the imports for heating and cooling supply technologies. Its strong position is reflected in two fields, wood pellet boiler and cooling supply technology, while the remaining technology exports are dominated by the US followed by China. Although Japan and the EU are the leaders in solar heat system patents, in terms of exports, the US emerges as the key player, closely followed by the EU. A similar trend is observed for the wood pellet boiler technology; the greatest ratio of patents is held by South Korea, while a big share of exports are coming from the EU.

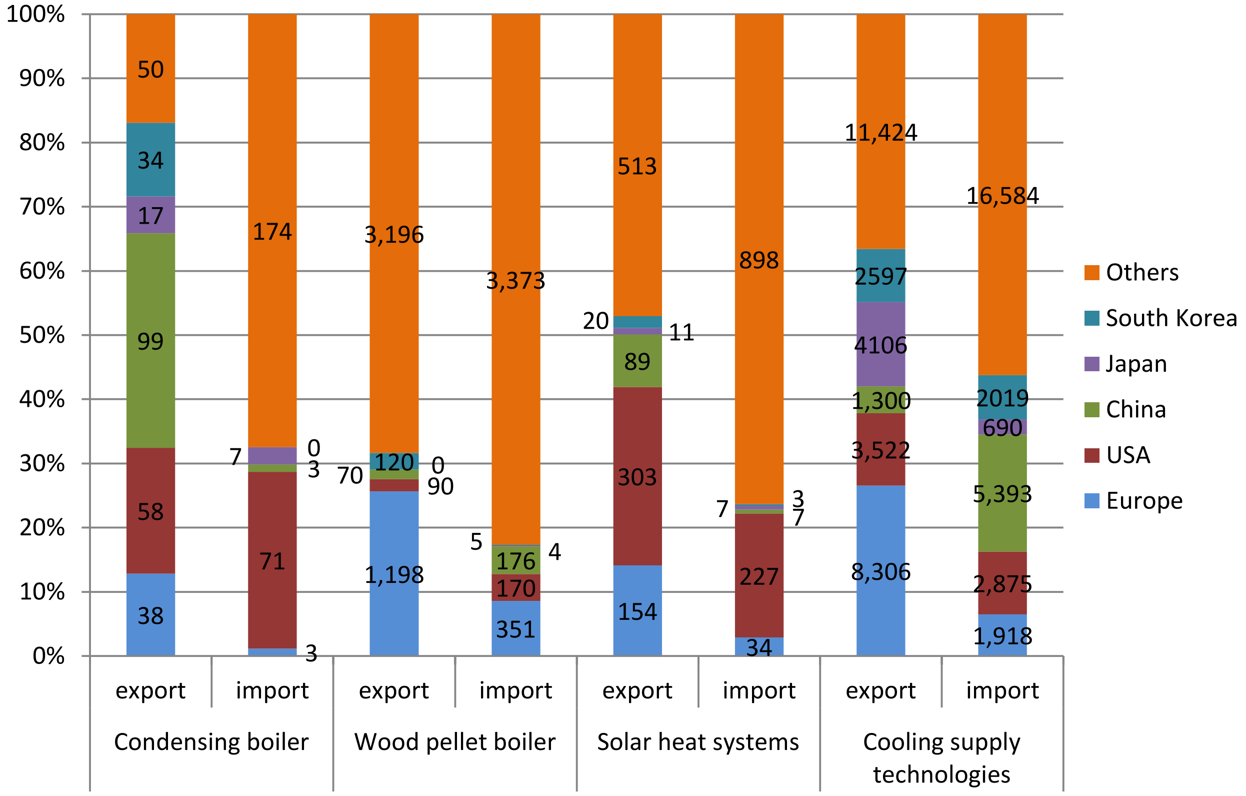


Figure II-VIII: Volume and ratio of import and export by country (Mio. €) within sub categories *Condensing boiler, Wood pellet boiler* and *Solar heat systems* and also in category *Cooling supply technologies*

II.B.5. Conclusions on Strengths and Weaknesses of the EU

The following table provides an overview of the geographical allocation of strengths and weaknesses regarding patents (•), publications (◦) and industrial key players (⋄) for theme 4.

Table II-II: Strengths and Weaknesses by country and category of measures listed in Theme 4

<table>
<tr><th colspan="2">Category</th><th colspan="2">Europe</th><th colspan="2">USA</th><th colspan="2">China</th><th colspan="2">Japan</th><th colspan="2">S. Korea</th><th colspan="2">Others</th></tr>
<tr><td rowspan="10">Heating Tech-nologies</td><td>Condensing boiler</td><td>••••
○○○○</td><td rowspan="10"></td><td></td><td rowspan="10"></td><td></td><td></td><td></td><td rowspan="10">◇◇◇
◇◇◇
◇◇</td><td></td><td rowspan="10">◇◇</td><td></td><td rowspan="10"></td></tr>
<tr><td>Low temperature boiler</td><td>••••</td><td></td><td>•</td><td></td><td></td><td>•</td><td>•</td></tr>
<tr><td>Wood pellet boiler</td><td>○○○○</td><td></td><td></td><td></td><td></td><td>••••</td><td></td></tr>
<tr><td>Compression heat pump</td><td>•••
○○○○</td><td>••
○</td><td>•••
○○</td><td></td><td>••
○</td><td>•</td><td>••
○○</td></tr>
<tr><td>Absorption heat pump</td><td>••
○○</td><td>•
○○</td><td>•••
○○○○</td><td></td><td>•••
○</td><td>•
○</td><td>••
○○</td></tr>
<tr><td>Adsorption heat pump</td><td>•••
○○○○</td><td>••
○</td><td>••
○</td><td></td><td>••
○○</td><td>•</td><td>••
○○</td></tr>
<tr><td>Solar heat systems</td><td>••
○○○○</td><td>••
○</td><td>••
○</td><td></td><td>•••</td><td>•</td><td>••
○○</td></tr>
<tr><td>Magnetic heating</td><td>•
○○○○</td><td>•</td><td>•••
○</td><td></td><td>••
○○</td><td>•</td><td>••
○</td></tr>
<tr><td>Cogeneration (CHP)</td><td>••
○○○○</td><td>•</td><td>••</td><td></td><td>•••</td><td>•</td><td>••
○</td></tr>
<tr><td>Trigeneration (CCHP)</td><td>○○</td><td>•
○○</td><td>••••
○○○○</td><td></td><td>○</td><td></td><td>○</td></tr>
</table>

<table>
<tr><th colspan="2">Category</th><th colspan="2">Europe</th><th colspan="2">USA</th><th colspan="2">China</th><th colspan="2">Japan</th><th colspan="2">S. Korea</th><th colspan="2">Others</th></tr>
<tr><td rowspan="2">Cooling Tech-nologies</td><td>Air-coolers</td><td>●●●
○○○○</td><td rowspan="2">◇</td><td>●●
○</td><td rowspan="2">◇</td><td>●●
○○</td><td></td><td>●●</td><td rowspan="2">◇◇◇
◇◇◇
◇</td><td>●</td><td rowspan="2">◇</td><td>●●
○</td><td></td></tr>
<tr><td>Thermoacoustic refrigeration</td><td>●●
○○</td><td>●●
○○○</td><td>●●●
○○</td><td></td><td>●●
○</td><td>●
○</td><td>●●
○○○</td><td></td></tr>
</table>

On the innovation scale, the **core strength of the EU is demonstrated in terms of patents for condensing and low temperature boilers, followed by the compression and adsorption heat pump and air-coolers. However, it holds a weak position overall for patent filings in the majority of the other heating and cooling supply technologies.** On the other hand, the EU is a leader in terms of research, reflected by the amount of publications. The EU accounts for the largest share of academic players, holding a lead position in the majority of technology fields. In terms of exports, the EU leads in three technology fields. In general the ratio between exports and imports is strong; as **exports largely outweigh imports across all categories**. In the stakeholder survey, the EU's involvement in advancing energy efficiency in heating and cooling ranked very high, similarly with its capacity to advance innovation in the field, even though the latter is not strongly reflected in the patent data.

II.C. Theme 5: Energy efficiency in industry and services

The industry and service sectors represent 39.1% of the total EU final energy consumption.[16] Many industries in the EU have made energy efficiency improvements, in an effort to decrease costs and improve competitiveness compared with those of other nations. However a larger effort is necessary to maintain its competitiveness in the global markets.

Analysed categories of technology

Energy management sensors and solutions
Heat recovery and heat valorisation in industrial processes
Waste heat utilisation (flue gas condensation, alternative concepts of biomass treatment)
System of autothermal torrefaction of biomass and wastes with additives integrated with drying raw biomass by heat recovery – producing solid biocoal
Frequency regulated electro-motor in industry
Optimized solutions for waste and residues

II.C.1. Overview

This theme will assess the advancement of these various energy efficiency technologies in industry and services within EU, US, China, Japan, and South Korea in terms of publications, patents, export/import and R&D investment. The graph below represents the geographical allocation of patents, publications, export and import data related to energy efficiency in the industry and services sectors.

Similarly, the chart below presents the distribution of R&D. As the data for China is not available, the comparison is limited to the other key players and therefore is not comprehensive. Based on the available R&D data, it is evident that the EU is the largest investor. The US is the second largest, investing about half the funds compared to the EU. Although the EU leads in this category, this is only reflected in strong position in terms of publications.

[16]Source: Eurostat, May 2014

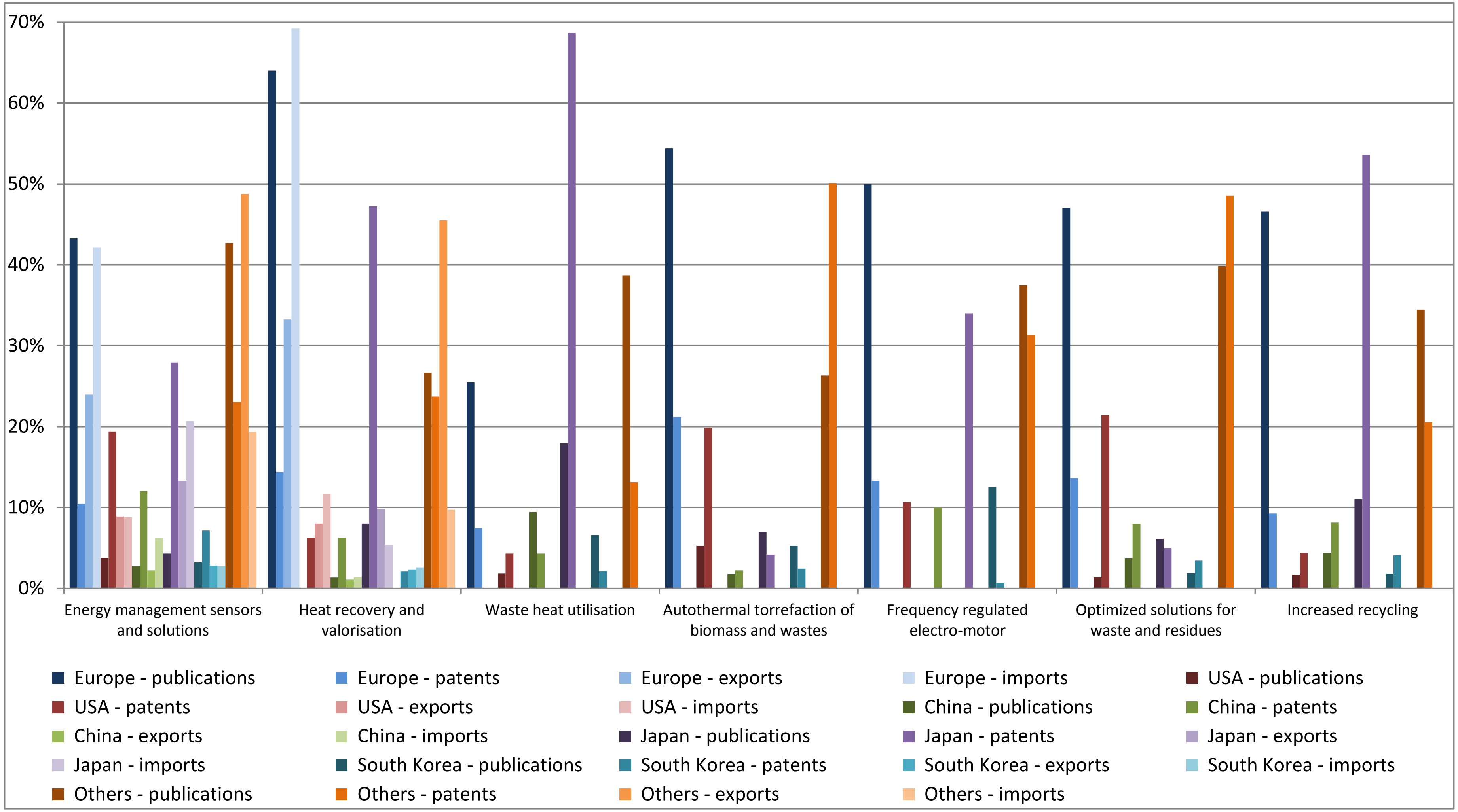


Figure II-IX: Total ratio of publications, patents, exports and imports by country for Theme 5

II.C.2. Number and Ratio of Publications

The large number of results within the 'increased recycling' category may be due to overlap with other technologies, as the technology definition is wide compared to that of others in the database. **Publications** for energy efficiency technologies in the industry and services **are dominated by the European Union**. China is the second largest contributor, by a wide margin specifically within the waste heat utilization category. China's production of scientific publications in general is ranked second after that of the US, but the percentage of top cited publications is well below 10%, one of the lowest in the OECD countries.[17] Within the increased recycling category, the EU produces the highest number of publications, other countries second highest, and China third.

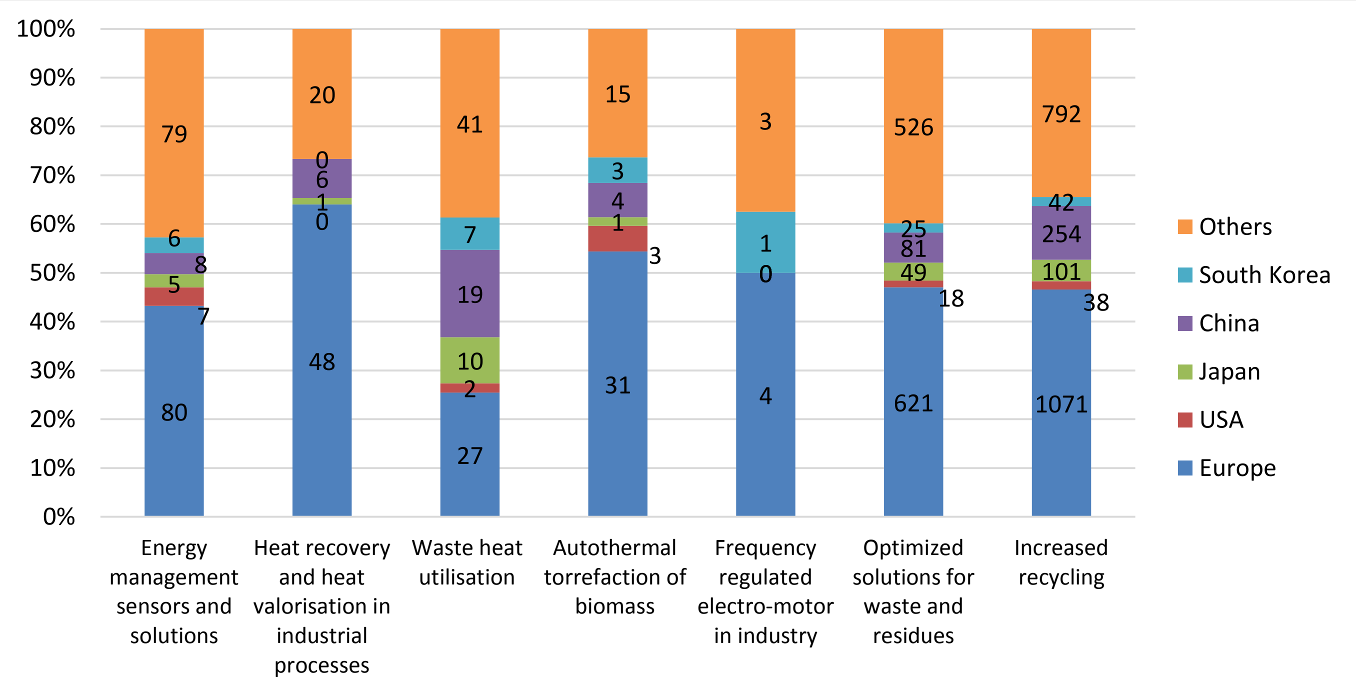


Figure II-X: Number and ratio of publications by country and category of technologies listed in Theme 5

II.C.3. Number and Ratio of Patents

Although the EU leads in research activities, **the patents issued related to energy efficiency of industry and services are mainly attributed to China**. While a mix of other countries, "Others" holds the second largest share, **the US holds the third largest share, followed by Japan.** EU's largest share of the patent filings is related to the category of systems for autothermal torrefaction of biomass. Similarly it has the third highest ranking in terms of increased recycling, other countries making up the second largest portion. However, this particular category faces the same data limitations as for publications, mentioned above. China's high level of innovation in recycling (reflected in patent numbers) may be explained by the boom in the recycling market. China is

[17] OECD (2013), *OECD Science, Technology and Industry Scoreboard 2013: Innovation for Growth*, OECD Publishing, Paris. p. 134

currently the largest consumer and importer of recycled materials in the world.[18] By 2018, the Chinese global market for recycled products is expected grow at a compound annual rate of 8.7%.[19]

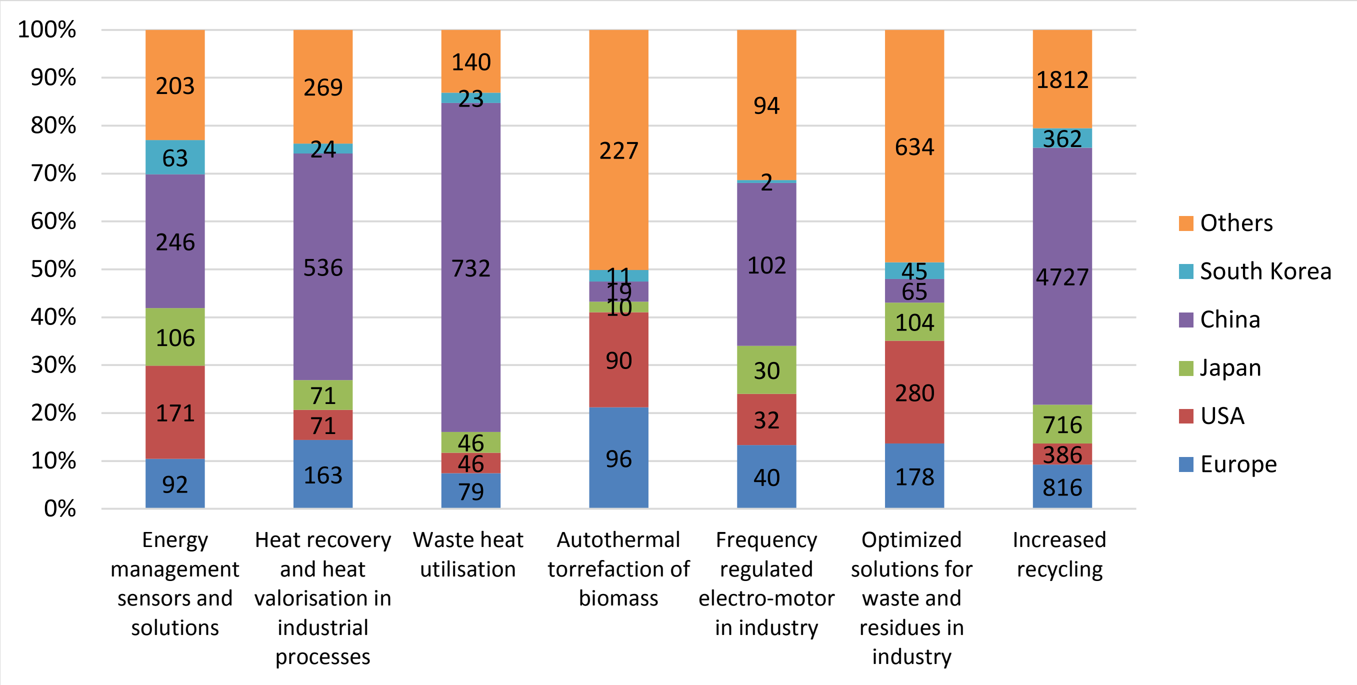


Figure II-XI: Number and ratio of patents by country and category of technologies listed in Theme 5

II.C.4. **Volume and Ratio of Import and Export**

Export/Import data may be inclusive of other technologies, due to the wide definition of export/import goods in the database compared to the narrow definition of the theme and technologies presented in this report. Compared to other countries, **EU is the largest exporter and importer within energy management sensors and solutions and heat recovery** and valorisation categories. However, it imports these technologies far more than it exports. China is the second largest player in terms of exports in both categories, and imports for energy management sensors and solutions. After EU, the US is the most significant importer of heat recovery and valorisation technologies.

[18] Szirmai, A., Naudé, W., & Alcorta, L. (Eds.). (2013). *Pathways to industrialization in the twenty-first century: new challenges and emerging paradigms*. Oxford University Press.
[19] BCC Research (2014). *Recycling Markets in China.*

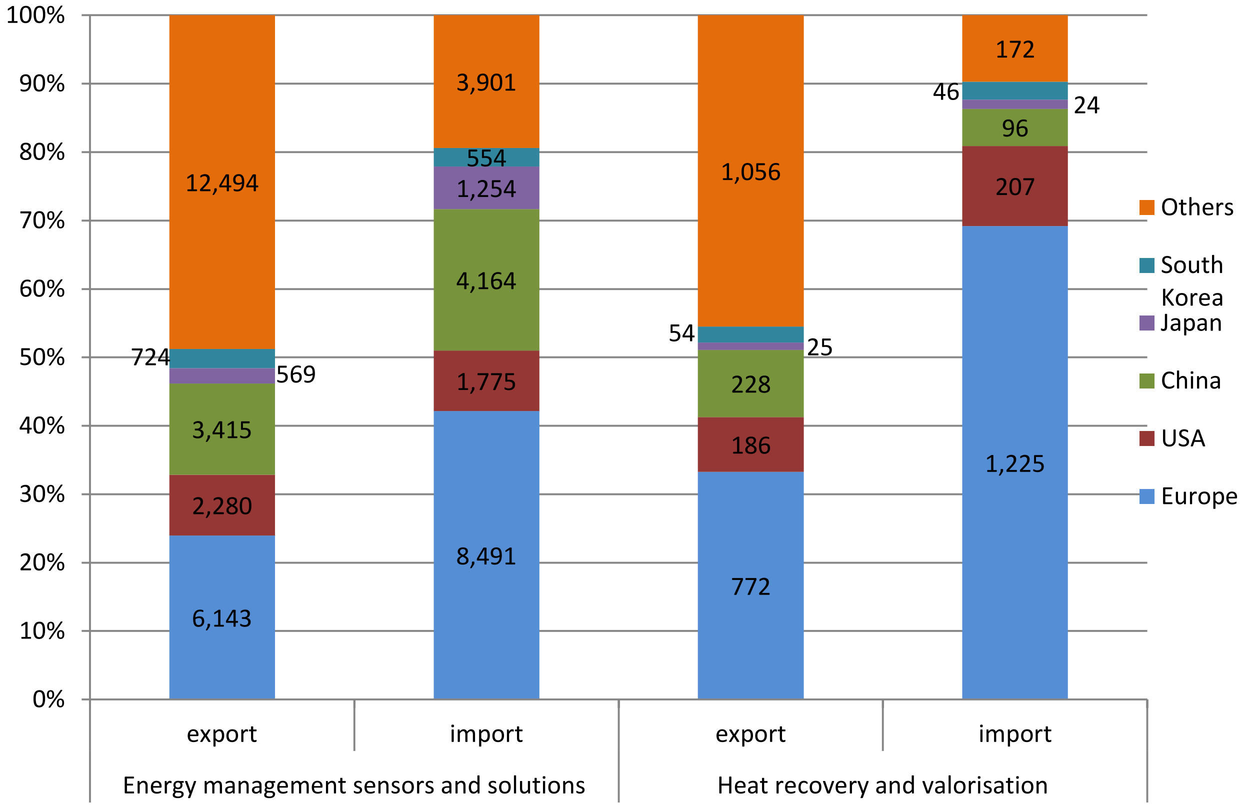


Figure II-XII: Volume and ratio of import and export by country (Mio. €) within categories *Energy Management* and *Heat recovery*

II.C.5. **Conclusions on the Strengths and Weaknesses of the EU**

The following table gives an overview about geographical allocation of strengths and weaknesses regarding patents (•), publications (◦) and industrial key players (⋄).

Table II-III: Strengths and Weaknesses by country and category of measures listed in Theme 5

Category	Europe		USA		China		Japan		S. Korea		Others	
Energy management sensors and solutions	• ○○○○		•• ○	◇◇◇	••• ○	◇◇◇	•• ○	◇◇◇	• ○		•• ○○○○	◇
Heat recovery and heat valorisation in industrial processes	• ○○○○		•		••••		•				•• ○○	
Waste heat utilisation (flue gas condensation, alternative concepts of biomass treatment)	○○		○		•••• ○○		○		○		○○○	
System of autothermal torrefaction of biomass and wastes with additives integrated with drying raw biomass by heat recovery – producing solid biocoal	•• ○○○○		••								•••• ○○	
Frequency regulated electro-motor in industry	•• ○○○○		••		••••		••		• ○		••• ○○○	
Optimized solutions for waste and residues in industry	• ○○○○		••		○		• ○				••• ○○○	
Increased recycling	• ○○○○				•••• ○		○				•• ○○○	

The EU has a very strong position in research across the majority of the technologies. In terms of publications it ranks the highest within the following categories: energy management sensors and solutions, heat recovery and valorisation, system of autothermal torrefaction of biomass, frequency regulated electro-motors, and optimized solutions for wastes. **Overall it is weak in terms of innovation; based on patent data, EU falls short compared to China and other countries**. Even though it exports the largest share among other key players, across the board it imports almost twice as much as it exports. Furthermore, **the EU is also weak in terms of key industrial players, with the majority being from the US, China and Japan**. All three countries have a similar share of key industry players.

III. Integrated challenge 3: System optimisation

System optimisation, storage and management are key topics in the energy sector today and will be for the foreseeable future. Transition of the electricity systems into new and modern grids is expected in the future by applying new technologies and by maturing of the consumers and society.

Summary of the situation regarding system optimisation

China clearly leads on patents in all technologies, followed by the US (which leads on patents for demand response applications). EU is only second as regards flexible AC transmission systems. However, Europe leads in number of publications in all areas except for smart distribution substations. Europe exports as much as it imports (€20bn), but it is the biggest exporter, followed by the US, while China is by far the biggest importer of smart grid technologies (€30 bn, while it exports less than €10 bn).

Japan is the country in recent years that has invested most in the development of electrical/electrochemical technologies (two times the investments in EU, three times the investments in US).

Patents: Japan clearly leads in electrochemical storage and heat storage patents (although EU has published a high number) while on mechanical storage, the EU, US and China are competing at similar levels. Interestingly the EU is strong in patenting immature technologies: flow batteries and syngas technologies, and in publications on chemical storage and power-to-X (although not in electrochemical storage research).

As regards large-scale storage, Japan is leading in patents on H_2 and on large-scale storage, but Europe is very active from a research perspective. Europe has a strong trade deficit on batteries – while Japan clearly exports more than it imports, while interestingly the biggest exporter seems to be the US):

Flexibility: includes flexible AC transmission systems, smart substations, ICT systems for smart grids, power components, and demand response programmes. Again, Europe is much stronger in publications than in patents. The only areas where Europe has a strong patent activity is innovative transmission network control and protection and DC grids with voltage source convertors. China leads in most patenting areas (in particular smart substations, ICT systems and monitoring systems).

Demand response: A study from Navigant Research concludes that, while most DR activity is taking place in the US (30 GW), "Europe is estimated to have a short-term potential of 15-20 GW of demand side resources based on a combination of opening market opportunities, smart grid roll out, and renewable resource integration for an estimated market value of around US$ 6 billion".

Smart Cities: despite the limitations due to the lack of sufficient data and indicators to compare the development in different regions, it can be concluded that the EU is the world player with the highest interest in the field.

III.A. Theme 6: Modernising the European electricity grid and establishing synergies between various energy networks

Europe's electricity networks have successfully provided the vital links between producers and consumers for many decades. These networks have been developed to increasingly integrate renewable energy sources and to meet the requirements of liberalisation of the electricity markets, leading to an increase in traded volumes. The current challenges are flexibility to adapt and anticipate demand, accessibility, reliability and cost efficiency. The overall focus is on smart transmission and distributed networks as well as large-scale storage.

Europe is a significant player in the area of smart transmission and distribution networks. Its strength appears to lie in converting published and patented research carried out by European industry and academia respectively, into exports of state-of-the-art technology. Data collected in this study shows that Europe outperforms other regions in academic output in the field of smart distribution and transmission networks. Furthermore, while the overall patent activity of Europe in the area of smart transmission and distribution networks may seem weak in comparison to other countries and regions – notably China – European companies are among the top innovators in the field.

III.A.1. Overview

Across Europe, the modernisation and expansion of the electricity grid has become an urgent objective. Factors such as the increasing power demand and the fast growing share of variable and decentralised renewable generation require a fast adaptation of the grid, both on a European scale and at the local level.

The new grid needs to be more flexible, increase capacity, and include demand response and active user involvement while minimizing the environmental impacts. The new integrated energy market will be achieved through the integration of balancing opportunities offered by generation, demand response and storage at different levels and scales. This chapter presents the main developed technologies that could enable this transition and the geographical distribution of major industrial and academic players for each technology.

Analysed categories of technologies

Smart transmission and distribution networks	Flexible AC transmission systems (FACTs)
	Optimisation software and models for asset management
	Network monitoring
	DC grids with voltage source converters
	Control and protection systems
	Smart substations with decentralised measurement and switching
	Innovative controllable power components
	ICT systems ensuring link to final consumer or utility
	Power electronics components based on new materials
	Demand response applications

III.A.2. **Number and ratio of publications**

The following graph shows the geographic allocation of publications from academic institutions in the last 5 years relating to smart transmission and distribution networks.

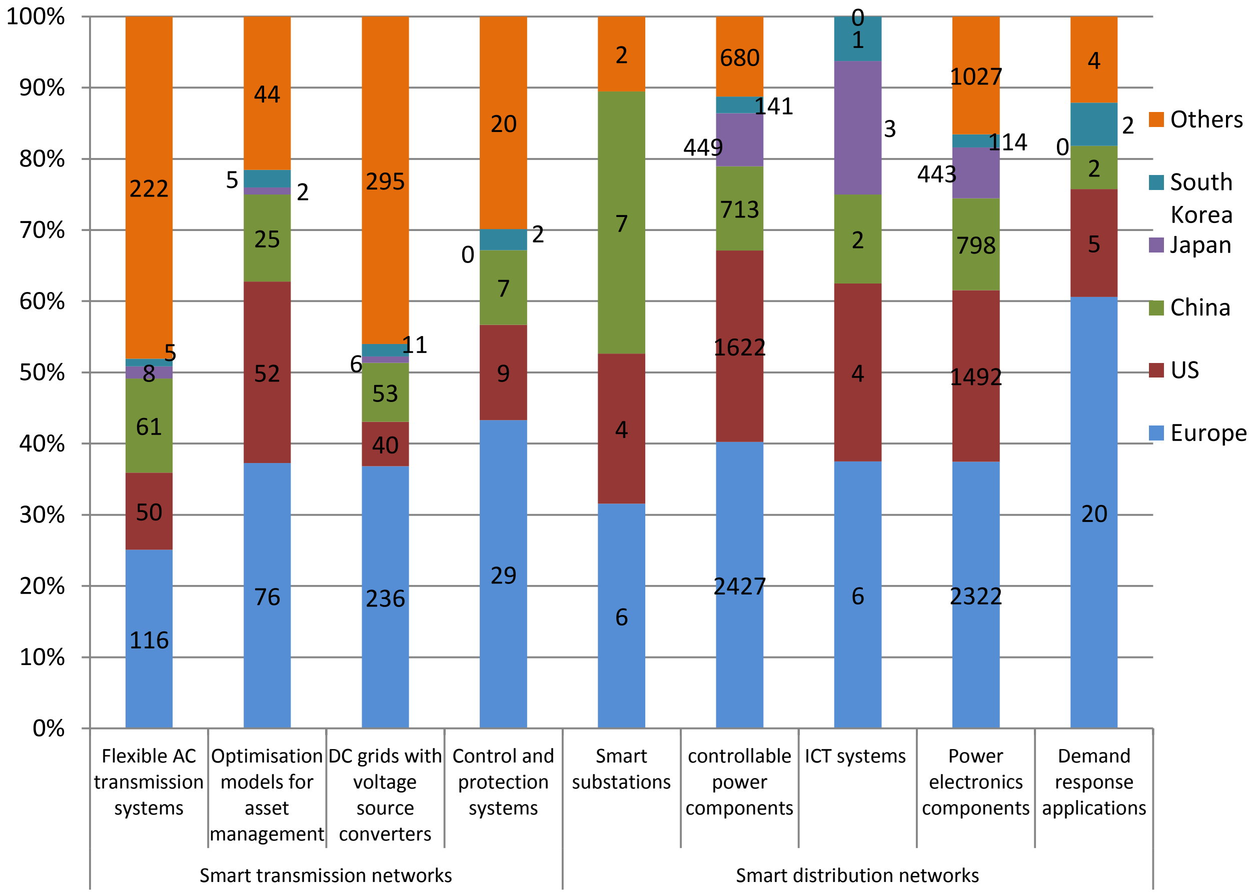


Figure III-I: Number and ratio of publications on transmission and distribution networks field by region

As show in Figure III-I

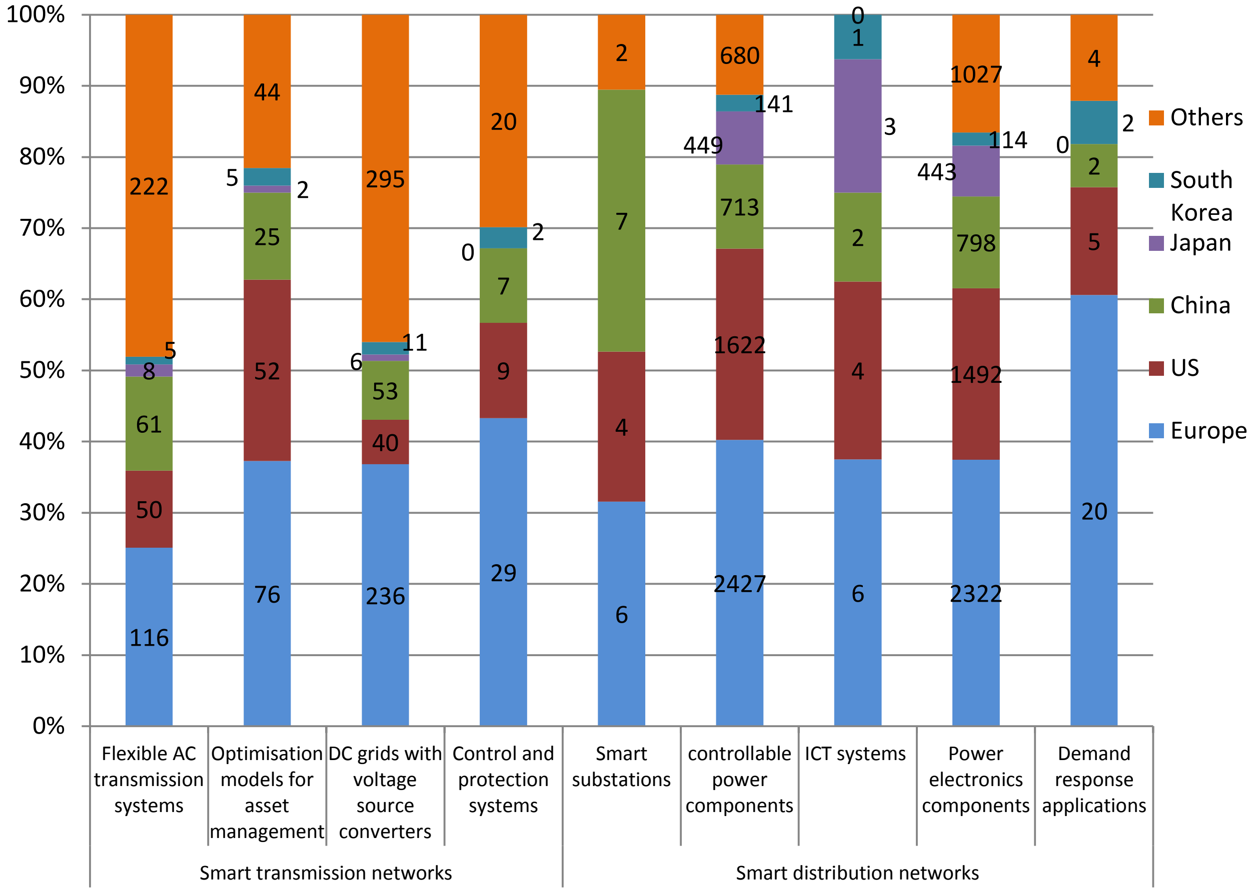


Figure III-I, **Europe outperforms all the other regions in academic research on smart transmission and distribution networks.** It leads the ranking by number of publications in all the fields with a share over 35% for each field, except for FACTs (25%). American academics are also well represented on this graph with 27% and 24% of the total share of publications on new controllable power compounds and power electronic compounds. Chinese ranks third with about 12% of total number of publications.

III.A.3. **Number and ratio of patents**

Figure III-II shows the numbers and ratios of patents relating to distribution and transmission networks technologies by region, since 2000.

Chinese companies have by far the most of patents for almost all the technologies and devices (except ICT systems, new power electronic compounds and demand response applications). **The United States comes second, followed by Japan.** Each region has published about 20% of the total number of patents. Meanwhile, in Europe, the patent activity is very weak, with companies holding 10% of the total patents.

Still, major European players like ABB, Siemens and Alstom come out among the leading companies in terms of number of patents. Their effectiveness is justified by the numerous R&D

collaboration agreements they have with European and Asian universities and by their recent acquisitions.

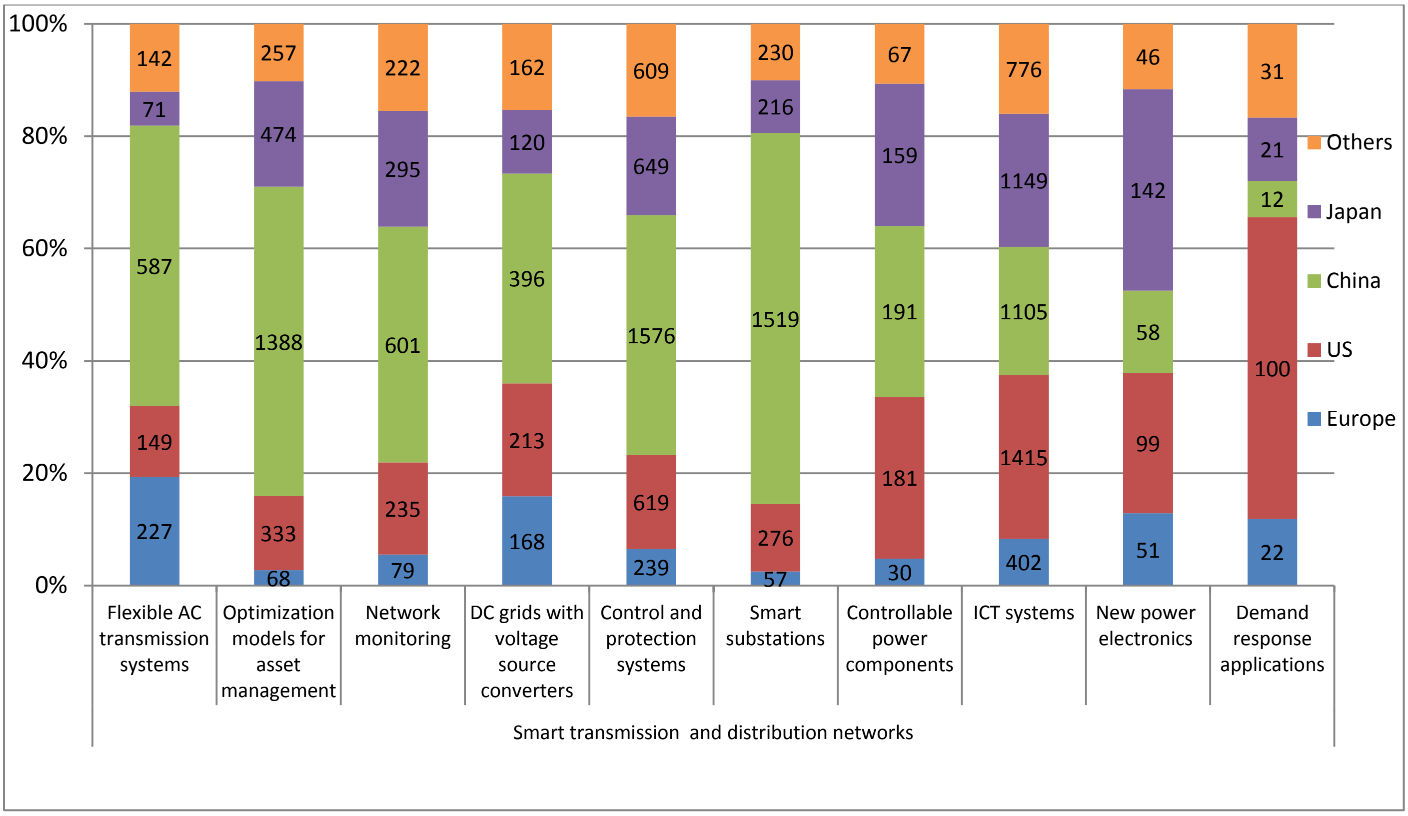


Figure III-II: Number and ratio of patents about transmission and distribution networks by region

III.A.4. **Volume and Ratio of Import and Export**

The following Figure III-III shows the average volume and ratio of exports and imports in 2014 for selected technologies for transmission and distribution networks. Although the dominance of Asian players in patent publishing, **China and Japan export much less than Europe,** who have high export values across all the technologies. **United States** which is ranked third in terms of export values, after China, **is the only country that has a positive trade balance** for all the technologies represented.

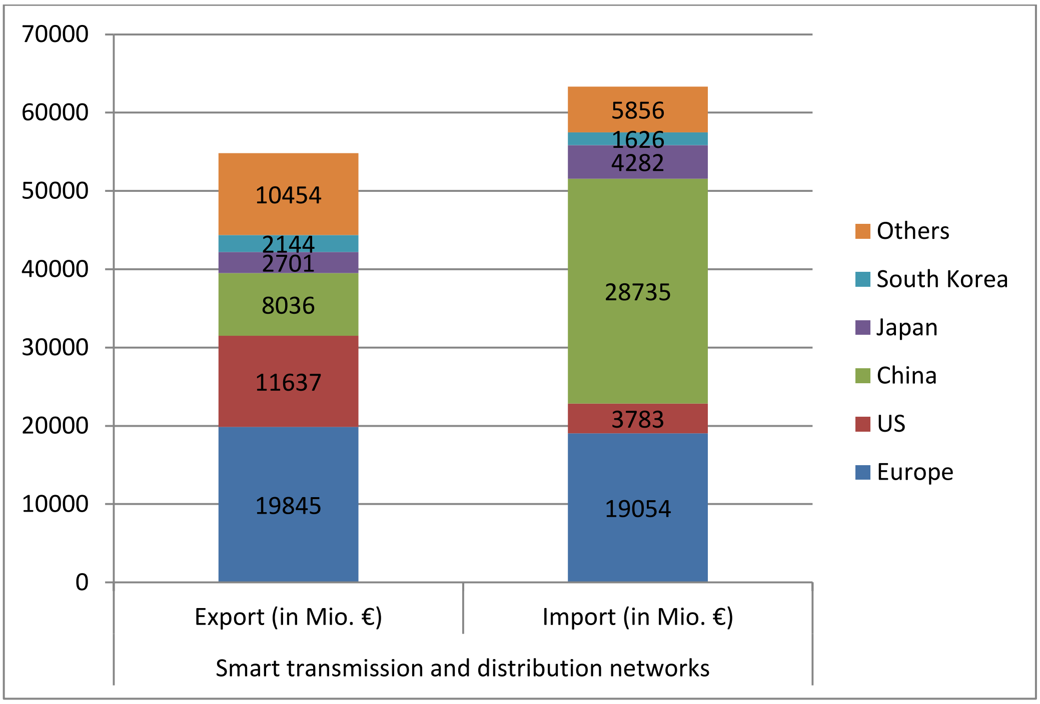


Figure III-III: Volume and ratio of import and export by country (Mio. €)

III.A.5. Conclusions on the Strengths and Weaknesses of the EU

The following table gives an overview of the geographical allocation of strengths and weaknesses regarding patents (•), publications (○) and export values (◇).

Regarding the similar results between measures of each category, they were regrouped to study the main trends. As described earlier, Europe has not published many patents in recent years compared to other regions. It has contributed more in academic research, through the most publications in both fields: transmission and distributions networks. This is despite European research institutes not ranking in the top ten reference research centres. In terms of exports, Europe has by far the biggest export values.

Table III-I: Strengths and Weaknesses by country and category of measures listed in Theme 6

<table>
<tr><th>Category</th><th colspan="2">Europe</th><th colspan="2">USA</th><th colspan="2">China</th><th colspan="2">Japan</th><th colspan="2">Others</th></tr>
<tr><td rowspan="2">Smart transmission and distribution networks</td><td>•</td><td rowspan="2">◇◇◇◇</td><td>••</td><td rowspan="2">◇◇</td><td>••••</td><td rowspan="2">◇</td><td>••</td><td rowspan="2">◇</td><td>•</td><td rowspan="2">◇◇</td></tr>
<tr><td>○○○○</td><td>○○</td><td>○</td><td>○</td><td>○</td></tr>
</table>

III.B. Theme 7 - Unlocking the potential of energy storage and conversion of electricity to other energy carriers

Another way to introduce flexibility into the system is through increased energy storage capacity, which allows for improved matching of electricity supply and demand. This need would be covered by several (combinations of) technologies. "Power-to-x" technologies will also play a key role in transforming, storing and transporting electricity from variable renewables over long distances.

On average, OECD statistics[20] indicate that a 10% increase in targeted public-sector R&D results in approximately 0.4%-0.5% increase in storage-related patents. This effect looks relatively small and points out that the sector is very R&D-intensive, and that encouraging innovation in advanced energy storage technologies is a capital-intensive activity.

Country-specific data are incomplete (e.g. data are missing for several years, China is not part of the database, etc.) and do not allow a comprehensive benchmark assessment across the key regions of the world. However, the "qualitative" findings suggest that **Japan** is undoubtedly **the country which invests most in the development of electrical/electrochemical technologies** in recent years (two times the investments in EU, three times the investments in US).

These data do not directly reflect the level of "innovation" of the region, since reported import and export volumes take into consideration both innovative as well as standard technologies. Products are grouped into two commodity sets[21] as classified in the UN Comtrade Database[22], and refer to 2013.

[20] *Energy and Climate Policy Bending the Technological Trajectory*, OECD, 2012.
[21] CommoditySet-1: Electrical capacitors, fixed, variable or adjustable. CommoditySet-2: Primary cells and primary batteries - Lithium
[22] http://comtrade.un.org/

Analysed categories of technologies and measures

Mechanical storage	Pumped hydro storage
	Compressed air energy storage
	Flywheel Energy Storage
Heat storage	Water
	Molten-salt energy storage
	Phase change material storage
Electrical storage	Supercapacitors
	Superconduction magnetic energy storage
Electrochemical storage	Sodium-sulfur
	Lithium-ion
	Flow batteries (e.g., Vanadium redox-flow batteries)
Chemical storage	Hydrogen
	Synthetic natural gas
	Other chemical, e.g., methanol, ethanol
Power-to-X	Power-to-gas
	Power-to-heat

III.B.1. Number and Ratio of Publications and Patents

The following figures show the geographical distribution (vertical bars) and the actual numbers (data labels) of publications followed by patents for the analysed set of technologies across key regions of the world.

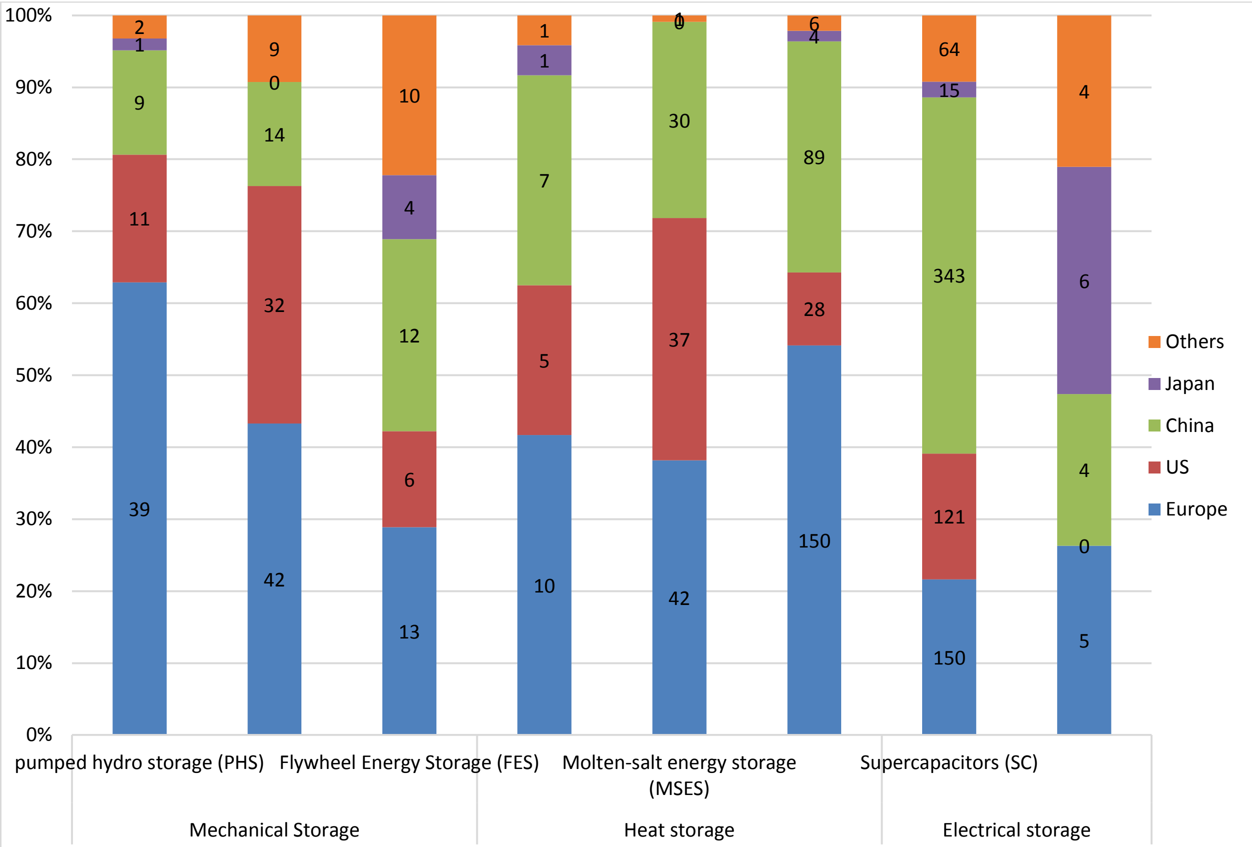


Figure III-IV: Number and ratio of publications by country and category of technologies

Figure III-IV illustrates that the EU submits more studies than US, China and Japan for all the three themes selected (PHS, CAES, FES) in the *mechanical storage* field of research. A similar conclusion can be drawn about the ***heat storage*** for which **European academic institutions are the most active** in the world although US and China perform well too. Almost 100% (around 270 studies) of the publications about *phase-change-material storage* are produced by three key regions, 50% of which are in the EU.

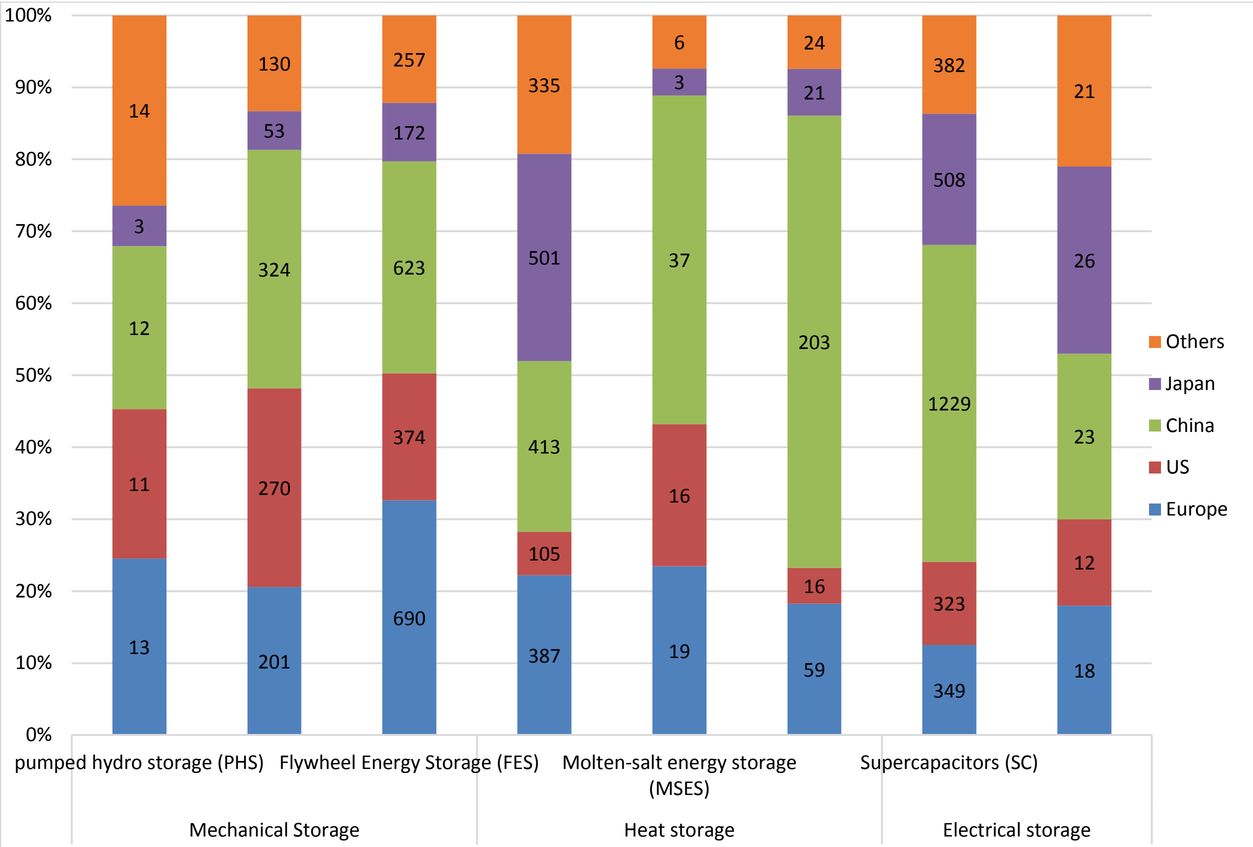


Figure III-V Number and ratio of patents by country and category of technologies

Looking at the above Figure III-V, it is evident that industrial players of several countries own patent rights in the area of energy storage, and that countries tend to favour/focus on specific branches of the storage technologies rather than others. Thus, as concerns ***mechanical storage* EU, China and US have similar number of patents** per type of technology, while Japan looks less strong in this area.

Conversely, in the area of *heat storage* and, above all, **in the areas of *electrical / electrochemical storage,* Japan (and China) dominates in patents** with the largest shares of exclusive rights granted to inventors. EU plays a very important role in particular in the industrial development of two types of technologies which have a relatively low number of total patents (early stage of development): the "flow batteries" (140 out of 500 total patents) and the "synthetic natural gas" technologies (26 out of 74).

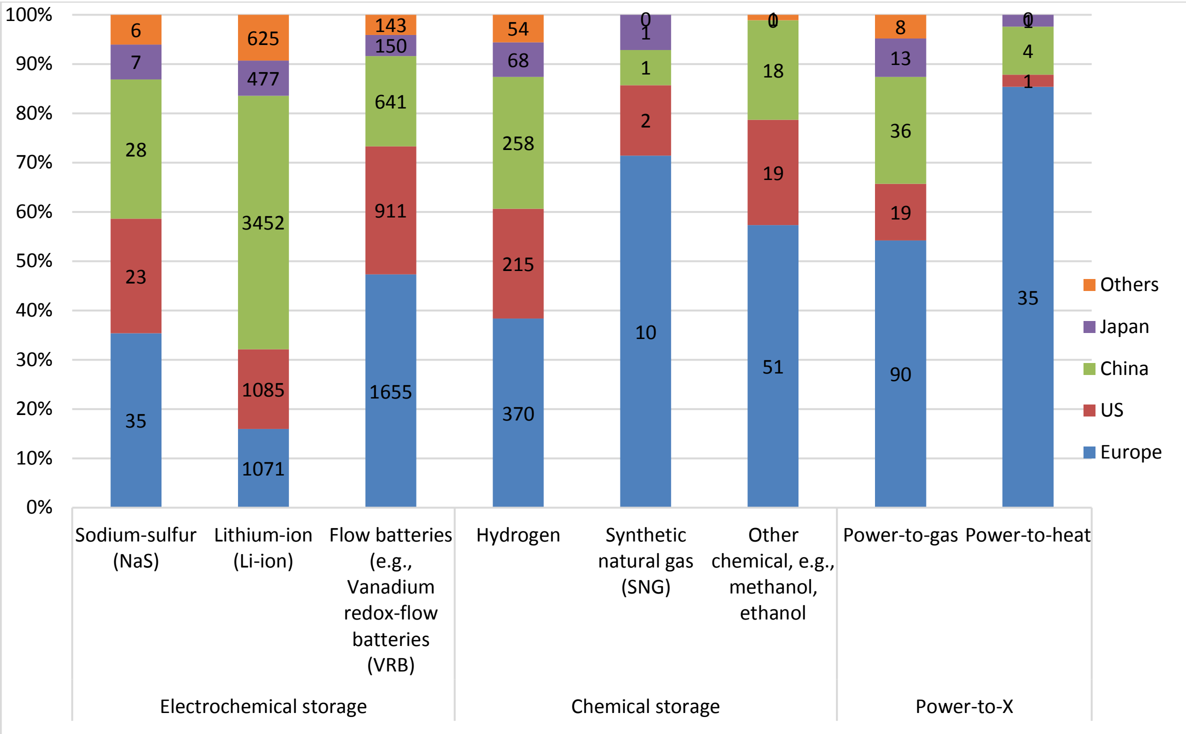


Figure III-VI: Number and ratio of publications by country and category of technologies

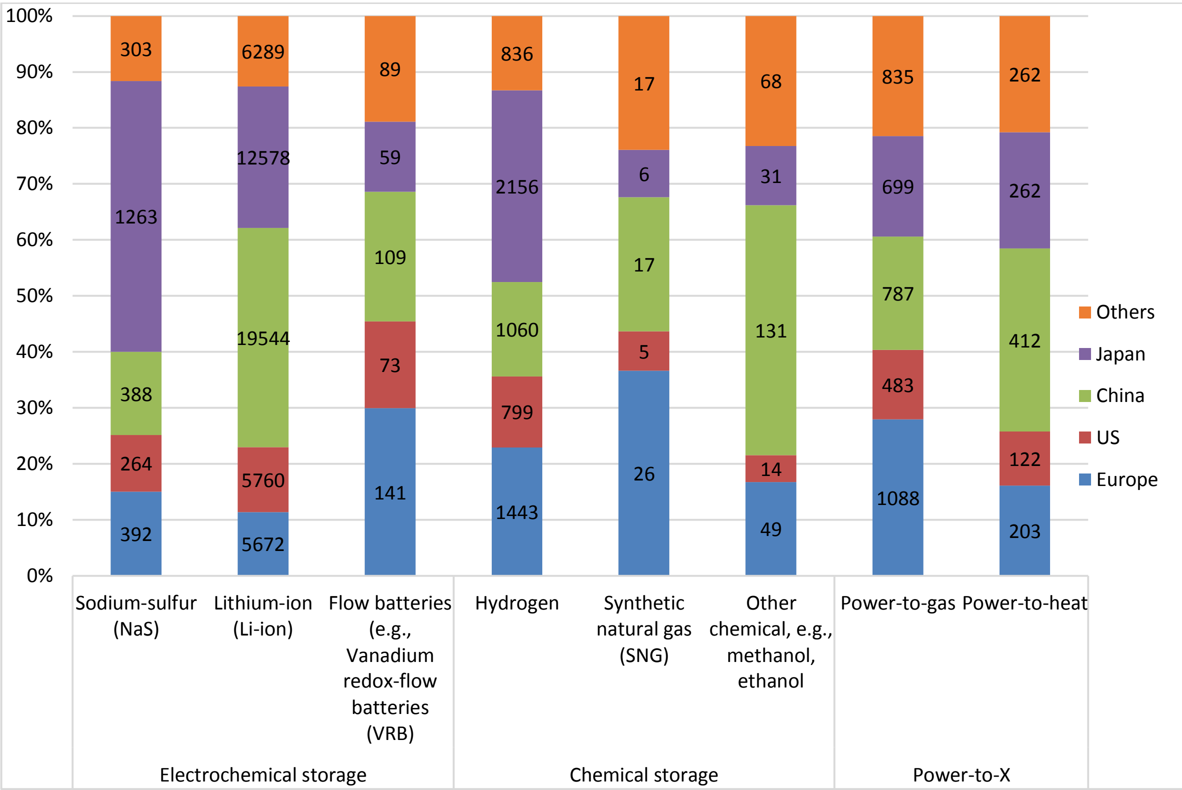


Figure III-VII: Number and ratio of patents by country and category of technologies

By considering Europe as a single actor (aggregation of Member States), it is easy to see that EU makes a significant effort in academic publishing on almost all the technologies/measures. **Strong results are recorded in fields of research like the *chemical storage* and the *power-to-x***, for which the shares for European academic institutions are always well above 30% of the total. The picture is different when looking at the *electrical / electrochemical storage* technologies which are important themes of research for Chinese, Japanese and American institutions. EU still has a non-negligible share but other countries are clearly leaders in these areas.

Looking at the "large-scale storage", an alternative (complementary) search has been performed with the aim to cover the whole storage-related set of technologies. The analysed categories of technologies are reported below.

Large-scale storage	Compressed-air
	Large-scale batteries
	Hydrogen
	Thermal

The ratios of publications (Figure III-VIII) on large-scale storage makes evident that **European academic groups are highly active in research on different types of technologies**. Only Chinese institutions have similar numbers of publications for large-scale batteries and thermal storage.

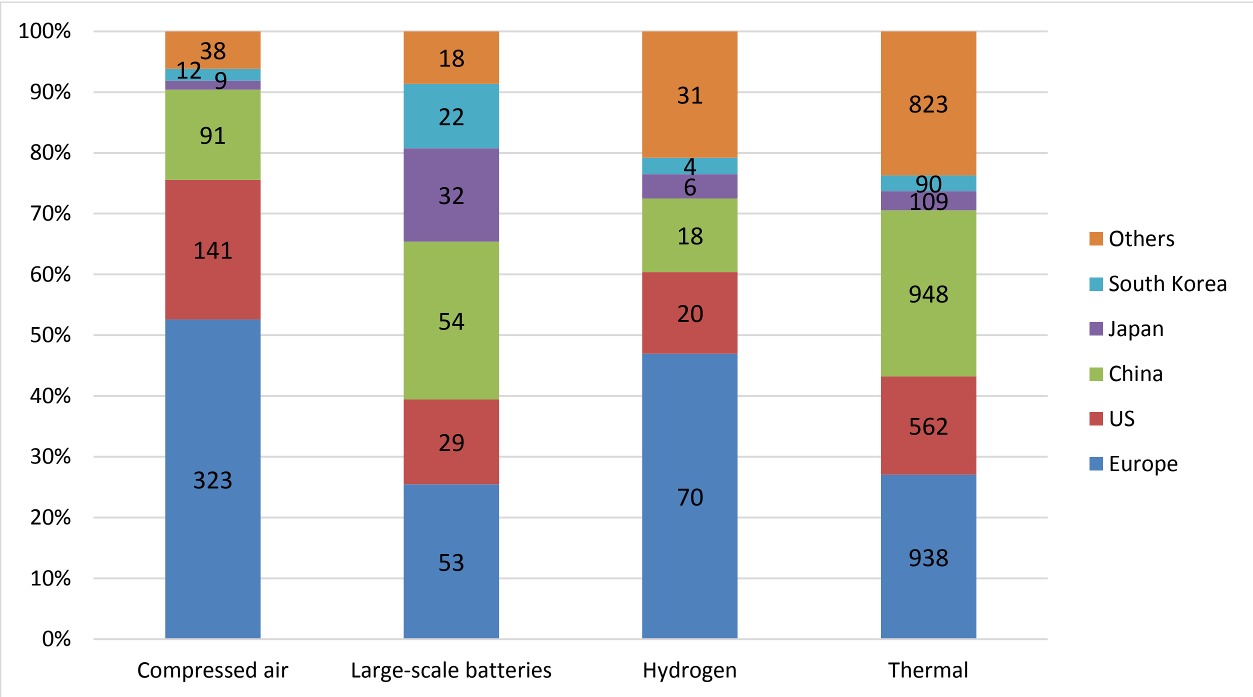


Figure III-VIII: Number and ratio of publications by country and category of technologies

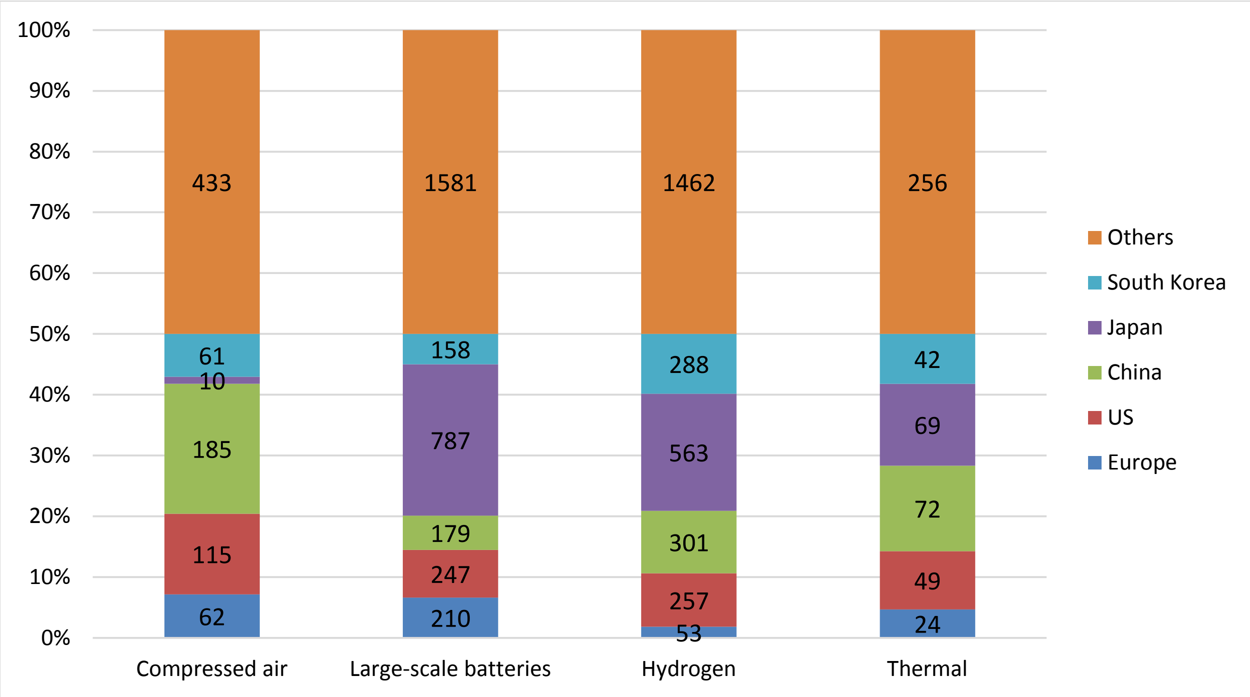


Figure III-IX: Number and ratio of patents by country and category of technologies

In the large-scale energy storage field, it is Japan who comes first in the ranking by number of patents (Figure III-IX**) for large-scale batteries and hydrogen,** due to the activity of its two leading companies: Panasonic and Hitachi the pioneer of lithium ion batteries for automobile use. China published the most patents about compressed air, while US contributes in all technologies with high numbers of exclusive rights (18% of total number of patents on average).

III.B.2. **Volume and Ratio of Import and Export**

The volume of export and import aims to show the sizes of the market (present sales and values of the exported/imported products), the level of market competitiveness (export-import ratio), and can also be interpreted as a self-sufficiency-like indicator in terms of local knowledge and actual production of the technologies demanded by the domestic market.

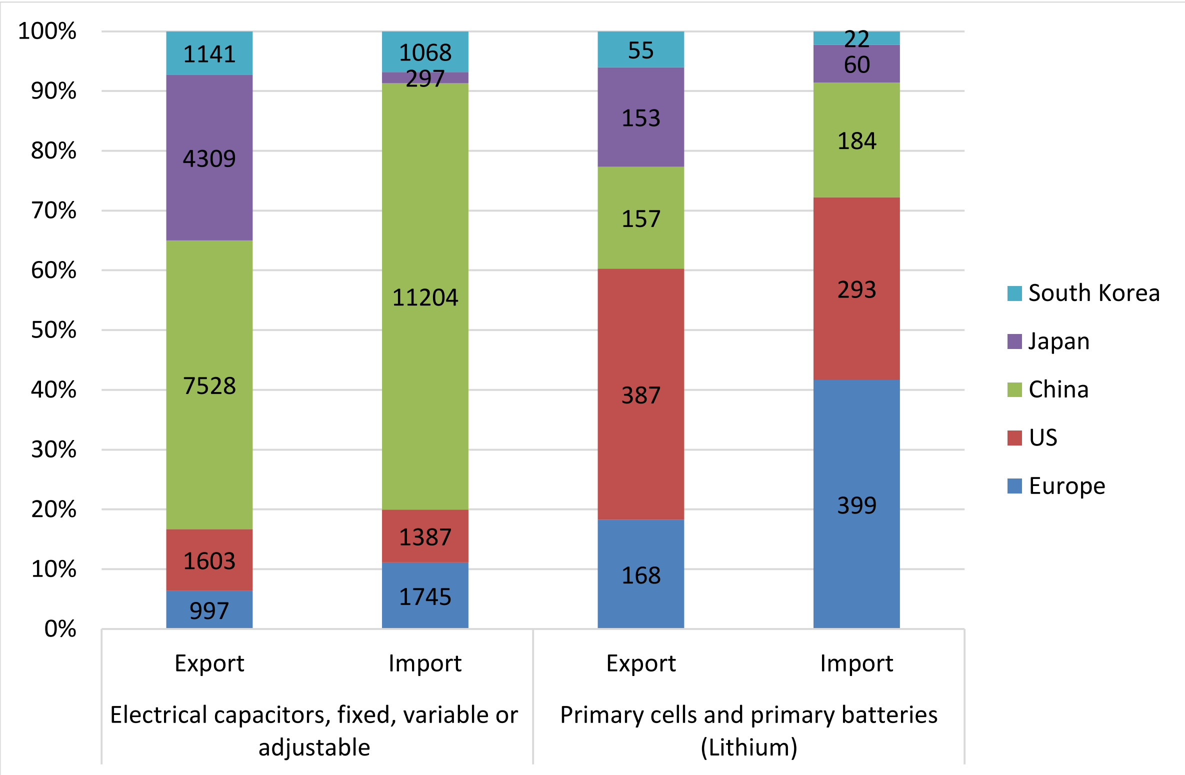


Figure III-X: Volume and ratio of import and export (Mio. US$) by country and selected technologies

Our data collection shows that **Europe has a net deficit** (value of exports lower than imports) across both groups of technologies, **in particular for cells and batteries (lithium)** for which the economic value of the import is much higher than the value of the export. The market share of European industrial companies (export from EU) in the sector of cells and batteries is of a similar size to the Chinese and Japanese firms, but the value of the volume imported is much higher than in any other region.

As concerns the electric capacitors, import-export volumes (economic value) from/to EU are of a similar size to the US and Korea. Japan is the only country with an evident net surplus. Large-scale energy storage import and export data are not represented due to lack of data.

III.B.3. **Conclusion on the Strengths and Weaknesses of the EU**

The following table gives an overview of the geographical allocation of strengths and weaknesses regarding patents (•), publications (◦) and export values (⋄).

Table III-II: Strengths and Weaknesses by country and category of measures listed in Theme 7

Category		Europe	USA	China	Japan	Others
Mechanical storage	Pumped hydro storage	●● ○○○○	●● ○○	●● ○	● ○	●● ○○
	Compressed air energy storage	●● ○○	●● ○○	●●● ○	● ○	●● ○○
	Flywheel Energy Storage	●● ○○	●● ○	●●● ○○	● ○	●● ○○○
Heat storage	Water	●● ○○	● ○	●● ○○	●●● ○	●● ○○○○
	Molten-salt energy storage	●● ○○	●● ○○	●●● ○○	● ○	●● ○
	Phase change material storage	●● ○○○	● ○	●●● ○○	● ○	●● ○
Electrical storage	Supercapacitors	●● ○○	●● ○○	●●● ○○○	●● ○	●● ○
	Superconduction magnetic energy storage	●● ○○	●● ○	●● ○○	●● ○○○	●● ○○
Electrochemical storage	Sodium-sulfur	● ○○	● ○○	●● ○○	●●● ○	●● ○○
	Lithium-ion	● ○	● ○	●●● ○○○	●● ○	●● ○
	Flow batteries	●● ○○	●● ○○	●● ○○	● ○	●● ○○
Chemical storage	Hydrogen	●● ○○	● ○○	●● ○○	●●● ○	●● ○○
	Synthetic natural gas	●●● ○○○○	● ○○	●● ○	● ○	●● ○
	Other chemical	●● ○○	● ○○	●●● ○○	● ○	●● ○○
Power-to-X	Power-to-gas	●● ○○○	●● ○	●● ○○	●● ○	●● ○○
	Power-to-heat	●● ○○○○	●● ○	●●● ○	●● ○	●● ○

The energy storage and conversion of electricity to other energy carriers sector is very R&D-intensive, in particular for many OECD Countries. **In the case of the EU for example, the high number of publications** (in the mechanical, heat and chemical storage, as well as in the power to-x technologies) **does not correspond to an equivalent number of patents, neither to a high volume of export. The Asian Pacific area dominates in terms of industrial innovation** (long tradition in research and development of batteries for different uses) as well as in terms of actual production for the electrical and electrochemical technologies (Japan has a net surplus of import/export trades in 2013).

It is worth noting that Japan spends on average much more than EU (almost two times) in R&D on electrical and electrochemical technologies (high level of innovation), that the number of patents is almost the double (same "intensity"), but that the export volumes (capacitors) is four times higher than the EU, highlighting the competitiveness of the industrial chain of capacitors in Japan (R&D-production-commercialization) looks much higher than in any other country.

III.C. Theme 8 - Providing the energy system with flexibility, security and cost-effectiveness

The accommodation of more variable energy supply from renewable sources, including from remote sites with respect to consumption centres will require a strong increase in the flexibility of the energy system. Providing this in a secure and economic way will need to be ensured by contributions from a range of sources in the energy system as described in the SET Plan, such as flexible generation, cross-energy vector coordination as well as demand response programmes. Electronic and electrical components (smart substations or technologies for automation of substations, switching schemes power components used in power supply and in power distribution networks that disseminate intelligence and grid controllability), ICT systems (applications and services enabled by ICT systems and that have a link with the final user and/or with the utility), as well as programs and activities designed to encourage consumers to change their electricity usage patterns (including timing and level of electricity demand) have been taken into consideration for a comprehensive comparative analysis across the key countries aiming at "measuring" the innovation level of the EU on the flexibility and security of the energy system.

Low levels of expenditure in research and technical development are often considered a barrier to innovation, and R&D intensities are metrics for measuring the "efficiency" of such innovation effort. Unfortunately, the available data are incomplete[23] (e.g. data is missing in several years, China is not part of the database, etc.) and do not allow a comprehensive benchmark assessment across the key regions of the world, neither a consistent calculation of "innovation-intensity"-like indicators (e.g. R&D expenditure over the period 2010-2015 over the number of patents in the same period).

However, the "qualitative" findings suggest that **EU invests significantly in R&D, more than US and Japan, for both hardware** (cables, conductors, convertors, etc.) **as well as for the software** (e.g., control systems, monitoring and integration tools, grid security software and mechanisms).

Analysed categories of technologies and measures

Transmission & Distribution	Semiconductor enabled transmission technologies e.g. flexible AC transmission systems and HVDC networks
	Smart substation with decentralised measurement and switching
	Innovative distribution network control and protection
ICT	ICT systems for enhancements of existing distribution assets into smart grids and market models
	Monitoring systems
	Innovative transmission network control and protection

[23] OECD Stat enables users to search for and extract data from across OECD's databases including expenditure in "electricity transmission and distribution technologies" statistics.

Power components	Innovative controllable power components
	Power electronic based power components
	DC Grids with Voltage Source Convertors
Flexibility mechanisms	Optimising electrical systems with support of heat systems
	Large-scale storage
Demand response programmes	Demand side resource available to market participants-2014 (GW)
	Demand side resource available to market participants-forecast 2020 (GW)
	Demand response management system (DRMS) market (expected growth)

III.C.1. Number and Ratio of Publications and Patents

The following figures show the geographical distribution (vertical bars) and actual numbers (data labels) of publications (Figure III-XI) and patents (Figure III-XII), respectively, for the analysed set of technologies across key regions of the world.

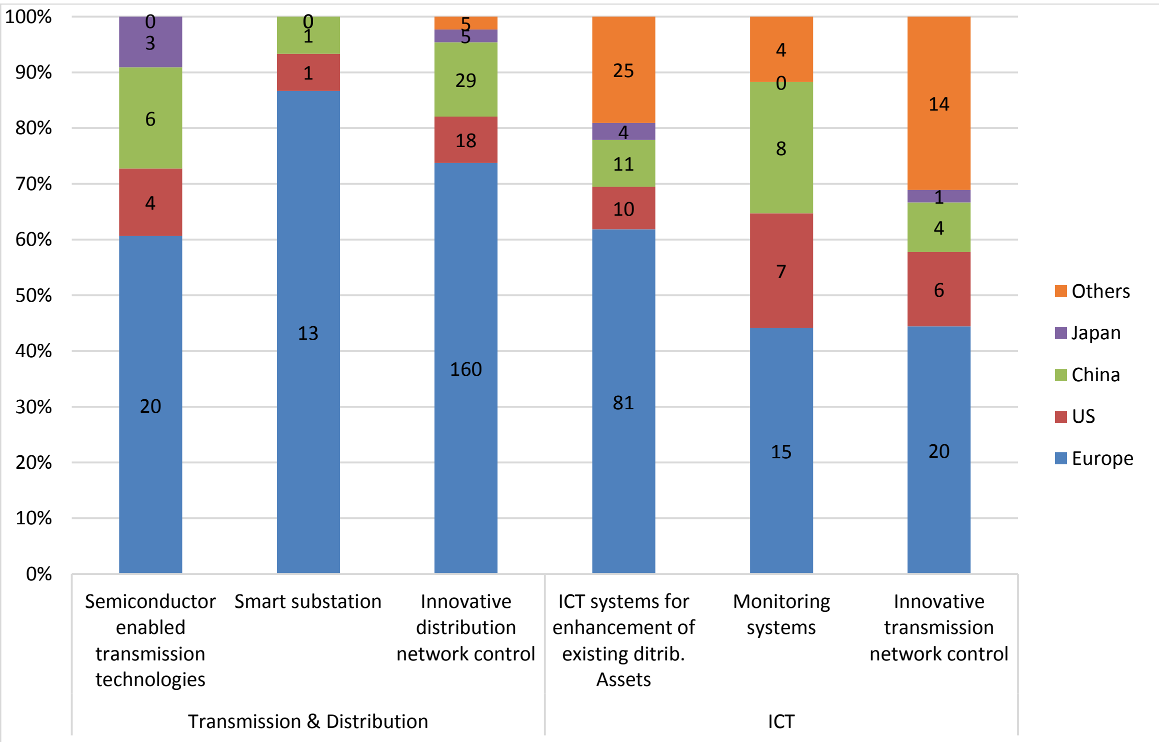


Figure III-XI: Number and ratio of publications for by region for selected technologies

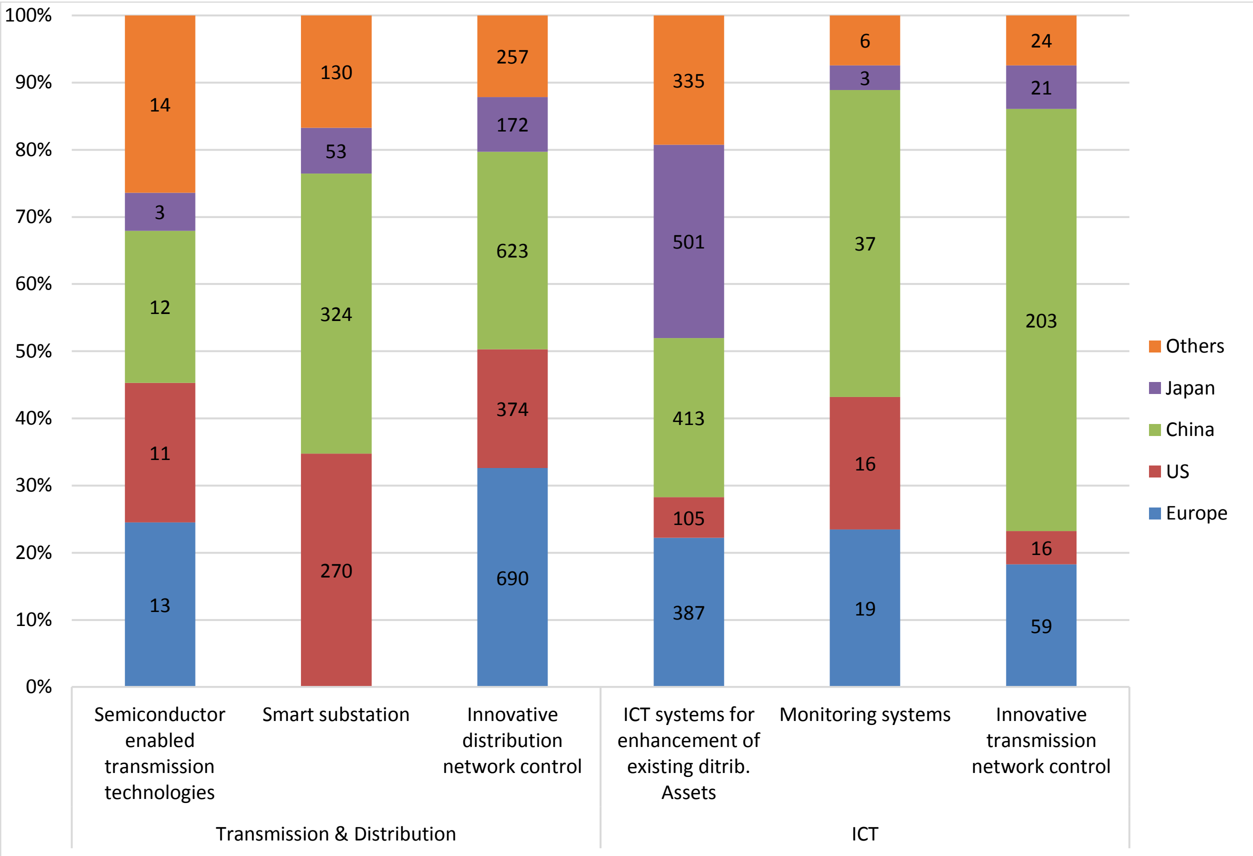


Figure III-XII: Number and ratio of patents by region and topic

The analysis shows that four regions of the world together have a very large share, almost 80% of the total, of the total exclusive rights granted to inventors, in the sector of system flexibility and security. The benchmark of the EU performance is then limited to the comparison with the US, China and Japan. In particular, **China seems to be the leader in invention of solutions for smart and switching components as well as in ICT systems**, while **shares of EU are comparable with those of US and Japan for most of the technologies/measures** included in the category.

In the "transmission & distribution" field, research is widespread across many countries, as not only the usual key players conduct research and submit publications. However, from 20% (semiconductors) to over 50% (distribution network control) of the total scientific studies comes from European academic institutions, with no other country / region coming close, as shown in Figure III-XI. Although the number of tracked publications is lower, the EU share in the fields of research is more oriented to the ICT-based applications and services, where the share is always above 40% of the total. Only in the case of monitoring systems, US and China's shares (around 25% for both) are not far behind from the European values.

However, the picture is totally different for the category of electronic-based power components (Figure III-XIII), where the most recent research activity seem to be much more concentrated in three key regions (Europe, US, China), with a strong presence of Chinese institutions (30%), similar to the EU level (40%). Europe also plays a dominant role (25%-30% of the total publications, as shown in Figure III-XIII) in research on flexible mechanisms (integration and optimisation of all sources and levels of energy, and storage), but China is the dominant player in the industrial-related indicator of innovation (patents, as shown in Figure III-IV).

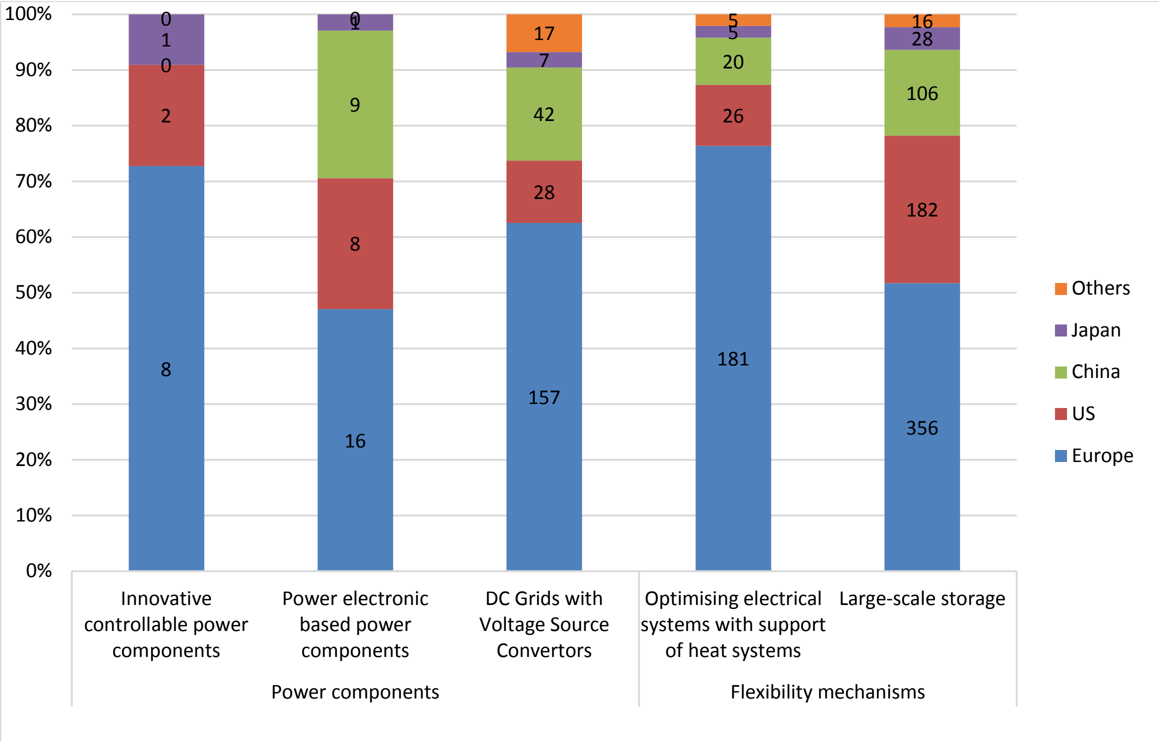


Figure III-XIII: Number and ratio of publications by region and selected technologies

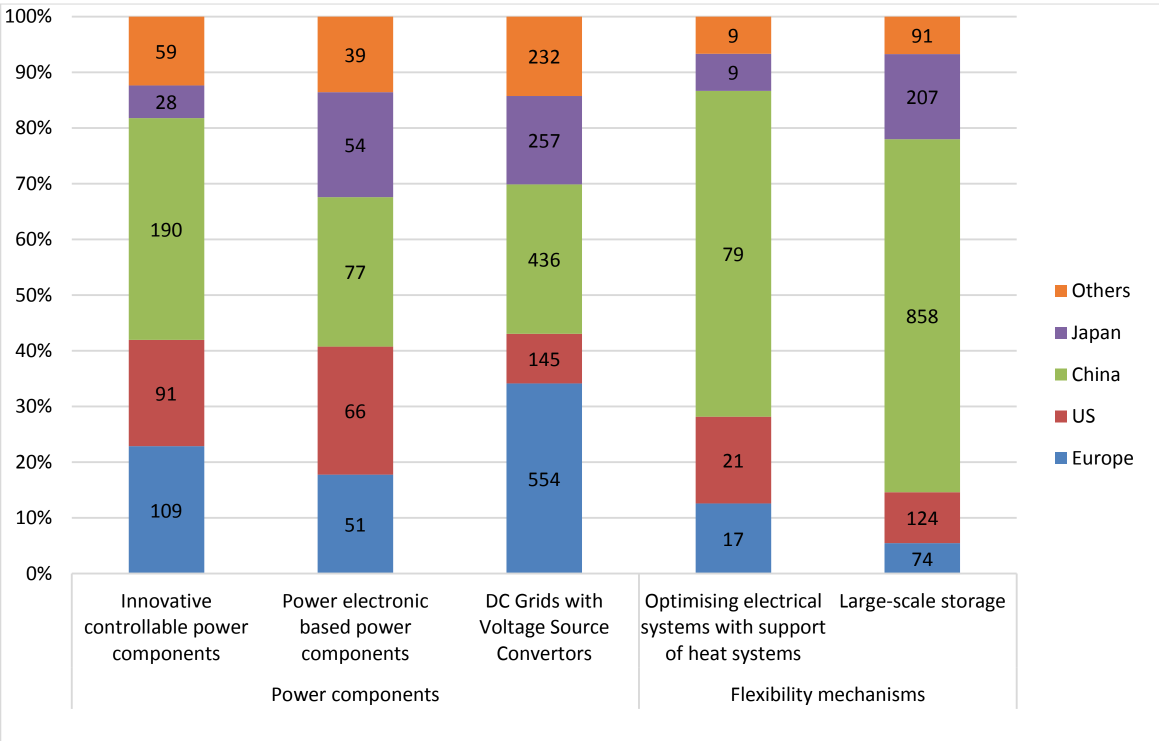


Figure III-XIV: Number and ratio of patents by region and selected technologies

III.C.2. **Volume and Ratio of Import and Export**

The volume of export (positive component of the bar) and import (negative component of the bar) aim to show the size of the market (present sales and values of the exported/imported products), the level of market competitiveness (export-import ratio) and can also be interpreted as a self-sufficiency-like indicator in terms of local knowledge and actual production of the technologies demanded by the domestic market. Products are grouped into four commodity sets[24] as classified in the UN Comtrade Database[25].

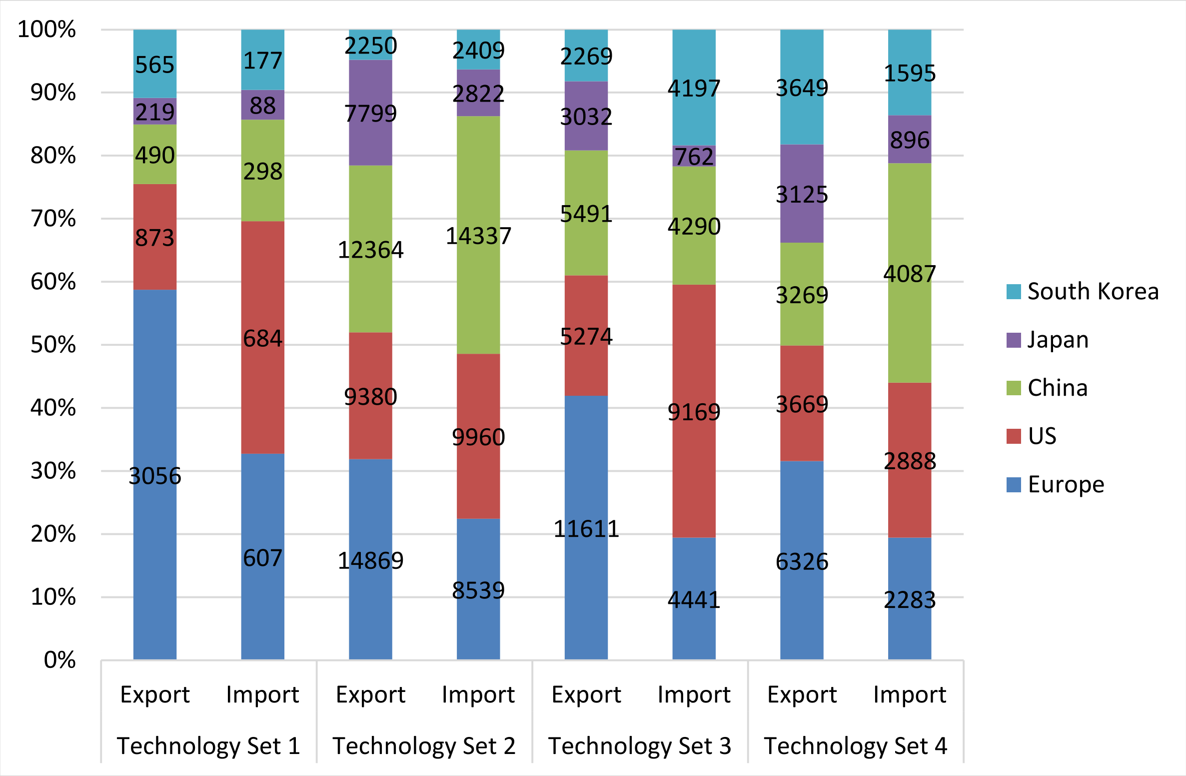


Figure III-XV: Volume of exports and imports (Mio. US$) by country by Technology Set

Our data collection shows that Europe has a net surplus in 2013 (value of the export greater than the value of the import) in all four categories of technologies identified in footnote 15. Market penetration of European players (export) is greater than in any other "key region" both in terms of absolute values as well as in terms of shares.

It is important that EU keeps developing high quality level and innovation in the sector, to maintain such a surplus and gain additional market share (in spite of a huge industrial capacity, fast growing economies like China may still demand products from the market).

[24] TechnologySet-1: Electrical apparatus for switching or protecting electrical circuits, or for making connections to or in electrical circuits for a voltage exceeding 1,000 volts. TechnologySet -2: Electrical apparatus for switching or protecting electrical circuits, or for making connections to or in electrical circuits for a voltage not exceeding 1,000 volts. TechnologySet-3: Boards, panels, consoles, desks, cabinets and other bases for electric control or the distribution of electricity. TechnologySet-4: Parts suitable for use solely or principally with the mentioned electrical apparatus

[25] http://comtrade.un.org/

III.C.3. **Demand response programmes**

Demand response is a component of the energy conservation, with a specific focus of demand-side management (DSM) programs, with the aim of encouraging consumers to use less electricity during peak hours or to shift their energy use to off-peak times. Thus, demand response management systems (DRMS) are tools to manage peak energy loads and lower the difference between demand and supply of energy, and to help the customers to modify their usage patterns of power according to the capacity of supply. The DRMS market can offer "price-based" and "incentive-based" options, which motivates customers to reduce their energy usage during peak hours.

There are a number of drivers that explain the increased demand response adoption in North America first and in other regions of the world subsequently. The changing resource mix in electric grids globally is creating more potential for demand response to play a key role. Conversely, as large-scale intermittent renewable resources like wind and solar power fill in this gap, they require backup solutions.

Three main indicators have been used to track the competitiveness of key regions of the world in the field of demand response programmes: a quantification of the available-to-market participants, a short-term forecast of the same variable, and an economic estimate of existing and future markets.

Currently, almost all of the demand response activity takes place in the US (around 30 GW). This situation is expected to change in the upcoming years, as all world regions continue to develop or convert the pilot phase of demand response into full-scale markets or programmes.
Europe is estimated to have a short-term potential of 15-20 GW of demand side resources based on a combination of opening market opportunities, smart grid roll out, and renewable resource integration for an estimated market value of around US$6 billion.

Table III-III: Competitiveness of demand response programmes by key regions

Region	Demand side resource available to market participants-2014 (GW) [26]	Demand side resource available to market participants-forecast 2020 (GW)	Demand response management system (DRMS) market (expected growth)[27]
EU	<1	15-20	From US$1,355.7 million in 2014 to US$6,376.1 million by 2019, at a CAGR of 36.3%., during the forecast period.
North America	≈30	50-55	From US$4.14 billion in 2014 to US$12.70 billion in 2019 at a CAGR of 25.1% during the forecast period.
Asia-Pacific	<1	20-25	From US$584.3 million in 2014 to US$2440.4 million by 2019, at a CAGR of 33.1% for the period 2014-2019.
Latin America	≈0	<1	From US$416.8 million in 2014 to US$2060.3 million by 2019, at a CAGR of 38.3% during the forecast period.
Middle East and Africa	0	<1	From US$279.9 million in 2014 to US$1417.7 million by 2019, at a CAGR of 38.3% during the forecast period.
Key Country details:			
- USA	29.5	n.a.	From US$3.31 billion in 2014 to US$9.21 billion in 2019 at a CAGR of 22.7% during the period 2013-2019.
- China	n.a.	n.a.	n.a.
- Japan	>0	Potential: 4-5 GW	From US$0.12 billion in 2014 to US$0.49 billion in 2019 at a CAGR of 31.4% during the period 2014-2019.
- Brazil	>0	n.a.	From US$0.10 billion in 2014 to US$0.50 billion in 2019 at a CAGR of 35.8% during the period 2014-2019.

[26] *Executive Summary - Demand Response, Commercial & Industrial DR, Residential DR, and DR Management Systems: Global Market Analysis and Forecasts*, Navigant Research, 2014.
[27] *The Europe Demand Response Management System (DRMS) market report,* MicroMarketMonitor.

III.C.4. **Conclusions on the Strengths and Weaknesses of the EU**

The following table gives an overview of the geographical allocation of strengths and weaknesses regarding patents (•), publications (○) and export values (◇).

Table III-IV: Strengths and Weaknesses by country and category of measures listed in Theme 8

Category		Europe		USA		China		Japan		Others	
Transmission & Distribution	Semiconductor enabled transmission technologies e.g. flexible AC transmission systems and HVDC networks	●● ○○		●● ○		●● ○		●● ○		●● ○○○	
Transmission & Distribution	Smart substation with decentralised measurement and switching	● ○○○		● ○		●●●● ○		● ○		● ○○	
	Innovative distribution network control and protection	●● ○○○		●● ○		●●● ○		● ○		●● ○○	
ICT	ICT systems for enhancements of existing distribution assets into smart grids and market models	● ○○○		● ○		●●● ○		● ○		●● ○○	
	Monitoring systems	● ○○○		● ○○		●●● ○○		● ○○		●● ○	
	Innovative transmission network control and protection	●● ○○○		●● ○○		●● ○		● ○		●● ○○	
Power components	Innovative controllable power components	●● ○○○		●● ○○		●●● ○		● ○		●● ○○○	
	Power electronic based power components	●● ○○○		●● ○○		●● ○○		●● ○		●● ○	
	DC Grids with Voltage Source Convertors	●●● ○○○		● ○		●● ○		●● ○		●● ○○○	
Flexibility mechanisms	Optimising electrical systems with support of heat systems	● ○○○		● ○		●●● ○		● ○		● ○	
	Large-scale storage	● ○○○		● ○○		●●● ○○		●● ○		● ○	

The level of EU innovation in the sector of flexibility and security of the energy system is strongly dependent on the metrics used to evaluate and compare the regions. According to the indicator of publications number, **EU is ranked first in most of the areas of research** (e.g. flexibility mechanisms). On the opposite, **China plays an evidently dominant role in terms of number of patents**. Such a decoupling highlights that **Europe is not able to "translate" the entire effort of academic research in an equivalent number of patents**, while China seems to pay much more attention to industrial-oriented innovation. Nevertheless, competitiveness of the electrical components industrial chain in Europe (R&D-production-commercialisation), reflected by a net trade surplus, is higher than in any other country.

The DRMS market reports[28] provide current market size estimates and future growth potential across world regions. Europe is expected to reduce the gap with US in the adoption of demand response programmes but not to replace US as a leader of the sector in the short term.

[28] Among the leading industrial players cited in the study are some European companies: GE, Siemens, Schneider Electric, EnerNOC, Honeywell.

III.D. **Theme 9 - Development and demonstration of holistic system optimisation at local/urban level (Smart Cities and Communities)**

More than half of the world's population now live in cities and the figure will rise to more than two thirds by 2050, according to United Nations forecasts. In Europe, already three quarter of the population live in urban areas. North and South America are also very urbanized regions, with slightly over 80% of residents on both continents residing in cities. The share in Asia and Africa is lower, about 40%; however, both continents are undergoing an unprecedented migration to cities from the rural areas and the number of city residents in the medium term is expected to be huge.

Already city dwellers are thought to be responsible for up to 70% of the world's greenhouse gas emissions, and urbanisation has relevant environmental consequences even at local level. Growing numbers of city residents put pressure on energy and water resources, waste management, sewer systems, and transport networks, and reduces arable land and green spaces. Therefore, in order to tackle climate change, avoid damage to vital ecosystems, and improve the health and wellbeing of billions of people, solutions to these problems must be faced at the municipal level.

At the same time, environmental sustainability must go together with other important goals such as promoting economic development and improving quality of life. The "green" goals are necessary parts of holistic, city-led strategies for economic, social and environmental sustainability, so that the establishment and implementation of a "comprehensive methodology" for enhancing sustainable planning, by addressing the current and future city energy needs through an integrated and multi-disciplinary/multi-criteria planning approach are expected to play a "key" role in the coming years.

The participation of stakeholders (e.g., citizen groups, market associations, etc.) is also essential in forming an acceptable, realistic and net beneficial action plan. These issues can be effectively addressed through cooperation of city authorities with groups of technical and scientific expertise. Moreover, the outcomes of such collaborations and the best practices of "planning implementation" and "sustainable urban governance", should be disseminated, diffused and exchanged appropriately in a way that will address the pluralism of cities' characteristics, organization and needs.

III.D.1. **Criteria for a benchmarking the innovation**

Assessing the level of innovation in the area of "smart cities" is not trivial. The definition itself of words like "holistic" (on which level of complexity?), "optimisation" (of which variable?) and "smart" (according to which criteria?) is often subjective and approached in different ways by country (and, within the same country, by city or urban area) and by analyst.

The present research aims to collect and highlight some[29] of the most interesting metrics, based on which the performance of EU and other "key world players" may be measured and compared.

Due to the non-unique nature of the criteria, such a data collection and benchmark are *literature-based*. A robust "assessment framework or metric" has to provide a shared understanding of smart city concepts, thus ensuring that data are analysed in a consistent manner, but only few analyses have been conducted to identify common metrics for (country)-list-wise or (country)-pair-wise

[29] List is far from being exhaustive.

comparisons around the world. Driven by the requirement of consistency across the countries, some reports, studies and databases have been navigated and analysed, and a comparative assessment of key indicators across the countries has been undertaken.

This paragraph aims to present and describe the metrics used for such a comparative assessment.

Number of smart green city projects ongoing or completed

This is a quantitative-oriented indicator which keeps track of different initiatives and implementation practices around the world. The conceptual framework used to identify the cities was based on a "total approach" to the smart city concept, built on six different domains which have to be present and considered in the local plans (Governance, Infrastructure integration, Intelligence & Sustainability, Urban Innovativeness, Collaborative Partnerships, Service Innovation, Urban Openness). By analysing data provided by several companies (e.g. IBM Corporation, Cisco System, ABI Research e Gartner, etc.), the number of "comprehensive strategies" at municipal level, undertaken in the world, has then been estimated.

Green city indicators

A set of quantitative-oriented metrics touching on a wide range of indicators, from environmental governance and water, consumption to waste management and greenhouse gas emissions. Although data used for each regional "Green City Index" are difficult to compare to other regions (due to differences in the way statistics are collected), a number of indicators are computed where the data allow. A summary of indicators that are comparable across at least two regions provides an alternative framework to benchmark the EU against other areas of the world.

Monitoring capability of urban spatial indicators

How the physical form of a city changes over time and how different cities compare to each other in terms of "morphology" and capability to track spatial indicators, are getting higher attention due to the evident interdependency between the "urban form" and the different domains of the "smart city" concept (e.g. infrastructures, land use, transport, etc.). The availability of such data on international databases and the specific values of key indicators (the Sprawl index[30] for example) help in understanding which country is moving towards a transparent and consistent spatial-related data collection, and towards better scores for such criteria.

Pilot cities comparison

On the basis of the same assessment framework, the smart cities characteristics of 15 cities in EU and 15 cities in China are analysed and compared. The assessment framework (metric) incorporates the findings from several papers that have proposed Smart City frameworks, and it comprises of nine characteristics: (1) Smart City Strategy; (2) Stakeholders; (3) Governance; (4) Funding; (5) Value Assessment; (6) Business Models; (7) ICT Infrastructure; (8) Smart City Services and (9) Legal and Regulatory policies, which are all measured on a "qualitative" scale, based on the level of maturity (*not yet addressed*, *basic*, *average*, *more advanced*, *state of the art*, *not assessed*).

[30]The SI index is equal to zero when both population and built-up area are stable over time. It is bigger (lower) than zero when the growth of built-up area is greater (smaller) than the growth of population, i.e. the city density has decreased (increased)

Global Cities Registry™ for ISO 37120

Standardized indicators enable cities to assess their performance, measure progress over time, and also to draw comparative lessons from other cities locally and globally. Based on the first international standard on city data — ISO 37120 —, the WCCD Open City Data Portal allows to explore, track, monitor, and compare member cities on up to 100 service performance and quality-of-life indicators. The standard includes a comprehensive set of 100 indicators — of which 46 are core — that measures a city's social, economic, and environmental performance. It was developed using the framework of the "Global City Indicators Facility", extensively tested by more than 250 cities worldwide.

Cities can obtain different levels of certification based on a number of (semi-quantitative) indicators reported and verified according to ISO 37120; WCCD Certification levels (aspirational, bronze, silver, gold, platinum) reported per each urban area.

Categorized in 17 themes and 100 indicators for city services and quality of life, the ISO 37120 certification guides cities towards a smart and sustainable future on the basis of independently verified and globally comparable city data. WCCD certification also ensures data reliability with third party verification.

III.D.2. **Key results of the comparative assessment**

There are a lot of definitions of "smart cities" and "green cities" but one interpretation is to consider a "Smart Green City" in terms of the benefits that it will offer, both environmentally and socially, in the long term. 143 smart green city projects, based on a holistic approach, were ongoing or completed in 2012, 47 of which in Europe, 40 in Asia, 35 in North America, 11 in South America and 10 in Africa & Middle East. Such quantification is strongly dependent on the criteria used to classify the "smart city" projects. Alternative (EU-specific) sources report that more than 230 out of 468 cities with more than 100,000 inhabitants have undertaken a path towards the development of a smart city programme. This specific statistic cannot be used to compare the EU against other countries due to the heterogeneity of the approaches, but together with the previous metric provides an evident proof of the high interest about the "smart city" issue in the EU.

A metric purely based on the number of projects is relatively simplistic and does not give a precise picture of what are the efforts towards, and the development of, the interpretation of such holistic view for a smart city across the world key players.

By looking at the "environmental" criteria more in depth, the following metrics were used to measure the performance of 130 cities in different areas of the world. Data for China were not available or comparable. The table below summarises the numerical data followed by a summary of the key highlights.

Table III-V: Key results of the comparative assessment for theme 9

Criteria	EU	North America	Latin America	Africa	Asia-Pacific
Number of cities[31] studied by region:	30	27	17	15	22
- Green spaces (m^2/pers.)	-	-	255	74	39
- CO_2 emissions (CO_2 emissions per person (in metric tons))	5.2	14.5	-	-	4.6
- Energy intensity (MJ/US$)	1.5	-	-	-	1
- Water system leakage (leakage rate %)	23%	13%	35%	30%	22%
- Water consumption (L/pers./day)	288	588	264	187	278
- Waste production (kg/capita)	511		465	408	375
- Recycling rates (share of waste recycled in %)	18%	26%	-	-	-
- Modal split (Share of workers travelling by car vs. by public transport/bicycle/foot in %)	37% vs. 63%	87% vs. 13%	-	-	-
- Sulfur dioxide (Annual daily mean of SO_2 concentrations in µg/m^3)	7	-	15	-	23
- Particulate matter (Annual daily mean of PM10 concentrations in µg/m^3)	35	-	48	-	108
- Nitrogen dioxide (Annual daily mean of NO_2 concentrations in µg/m^3)	35	-	38	-	47

Highlights include:

- Latin American Index cities lead Asian and African cities for the amount of parks, open spaces and other green areas.
- Asian Index cities are by far the densest among the regions studied; US & Canada cities trail the rest.
- The US & Canada Index cities have higher per capita CO_2 emissions than Europe and Asia combined.
- Europe compares favourably with Asia for energy consumption per unit of GDP.
- Latin American Index cities lose the most water across the key regions of the world. US & Canada cities perform best on this metric.
- The US & Canada Index cities consume by far the most water among the five regions.
- European Index cities produce the most waste per capita, followed closely by Latin American and African cities.
- On average, US & Canada Index cities outperform European Index cities when it comes to recycling.
- Far more US & Canada Index city residents travel to work by car than in European Index cities.

[31] Capitals and/or major cities.

- Asian Index cities have higher sulphur dioxide concentration levels than European and Latin American Index cities combined.
- Particulate matter pollution in Asian Index cities far outstrips levels in Latin American and European Index cities.
- Asian Index cities have high levels of nitrogen dioxide, but there is a smaller gap between Europe and Latin American Index cities.

Regarding the spatial related data, EU and USA have the highest number of cities in the OECD Statistical Portal database (respectively 114 and 70). For all those cities the "sprawl index" is reported, while such a spatial related indicator is unknown or not available for other countries (Japan, Canada, etc.). The average values (+0.3 for EU, -0.69 for USA) suggest that in the period of analysis the indicator of population density in the EU urban areas has decreased while it has increased in USA, and at the same time that the construction growth rate in Europe has been greater than the population growth rate. Data highlight a trade-off, the "optimal" or "smart" value of the indicator is a city-specific matter. The assessment of the maturity level of pilot smart cities in Europe and China says that the level of EU innovation compared to another key country (China) is strongly dependent on the criterion selected.

Table III-VI: Assessment of the maturity level of pilot smart cities in EU and China

Criteria	Region	Not yet addressed	Basic	Average	More Advanced	State of the Art	Not assessed
Smart city strategy	EU			29%	70%	1%	
	CHINA		7%	27%	67%		
Stakeholders	EU		10%	10%	70%	10%	
	CHINA				60%	40%	
Governance	EU			20%	40%	20%	20%
	CHINA			7%	93%		
Funding	EU		10%	60%	20%		10%
	CHINA			87%	13%		
Value assessment	EU	10%		10%	40%		40%
	CHINA		7%	53%	27%		13%
Business model	EU			20%	40%		40%
	CHINA			20%	47%		33%
ICT infrastructure	EU			10%	80%		10%
	CHINA		7%	13%	80%		
Smart city services	EU				80%	10%	10%
	CHINA		13%	87%			

As concerns the "smart city strategies", in both the countries around 70% of the selected cities have a clear definition of the smart cities KPIs that are used to measure the city's performance in meeting the smart city objectives. In China, "stakeholders" play a more important role in the smart city context than in Europe; according to the comparative assessment around 40% of the pilot cities uses multiple forms of interactive technologies to engage with citizens, makes significant efforts to promote smart city developments to stakeholders, and provides training to help citizens to adopt new services. In the EU the stakeholder's role is clearly defined in 80% of the pilot cities but the citizen engagement is still limited (less developed).

Concerning the Governance criterion, two main data seem relevant. Around 20% of the selected European cities allow stakeholders to participate in decision making and are able to ensure transparency and accountability of the various stakeholders. At the same time for another 20% was not even possible to assess the indicator. More than 90% of Chinese pilot cities have city-specific governance structures with shared performance targets on the "smart city" issue, across departments.

The funding criterion highlights that both European as well as Chinese cities have to face funding issues, and that at the moment is not possible to meet all smart city objectives.

In the EU, around 40% of the pilot cities have established a smart city evaluation framework, which includes some non-financial factors (e.g., social, environmental); in China only 27% of the selected cities have similar characteristics.

In terms of development of business models as well as in terms of ICT potential exploitation, the performance of the countries is similar. Around 40% - 50% are exploring a variety of different business models for pilot projects (some proven and others in the experimental stage); around 80% have targeted ICT project investments, some of which are shared across smart city projects.

It is in terms of smart city services (education, health, logistics, transportation, waste management, open data etc.) that the performance of the EU cities appears to be very different from the Chinese one. 80% of the cities have a wide range of smart city services meeting the needs of a cross section of stakeholders, and an additional 10% have in place services which represent "Best Practice" and /or services which are delivered through open data and crowdsourcing initiatives. In the Chinese cities most of the services may still be pilot projects.

Environmental/energy and transport applications are the most popular services implemented by the pilot smart cities. This is not surprising given that environment and transportation are the most frequently identified challenge areas for the pilot smart cities and that both the EU and China policy direction is focused in these two areas.

Based on the limited public available information from the WCCD Global Cities Registry, the EU seems to have the largest number of "platinum" certification level (cities with the highest scores). The same number of cities is certified in USA, while the interest in an internationally recognized standard seems to be delayed in China, only one city of which is reported to be at the "aspirational" level.

III.D.3. **Conclusions**

In its effort to tackle climate change, the European Commission has acknowledged the significance of local and regional communities for the deployment of innovative low carbon technologies and their potential for sustainable energy production and use. In this respect, a number of initiatives and programmes (e.g. Covenant of Mayors, CONCERTO[32], CIVITAS[33], etc.) have been set up in order to engage European cities in the effort towards a low carbon future and an improved quality of life through sustainable economic development. Furthermore several EU projects have been financed in the area (e.g., INSIGHT[34]; InSmart[35]).

These initiatives have been generally successful and have resulted in the commitment of an increasing number of European cities towards sustainable development goals.

EU-related data appear in most or all the studies-databases analysed. Even in terms of transparency/willingness to self-measure and benchmark, **it is quite evident that EU is the world leader with the highest interest in the field of "smart city".** Most of the selected indicators reflect EU commitments on efficiency, reduction of emission, participatory and integrated approach in decision making.

Due to city-by-city differences, a universal approach cannot be applied to measure and compare the urban areas in terms of level of maturity of the "smart city" concept. Results of the present report depend on - by default - the choice of cities and the "average" operator, which is sometimes required to obtain "national-specific" data, starting from local-specific values.

In spite of the above mentioned limits, analysis can confirm the qualitative "impression" of the stakeholders about the "moderately advanced" level of development of the concept.

In the coming years, the adoption of open standards will be important as the basis for technology/measures choices underpinning a "smart" and "holistic" development, and will allow a more accurate evaluation of the actual performances across the cities.

---

[32] http://concerto.eu/
[33] http://www.civitas.eu/
[34] http://www.insight-fp7.eu/
[35] http://www.insmartenergy.com/

IV. INTEGRATED CHALLENGE 4: SECURE, COST-EFFECTIVE, CLEAN AND COMPETITIVE SUPPLY

The importance of a diverse energy supply is one of the key elements in the future development of the EU energy sector. The energy supply must be clean and, therefore, all solutions that will help energy supply diversity must have low carbon footprint. One of the key goals of the EU Energy Roadmap 2050 is decarbonisation of electricity production, transport, heating, and cooling.

Integrated challenge 4 addresses secure, cost-effective, clean and competitive energy supply through four themes. Theme 10 addresses the development of renewable electricity, heating, and cooling technologies, taking into account possible renewable energy options. Theme 11 addresses efficient CO_2 capture technologies, conversion of CO_2 into useful products, and improvements in fossil fuelled power plants. Theme 12 looks into safe, efficient, and innovative nuclear energy solutions, and theme 13 addresses the transport sector, investigating sustainable biofuels, fuel cells, hydrogen, and alternative fuel mixes for transport.

Summary of the situation regarding secure, cost-effective, clean and competitive supply

Overall, looking at the results provided for themes 10-13, there is a clear leader emerging from each category analysed. The **EU,** in particular, holds **strong positions concerning the number of publications** within almost all categories. **However, in terms of patent filing, the EU holds an average to weak or even very weak position** across all analysed categories of low-carbon supply. This is to be expected, as **the EU is very weak in terms of research and development expenditure across all themes except renewables**. As such, European industries should try to strengthen their market position in other areas to match that of its technologies for renewable electricity and heating/cooling.

The EU's main competitors are China, in terms of patents, and the USA, in terms of research and development expenditure. Both China and the USA have very dominant positions in their respective categories. It may seem surprising that the USA is leading in R&D expenditure whilst being significantly behind China in patent filings. But this is due to a lack of available data on R&D expenditure of China, which could have clarified whether its number of patents corresponds with its R&D expenditure.

It should be mentioned that publicly available R&D expenditure data was scarce and hence any conclusions based on this indicator must be made with caution.

IV.A. **Theme 10: Accelerating the development of renewable electricity and heating/cooling technologies**

Theme 10 investigates renewable energy sources for electricity productions and heating/cooling systems. Renewable energy sources are one of the key elements for a sustainable and diverse energy supply. Therefore, this theme will investigate present and future technologies related to wind, solar, ocean, geothermal and hydropower energy as well as biofuels used in combined heat and power production.

*Data on R&D expenditure from OECD I Library not available for China
** Data in UN Comtrade database overlap with other themes due to wide definitions of commodity codes

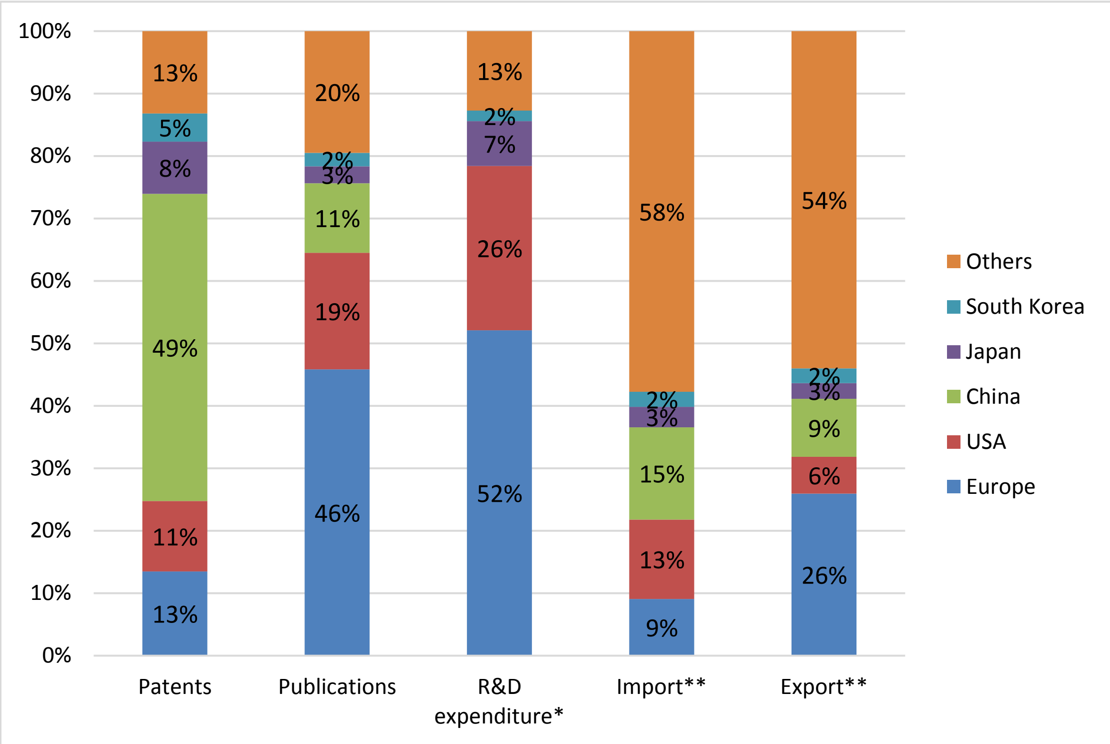


Figure IV-I Overall representation of the relative results for Theme 10

Analysed categories of technologies and measures

Wind Energy	Advanced turbines and components
	Accurate methodologies for wind resource assessment
	Offshore components and technologies
	Logistics, assemble and decommissioning process
	Grid integration and spatial planning for innovations
Photovoltaic Energy	Novel low cost and/or high efficiency PV technologies
	New pilot production lines
Concentrating Solar Power	Innovative receivers and heat transfer fluids
	Component development, hybrid concepts
Solar Heating and Cooling	Smart controllers and simplified storage for solar compact hybrid systems
	Solar compact hybrid systems for solar active houses
Ocean Energy	Site characterisation
	Ocean energy components
Geothermal Energy	Enhanced Geothermal systems
	Geothermal heating and cooling
Hydropower	Sustainable pumped storage
	Variable speed pump turbines and high-heat pump turbines
Combined Heat and Power from Biomass	Sustainable bio-liquids
	High-efficiency biomass conversion system

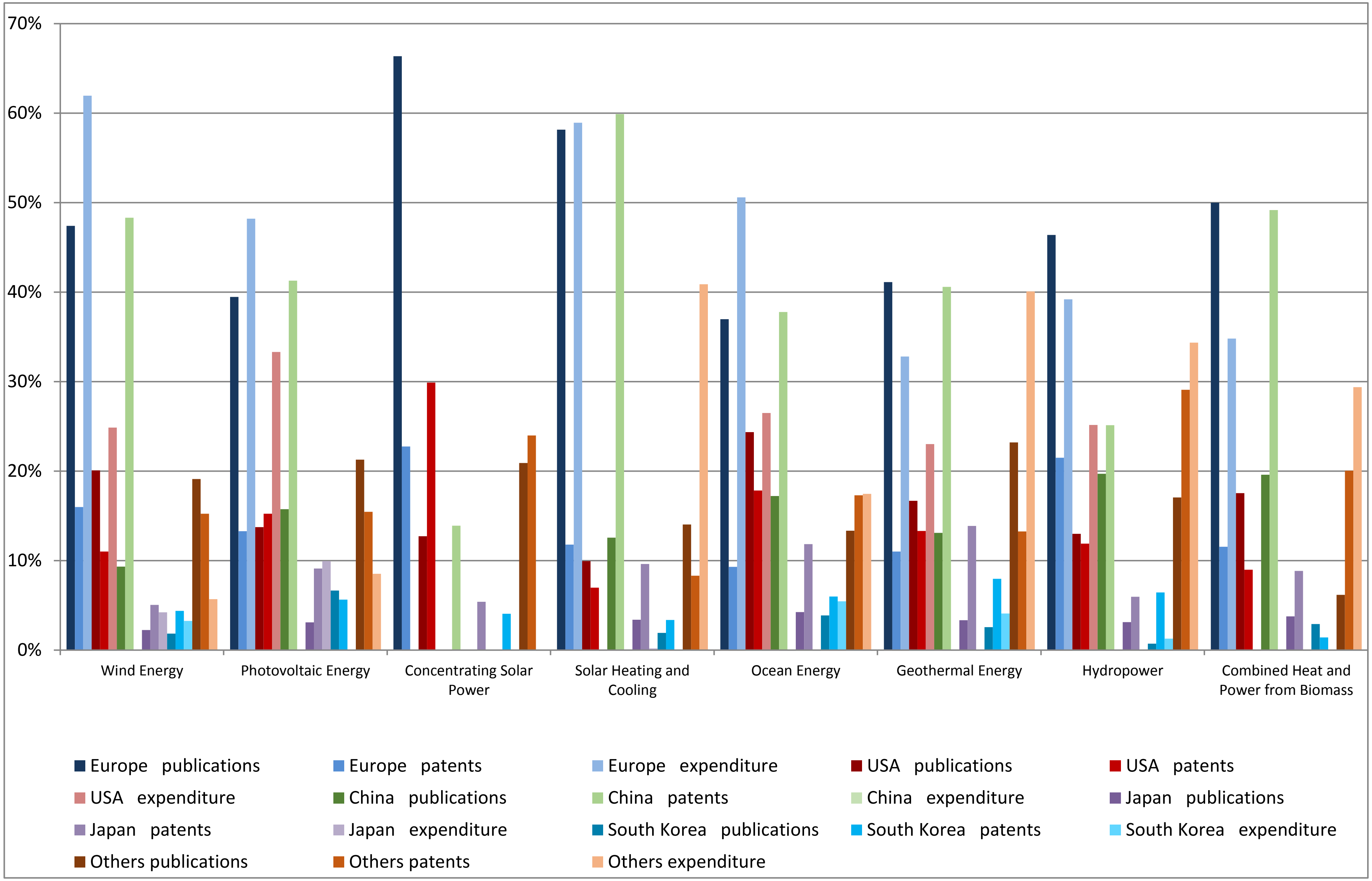


Figure IV-II: Total ratio of patents, publications and R&D expenditure (in Mio. €) by country and solution for Theme 10

Looking into the category of wind energy, it can be noticed that China is a leader in number of patents, primarily due to a large number of patents in *Logistics, assemble and decommissioning process, accurate methodologies for wind resource assessment,* and *grid integration & spatial planning*. This can be explained by the fact that locations with good wind resources have been well known in China for some time now, while market and resource exploration is still opening. **Europe is a leader in advanced turbines and components category.** This is expected due to the long history of wind energy technologies development in Europe. As far as the number of publications related to wind energy is concerned, Europe and USA are dominant.

In the field of ***Photovoltaic energy,* the number of patents is dominated by China** due to a large number of patent filings in *Novel low cost and/or high efficiency PV technologies*, demonstrated by constant lowering of PV costs by Chinese suppliers. **Number of publications on *Photovoltaic energy* is, however, dominated by Europe. For *Concentrating Solar Power,* the number of patents is dominated by USA followed by Europe.** As far as number of publications is concerned, Europe is once again the leader, followed by the USA, showing that these two regions are the main players for this technology. In the field of *Solar Heating and Cooling,* the number of patents is dominated by China, but the number of publications is again dominated by Europe, followed by China and USA.

For ***Ocean energy,* the number of patents is dominated by China, followed by Europe and USA**. Again number of publications makes Europe a leader followed by USA and China.

In *Geothermal energy*, the number of patents is dominated by China mainly related to *Geothermal heating and cooling*, followed by Europe and USA. Number of publications is dominated by Europe followed by USA and China.

Number of patents in *Hydropower* is dominated by China, followed by USA and Europe. Number of publications is dominated by Europe.

In the field of *Combined Heat from Power from Biomass,* the number of patents is dominated by China, but again Europe holds highest number of publications.

As China is not an OECD country, R&D expenditure data is not publicly available for China. Europe is investing heavily in R&D for *Wind Energy, Photovoltaic energy, Solar Heating and Cooling* and *Ocean energy*, representing around 50% total R&D expenditure.

IV.A.1. **Number and Ratio of Publications**

Figure IV-III shows the geographic allocation of publications from academic institutions in the last 5 years for accelerating the development of renewable electricity and heating/cooling technologies.

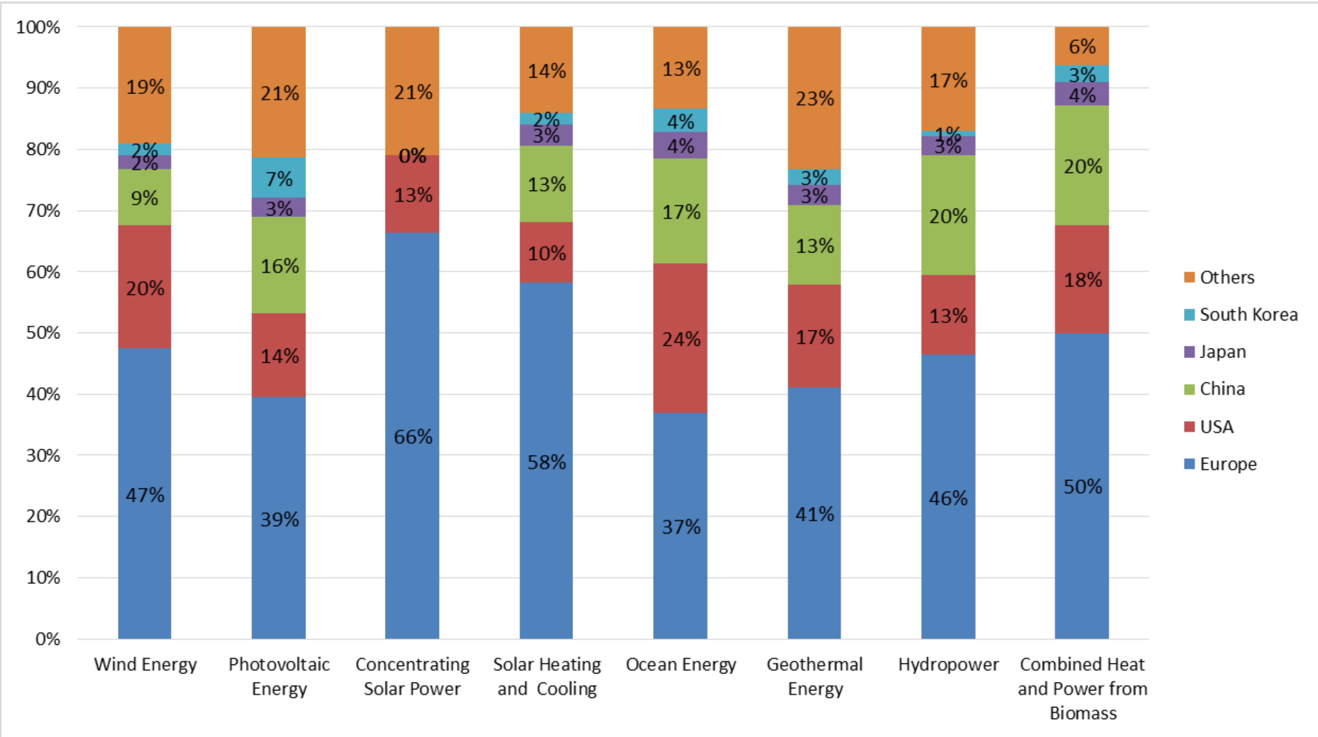


Figure IV-III: Number and ratio of publications by country and category of technologies listed in Theme 10

Publications for accelerating the development of renewable electricity and heating/cooling technologies show a clear dominance of academic players from the EU in every analysed category. This is most likely due to EU's strong RES policies aimed at ensuring that the 2020 goals are met. The second largest contributor of publications is comprised of the combined publishing efforts of *Other nations*, except in the category of combined heat and power from biomass. They are followed by China and the USA, with an almost equal over all contribution apart from the *concentrating solar power* category, where China has no contribution what so ever. The contribution from the remaining nations, Japan and South Korea, is negligible.

IV.A.2. **Number and Ratio of Patents**

The following diagrams show the geographic allocation of patents for accelerating the development of renewable electricity and heating/cooling technologies.

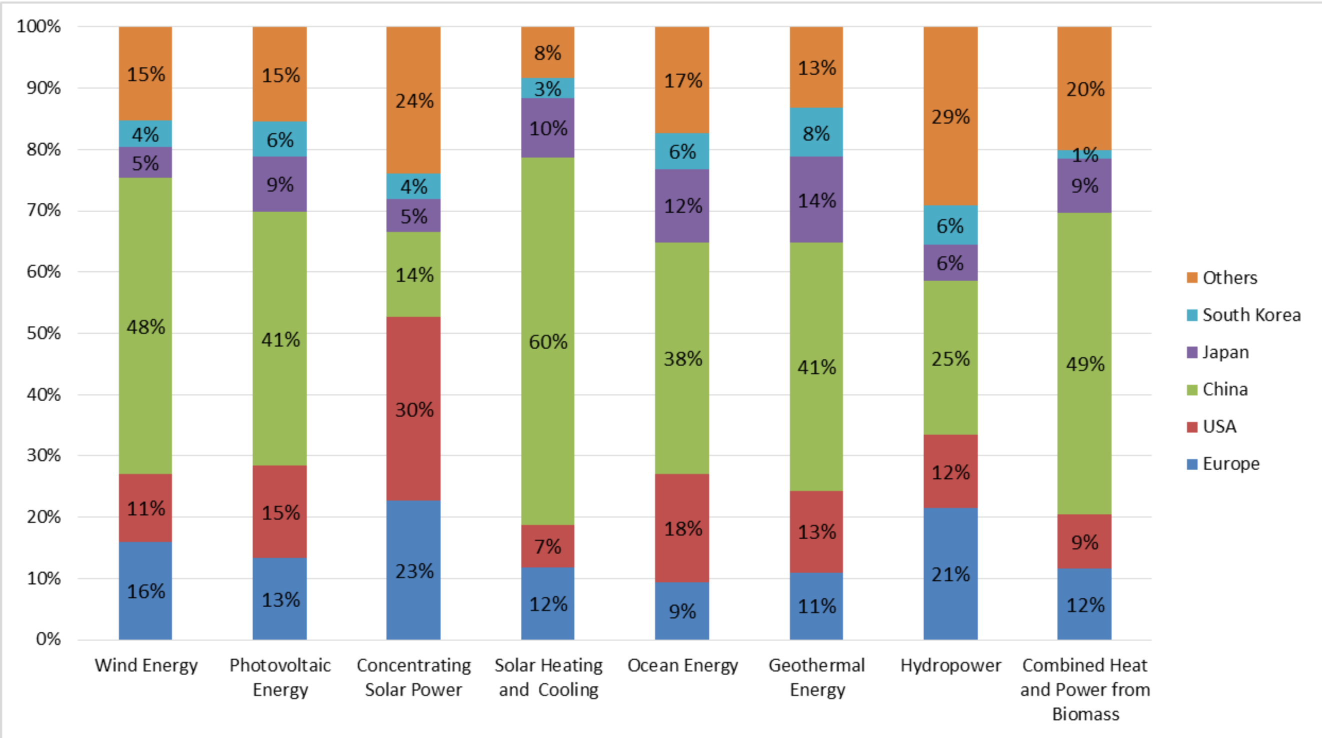


Figure IV-IV: Number and ratio of patents by country and category of technologies listed in Theme 10

Similar to the trends in publications for this theme, there is clear overall dominance of a single nation when it comes to patent ratios for accelerating the development of renewable electricity and heating/cooling. China is clearly dominant in most categories. It is the absolute leader in patents for *wind energy, PV energy, Solar Heating and Cooling* and *Combined Power and Heat from biomass*.

If we look into further details for the wind energy, China is dominant in the field of *logistics, assemble and decommissioning* patents, as well as patents related to *grid integration and spatial planning*. Europe is the leader in *advanced turbines and components*.

The USA is at the forefront for *Concentrated Solar Power* and EU is strong for *hydropower* patents.

IV.A.3. **Volume and Ratio of Research and Development expenditure**

The following diagram shows the average volume and ratio of research and development expenditure in the last 5 years for accelerating the development of renewable electricity and heating/cooling technologies. The research and expenditure volumes for: China across all categories concentrating solar power for all countries, solar heating and cooling and combined heat and power from biomass for USA and South Korea, ocean power, hydro power and geothermal power for Japan are not available.

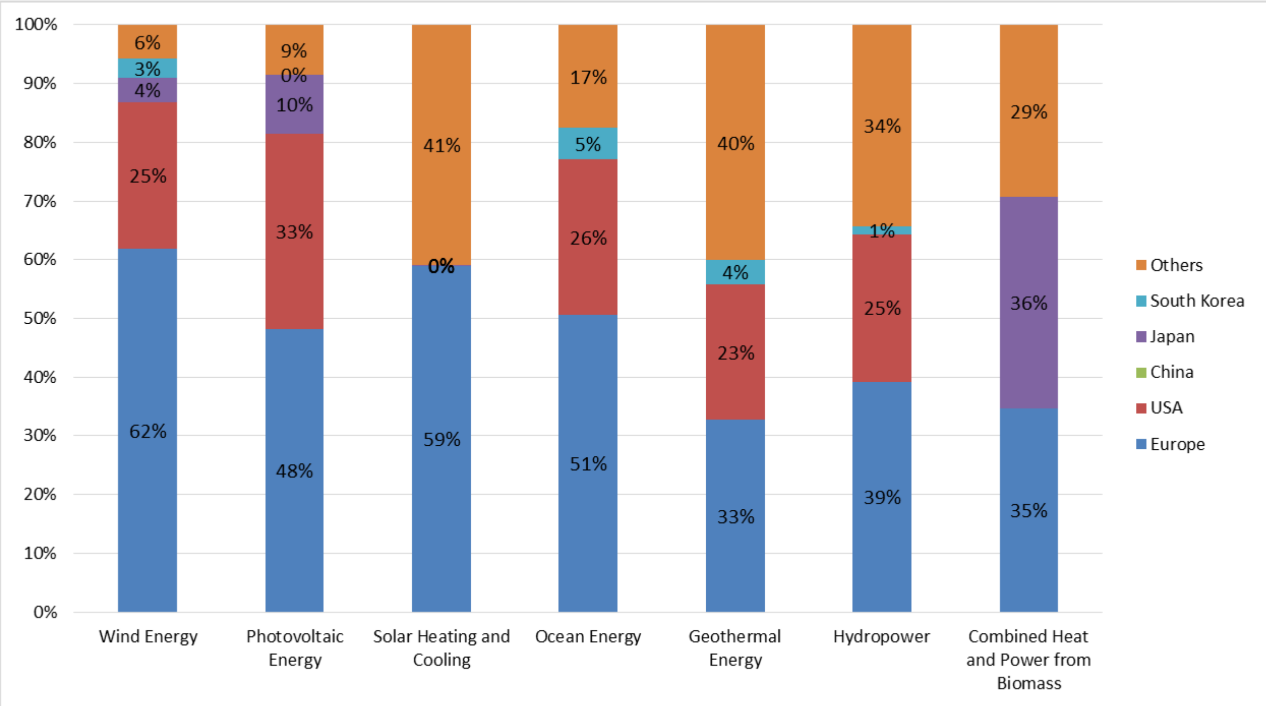


Figure IV-V: Volume and ratio of research and development by country and category listed in Theme 10

In almost all categories analysed, the EU has the greatest research and development expenditure, except for the category of *combined heat and power form biomass* for which Japan has the greatest expenditure. The combined expenditure by *Other nations* and the USA are almost equal to each other, with both being having the second largest share in three categories after the EU. The expenditures for research and development in South Korea are rather negligible in comparison.

IV.A.4. **Conclusions on Strengths and Weaknesses of the EU**

The following table provides an overview of the geographical allocation of strengths and weaknesses regarding patents (•) and publications (◦) and industry key players (◇).

Table IV-I: Strengths and Weaknesses by country and category of measures listed in Theme 10

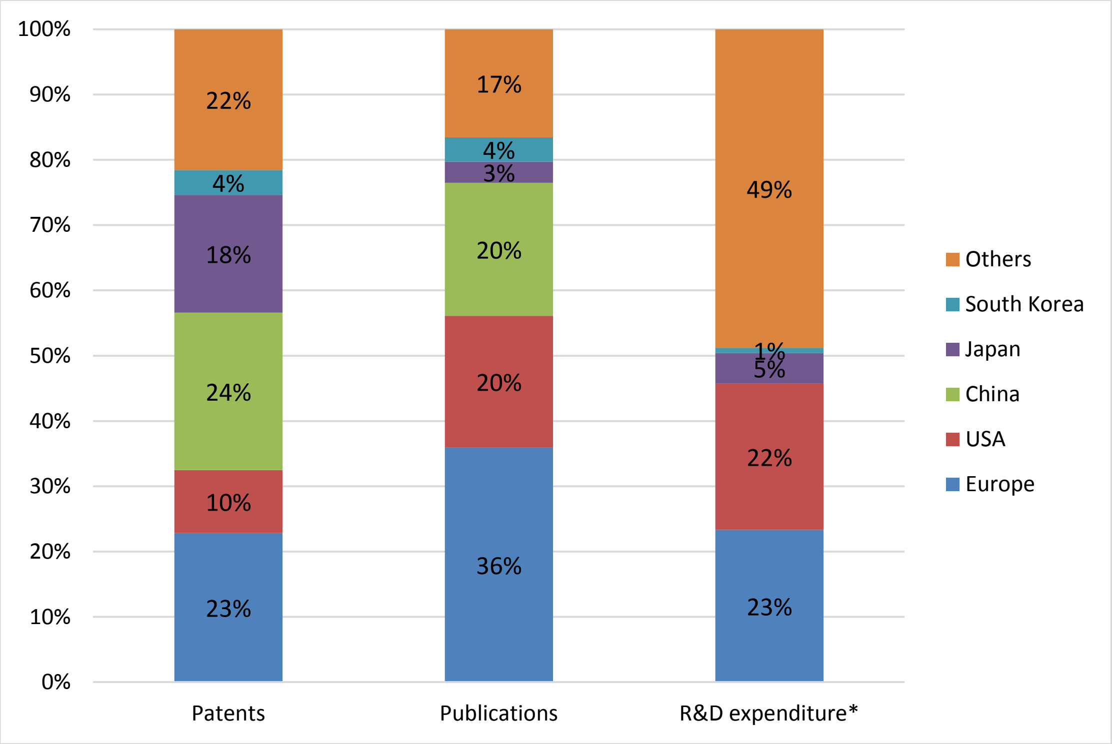
Category		Europe		USA		China		Japan		South Korea		Others	
Wind Energy	Advanced turbines and components	●●	◇◇◇ ◇◇◇ ◇	●●●	◇	●●	◇		◇			●●●	
		○○○○		○○		○						○○	
	Accurate methodologies for wind resource assessment					●●●●							
		○○○		○○		○						○○	
	Offshore components and technologies	●●		●		●●●		●		●		●●	
		○○		○○		○				○		○	
	Logistics, assemble and decommissionin g process					●●●●						●	
	Grid integration and spatial planning for innovations			●		●●●●						●	
		○○○○		○		○						○○	
Photo-voltaic Energy	Novel low cost and/or high efficiency PV technologies	●●	◇◇	●●●	◇◇ ◇	●●		●	◇◇◇ ◇◇	●●●			
		○○○		○○		○○		○		○		○○	
	New pilot production lines	●●●		●●		●●		●		●		●●●	
		○○○○											
Con-centrat-ing Solar Power	Innovative receivers and heat transfer fluids	●●	◇	●●●	◇◇ ◇◇ ◇◇	●●		●	◇	●●		●●●	◇ ◇
		○○○○											
	Component development, hybrid concepts	●●		●●		●●						●●	
		○○○○										○○○○	
Solar Heat-ing and Cooling	Smart controllers and Simplified storage for solar compact hybrid systems		◇	●●●●	◇	●	◇◇◇		◇◇◇ ◇◇			●●	
		○○○○		○		○						○	
	Solar compact hybrid systems for solar active houses												
		○○○		○		○○		○○		○		○○	
Ocean Energy	Site characterisation		◇◇◇ ◇◇	●●●	◇◇ ◇	●●		●●					◇ ◇
	Ocean energy components	●				●●●●						●●	
		○○○		○○		○○		○		○		○○	

Category		Europe		USA		China		Japan		South Korea		Others	
Geothermal Energy	Enhanced Geothermal systems	●●	◇	●●	◇	●●		●●	◇◇◇ ◇◇◇ ◇◇	●●		●●●	
		○○○○		○○		○		○				○○	
	Geothermal heating and cooling	●●		●●		●		●		●●●		●●	
		○○○		○○		○○		○		○		○○	
Hydropower	Sustainable pumped storage	●●	◇◇	●	◇◇ ◇◇ ◇◇	●●		●			◇	●●●●	◇
		○○○○		○		○○		○				○○	
	Variable speed pump turbines and high-heat pump turbines	●●●●		●									
		○○○○										○○	
Combined Heat and Power from Biomass	Sustainable bio-liquids		◇◇		◇		◇◇◇		◇◇				◇ ◇
		○○○○		○		○○				○		○○	
	High-efficiency biomass conversion system					●●●●							
		○○○○		○○		○○							

In terms of patent filings, the EU holds comparatively relatively weak to average positions, being dominant in only the category of *variable speed pump turbines* and *high-heat pump turbines*, while it has a rather strong position in the *new pilot production lines* category. However, in terms of publications it holds a strong to a very strong position in almost all analysed categories, except in the categories of *logistics, assemble and decommissioning process* and *site characterisation* for which the EU has no publications. As for the number of key industry players, the EU has at least one key player in each analyses industry but is most present in the *ocean energy* industry with 5 key players and in the *wind energy* industry with 7 key players.

IV.B. **Theme 11: Enabling carbon capture, CO_2 utilisation and storage technologies and increased efficiency of the fossil fuel-based power sector and energy intensive industry**

Theme 11 investigates carbon capture systems, CO_2 utilisation and storage technologies and increased efficiency of the fossil fuel-based power sector and energy intensive industry. A large amount of energy is still produced from coal and other fossil fuels and, as a by-product, we have CO_2 emissions. One of the goals for a sustainable and diverse energy supply is increasing the efficiency of conventional thermal power plants, efficient CO_2 capture technologies, and transformation of CO_2 to useful products and unconventional fossil fuels that will be investigated in this theme.



*R&D database does not include China

Figure IV-VI Overall representation of the relative results for Theme 11

Analysed categories of technologies and measures

CCS	Efficient CO_2 capture technologies
	CO_2 pipeline and transport systems
	CO_2 storage sites
	Bio-CCS
	Pilot CCS technologies
Conversion of captured CO_2 to useful products	Synthetic fuels and chemicals
	Conversion of CO_2 to chemicals
Clean Coal and Flexible/Back-up Generation for conventional thermal power plants	Improved efficiency of conventional thermal power plants
	Fossil fuelled power plants with CCS
	Coal combustion advanced ultra-supercritical technologies
	Real time power plant optimisation
Unconventional Fossil Fuels	Shale gas
	Coal gasification
	CO_2 storage in underground coal gasification
	Methane hydrates environmental impact

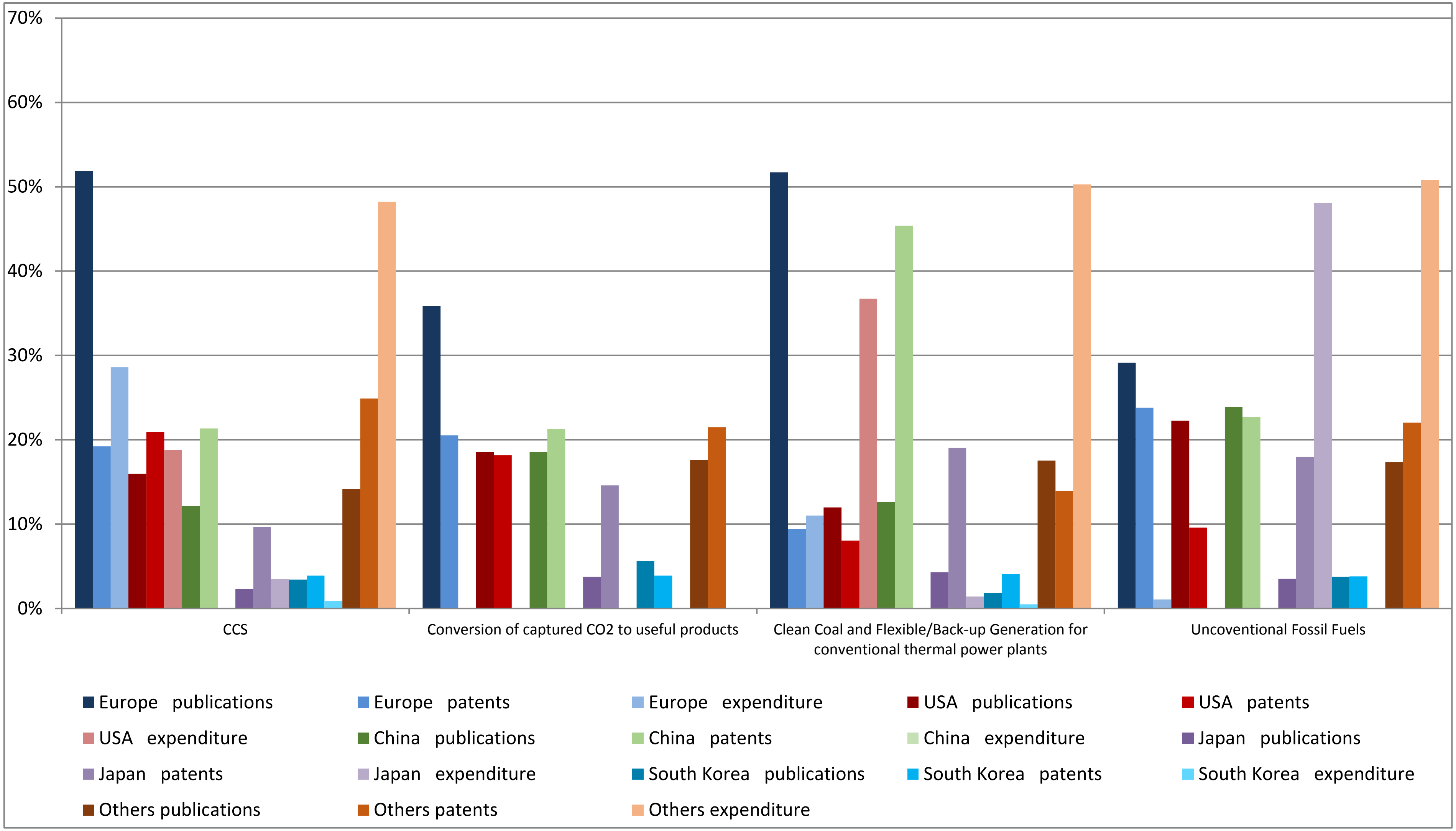


Figure IV-VII: Total ratio of patents, publications and R&D expenditure (in Mio. €) by country and solution for Theme 11

IV.B.1. **Number and Ratio of Publications**

The following diagrams show the geographic allocation of publications from academic institutions in the last 5 years for enabling carbon capture, CO_2 utilisation and storage technologies and increased efficiency of the fossil fuel-based power sector and energy intensive industry.

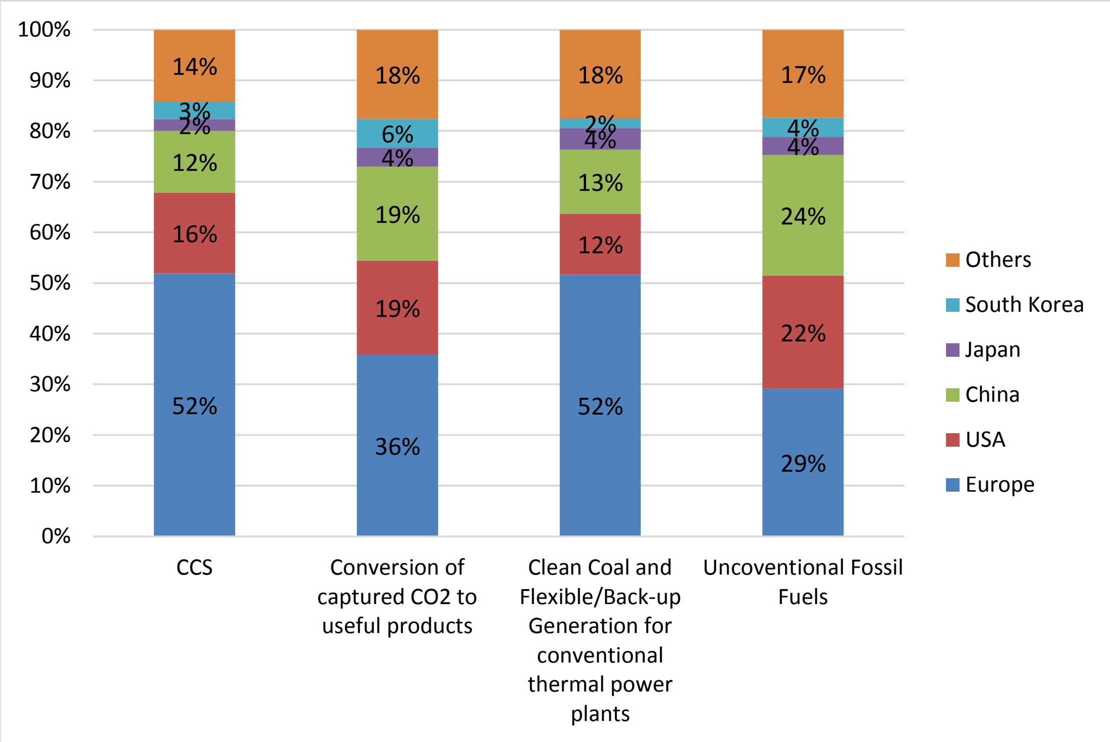


Figure IV-VIII: Number and ratio of publications by country and category of technologies listed in Theme 11

Publications for enabling carbon capture; CO_2 utilisation and storage technologies; the efficiency and flexibility of thermal power generation as well as unconventional fossil fuels are dominated by the EU across all categories. It is followed by publications of China, USA and the combined efforts of Other nations, with almost identical contributions. Japan and South Korea, also with similar contributions, have the smallest number of publications, and even combined have a smaller contribution, than any other nation.

IV.B.2. **Number and Ratio of Patents**

Unlike with publications with a clear overall trend in contributions of individual nations, the number and ratio of patents for this theme are more varied. **China has clearly dominant position in categories of unconventional fossil fuels**. It is the second largest contributor for CCS and lacking only in patents for conversion of captured CO_2 to useful products. The EU and USA have similar contributions overall that are moderate to weak, with the USA having slightly more patents in all categories except unconventional fossil fuels. Japan is the patent leader in the category of conversion of captured CO_2 to useful products and is second in the unconventional fossil fuels category. The reaming contributions of Japan are fairly weak. The combined publication of other nations have a high to moderate contribution overall, having the third highest number of publications for unconventional fossil fuels, most publications for CCS and second most for the remaining two categories. South Korea has the lowest contribution rate in all categories.

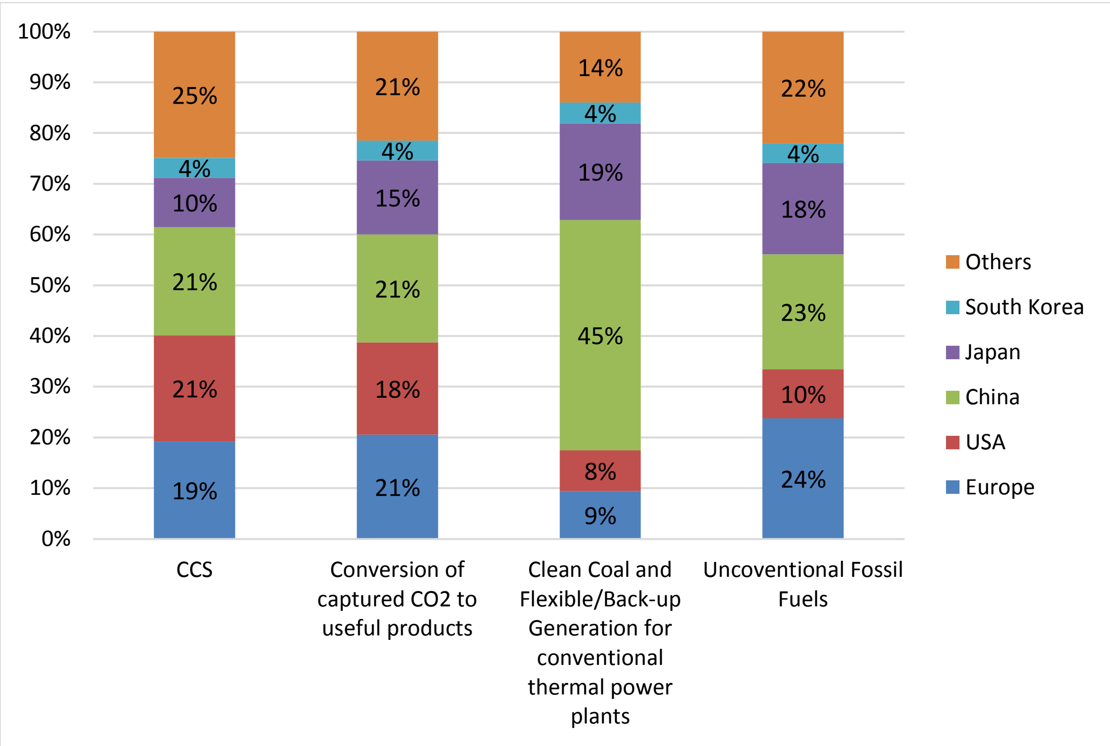


Figure IV-IX: Number and ratio of patents by country and category of technologies listed in Theme 11

IV.B.3. **Volume and Ratio of Research and Development**

The following diagram shows the average volume and ratio of research and development expenditure in the last 5 years for enabling carbon capture; CO_2 utilisation and storage technologies and for the increased efficiency of the fossil fuel-based power sector. The research and expenditure volumes for China across all categories, in the category of conversion of captured CO_2 to useful products for all countries, in the category of unconventional fossil fuels for USA and South Korea are not available.

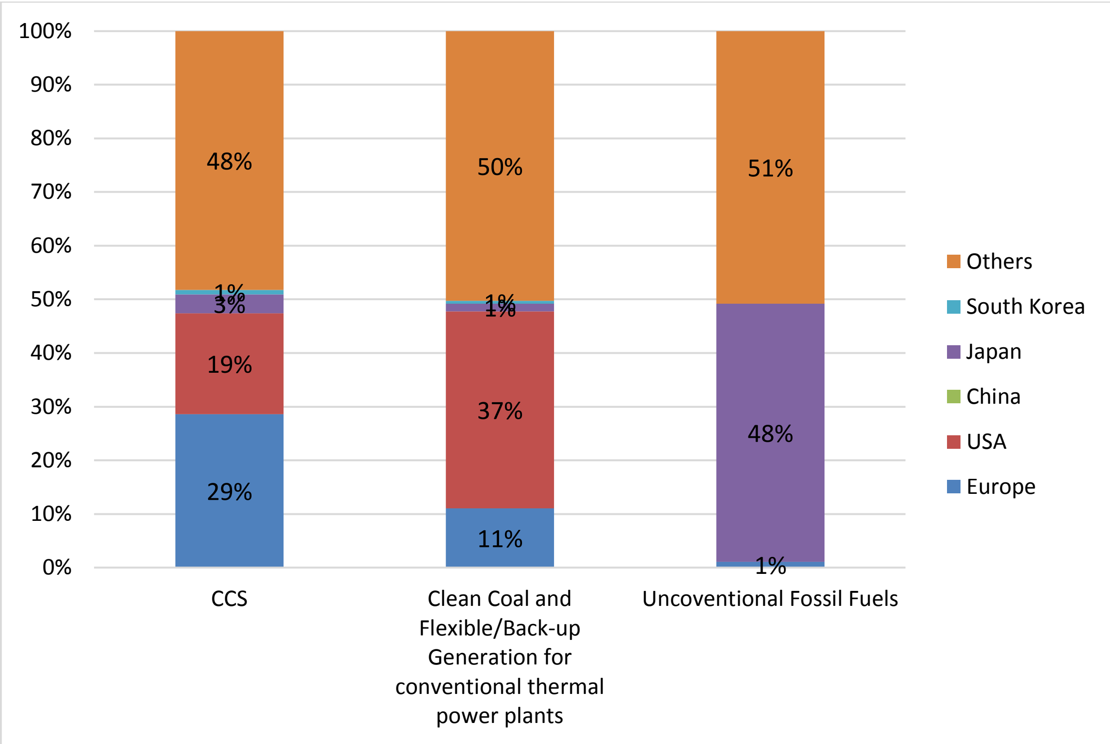


Figure IV-X: Volume and ratio of research and development by country and category listed in Theme 11

In terms of research and development expenditure, the combined effort of *Other nations* are by a large margin the most dominant, contributing to almost half of the expenditure across all sectors. The EU is the second largest contributor in the category of CCS and third largest contributor in flexible/back-up generation for conventional thermal power plants category whilst having a negligible contribution in the category of unconventional fossil fuels. The USA has a similar position by being the second largest contributor for clean coal and flexible/back-up generation for conventional thermal power plants category and third largest for CCS. Japan has the second largest expenditure for unconventional fossil fuels and a negligible contribution for the reaming categories. The contribution of the remaining nations is negligible.

IV.B.4. Conclusions on Strengths and Weaknesses of the EU

The following table provides an overview of the geographical allocation of strengths and weaknesses regarding patents (•) and publications (◦) and industry key players (◇)

Table IV-II: Strengths and Weaknesses by country and category of measures listed in Theme 11

Category		Europe		USA		China		Japan		S.Korea		Others	
CCS	Efficient CO_2 capture technologies	●●	◇◇	●●	◇◇◇ ◇◇◇	●●		● ●	◇	●●		●●●	◇
		○○○○		○○		○○				○		○○	
	CO_2 pipeline and transport systems	●●		●●								●●	
		○○○○										○○	
	CO_2 storage	●		●		●●●●		●				●	

Category		Europe		USA		China		Japan		S.Korea		Others	
	sites	○○○○		○○								○	
	Bio-CCS			●●		●●						●●	
		○○○○											
	Pilot CCS technologies	●●		●●●		●●		●		●●		●●●	
		○○○○		○								○	
Conversion of captured CO_2 to useful products	Synthetic fuels	●●	◇◇◇	●●●	◇◇	●●		●	◇◇◇◇			●●●	
		○○○		○○		○○				○		○○	
	Conversion of CO_2 to chemicals	●●		●●		●●		●●		●●		●●	
		○○○○		○○		○○		○		○		○○	
Unconventional Fossil Fuels	Shale gas		◇◇◇		◇	●●●●			◇◇◇◇◇				◇
		○○○		○○○		○○○		○		○		○○	
	Coal gasification	●●		●●		●●●		●●				●●	
		○○○		○○		○○		○		○		○○	
	CO_2 storage in underground coal gasification												
		○○○○										○○	
	Methane hydrates environmental impact	●●		●●●		●●		●		●		●●●	
		○○○		○○		○○		○		○		○○	

Overall, the strengths and weaknesses of the EU compared to other nations seem to be quite uniform across all sectors. In terms of patent filings, the EU holds a comparatively weak to very weak position, across all categories. On the other hand, in terms of publication the EU has strong to very strong position across all categories. As for the number of key players in the given industries the EU has a relatively weak position by having approximately one to three key players in each industry.

IV.C. Theme 12: Supporting safe and efficient operation of nuclear systems, development of innovative reactor concepts and sustainable solutions for the management of fissile materials and radioactive waste

Nuclear energy is a proven low carbon technology that provides 27% of the electricity production in EU. In terms of R&D expenditure, the EU accounted for 40% of the total amount spent on nuclear power research. The EU also accounts for 50% of the publications related with the field and more than half of the patents.

Analysed categories of technologies and measures

Operation in nuclear reactors	Accident management
	Risk assessment
	Radiation protection
	Plant safety and integrity
Innovative reactor concepts	Nuclear Cogeneration and HTR
	Fast Breeder Reactors (FBR)
	Tritium handling (Fusion Reactors)
	Nuclear data for fusion
	Remote handling (Fusion Reactors)
	Plasma and Advanced materials for fusion
	Research and innovation in LWR
	Supercritical-Water-Cooled Reactor (SWCR)
Management of fissile materials and radioactive waste	Decommissioning
	Reprocessing
	Volume reduction (P&T)
	Final disposal facilities

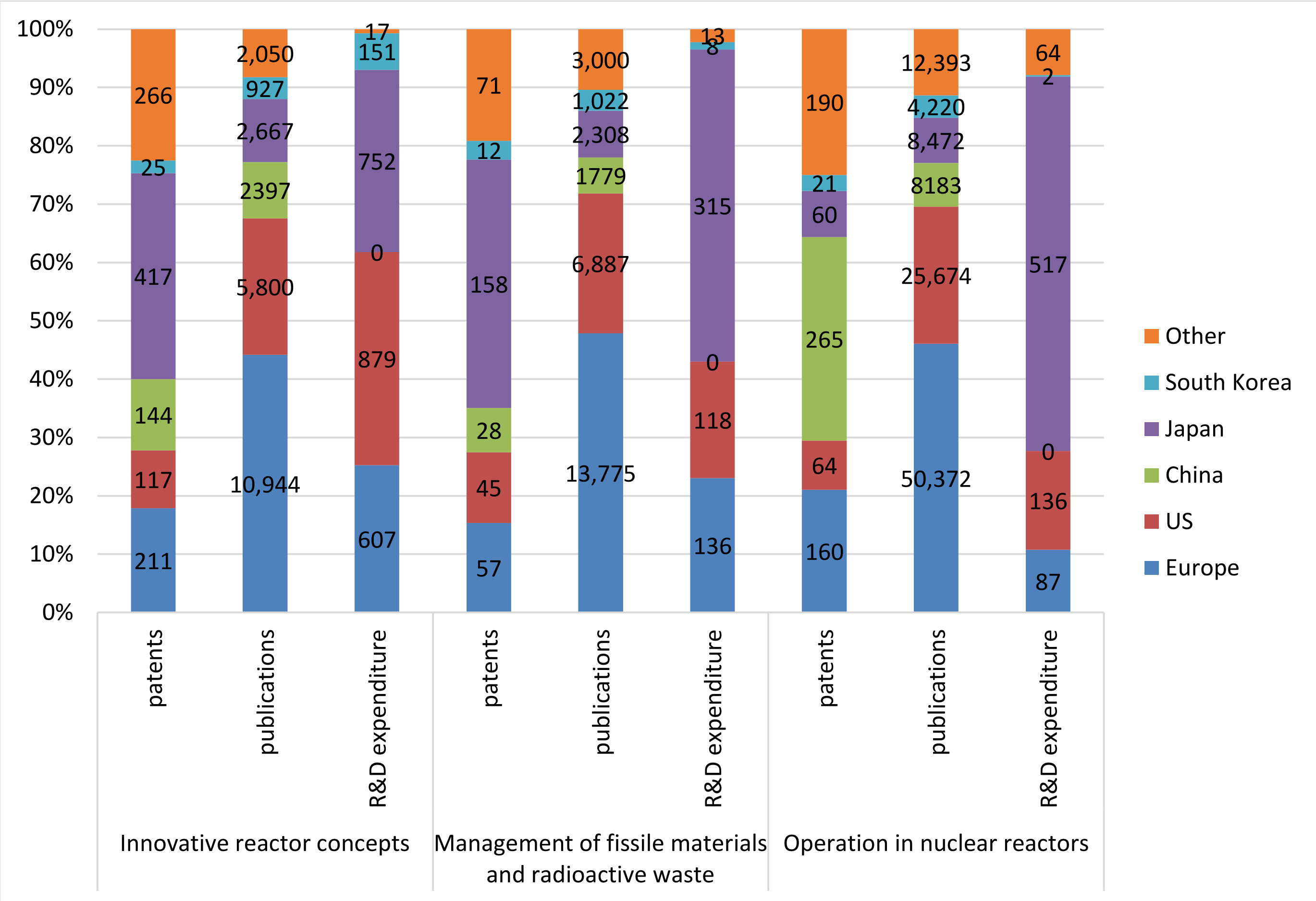


Figure IV-XI: Total number and ratio of publications, patents, and research and development expenditure by country for Theme 12

After the Fukushima accident in 2011, the Sustainable Nuclear Energy Technology platform (SNETP) set up R&D priorities for generation II and generation III reactors. These included four main areas related to the operation of nuclear reactors: accident management; risk assessment; radiation protection; and plant safety and integrity of operating reactors.

Several existing Light Water Reactors (LWR) around the world, the most common type of reactor, are extending their operational lifetime. For this reason, a better understanding of ageing mechanism and monitoring of ageing material has become a priority. Research and innovation in LWR has also lead to new PWR designs such as European Pressurized Reactor (EPR) and AP1000.

Cogeneration potential of Very-High Temperature Reactors (VHTRs) was also recognized by the SNETP for achieving the SET plan objectives. This represents significant potential since nuclear energy is a GHG-free source of electricity generation. The main European project being developed in this field is Nuclear Cogeneration Industrial Initiative (NC2I), which includes more than 20 technology partners. Members of this project include engineering companies (AREVA and EON), universities (such as AGH from Poland) and research institutions (such as CVR from the Czech Republic). NC2I has a focus on the demonstration of a moderate temperature, moderate size HTR connected to industrial processes, as a replacement of fossil fuel cogeneration supply.

Related to Fast Breeder Reactors (FBR), the results of studies and projects carried out under the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) can make a contribution and provide added value to a wide range of stakeholders in the nuclear and scientific communities of IAEA Member States. The program for FBR has involved 22 countries in connection with closed fuel cycle.

An agreement between the Japan Atomic Energy Agency (JAEA), CEA (France) and the US Department of Energy was signed in 2010. This agreement expanded the collaboration between the developers and getting private manufactures involved. JAEA is working on the design of the prototype of FBR Monju. France is developing Advanced Sodium Technical Reactor (ASTRID) and the US is now focussing on systems, materials and safety analysis based on the information provided from the past experiences (FFTF, EBR-II).

The main research and engineering project on fusion reactors is ITER36. This project is building Tokamak, the largest nuclear fusion reactor in the world, located at Cadarache (France). The countries participating in it are India, Japan, China, Russia, South Korea, USA, and the EU through EURATOM. The aim of this project is to clearly achieve full-scale electricity production with fusion reactors. The main challenges for the R&D in the fusion field are related to the plasma containment, operation modes, plasma stability, and alpha particle physics. The development of material that can operate for long periods with high neutron irradiation is the key to the viability of fusion power plants in the future.

The main problem of management of radioactive waste and fissile materials is that at present a defined policy for permanent storage of spent fuel (SF) and high level waste (HLW) does not exist. The Joint Convention has developed activities towards the implementation of a Geological Disposal Technology Platform. Complementary solutions to disposal are also under investigation in some countries, in particular partitioning and transmutation (P&T). Other technologies for recycling nuclear waste are reprocessing and volume reduction.

The greatest expenditure in accident management was incurred by Japan in 2011 (315 Mio. €) and in the US (104 Mio. €), where the National Regulatory Commission (NRC) has set up FLEX plan accident response strategy. Analysing the total number of patents we can, China emerges among the leading innovators in the field. France spent 54 Mio. € to research safety of its reactor fleet in collaboration with AREVA. Even if could seem that the R&D expenditure in new types of reactors is dominated by Fusion, the investment is practically the same globally (868 Mio. € and 744 Mio. €). Within the other types of reactors the main investment is for FBR. Japan did the greatest investment in the research of waste management and the final disposal of the SF (200 Mio. €). This amount was spend in Nuclear Waste Management of Japan (NUMO), focused on the safe implementation of disposal and geological studies, this research culminated in the used fuel storage repository in Mutsu (2013).

[36] https://www.iter.org/proj#history

IV.C.1. **Research and Development expenditure**

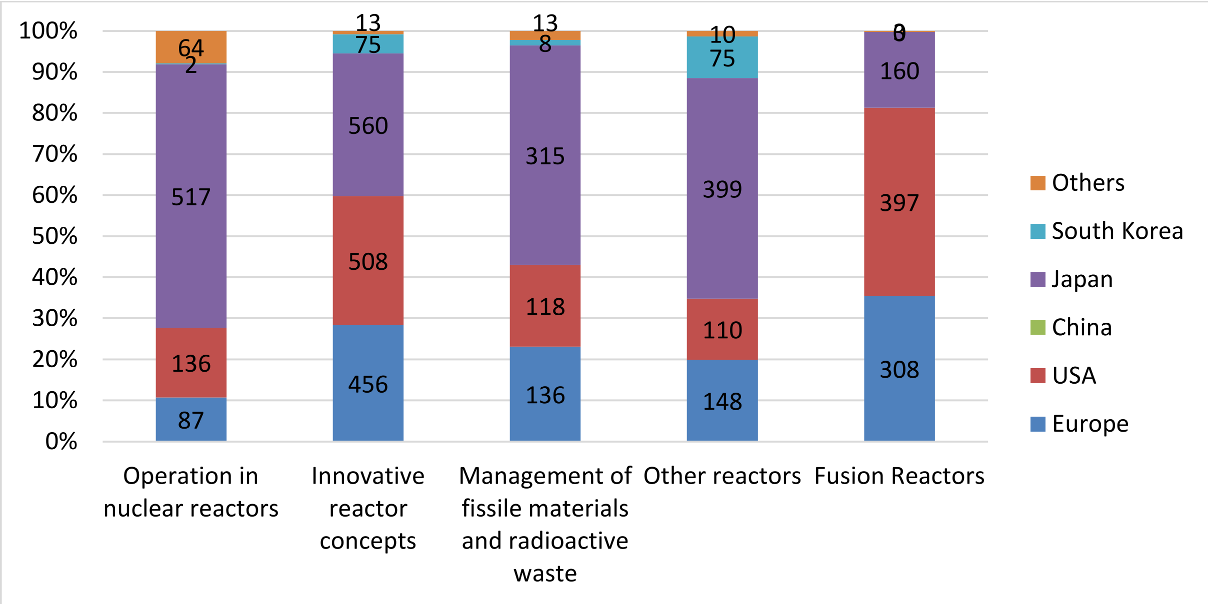


Figure IV-XII: Volume and ratio of R&D expenditure by country and category listed in Theme 12 (Mio. US$)

IV.C.2. **Number of patents**

China has the most patents registered in the field of radiation protection. It plays a very important role in nuclear energy technological and safety development due to the growth on nuclear market (the country operates currently 12 reactors but is constructing 24 others, and a further 12 are already planned). This plan is part of China's Program for Science and Technology Modernization developed between the governments of US and China. This program has a fund of US$67 billion to spend until 2020. Industry conglomerates and research institutes dominate Chinas scientific investigation, with the most important industrial player being China National Nuclear Corporation (CNNC). Tsinghua University's Institute of Nuclear and New Energy Technology (INET) is a leader in the development of fourth generation reactor technology. Japan has the highest number of patents registered in the field of new reactor concepts, specifically with FBR due to the JAEA's work on the design of a demonstration reactor to succeed the prototype FBR Monju. Due to the research on the study of repositories for the High Level Waste (HLW) and Spent Fuel (SF), Japan has also registered the highest number of patents in waste management of radioactive waste and spent fuel.

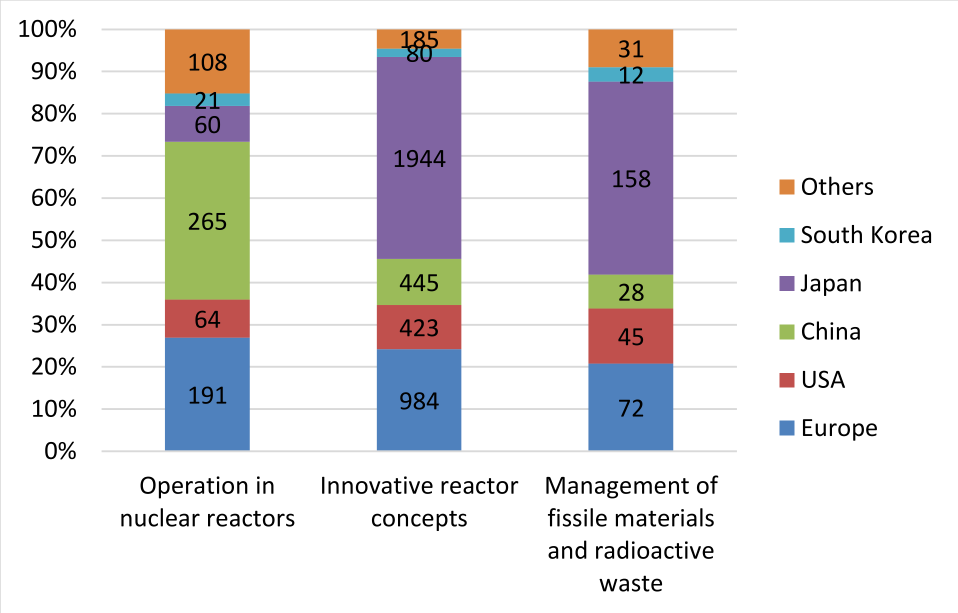


Figure IV-XIII: Number and ratio of patents by country and category of technology listed in Theme 12

IV.C.3. **Number of publications**

China, France, Germany, UK and US have the largest number of publications, but US achieves the highest number with 25,000 publication about plant integrity and 6000 publications with Fusion Reactors.

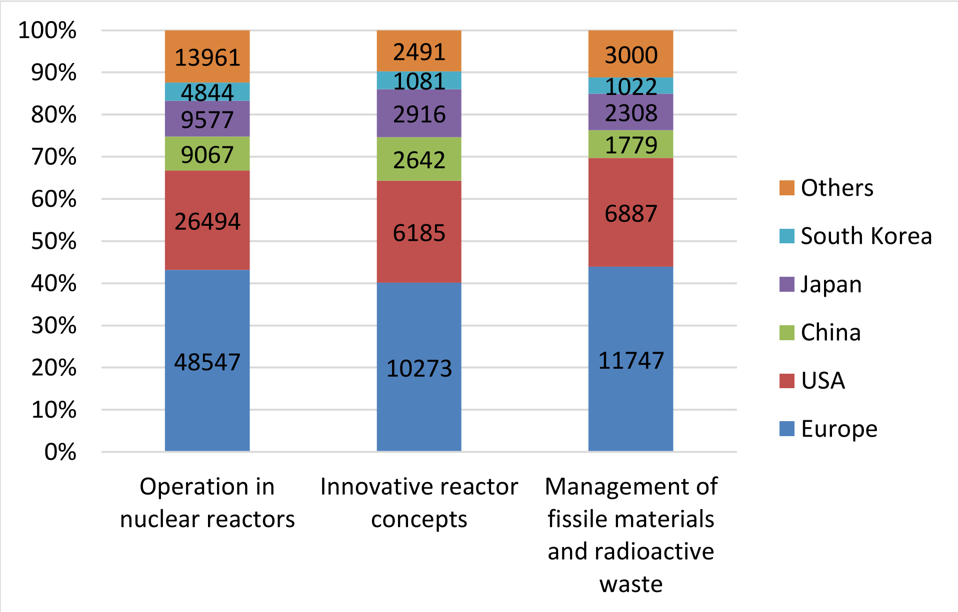


Figure IV-XIV: Number and ratio of publications by country and category of technologies listed in Theme 12

IV.C.4. **Conclusions on Strengths and Weaknesses of the EU**

The following table gives an overview about geographical allocation of strengths and weaknesses regarding patents (•), publications (○) and industrial key players (◇).

In terms of patents the EU has a moderate number of patents in all the fields, competing with Japan in all the technologies. EU has a high number of patents in tritium handling, decommissioning, and plant safety and integrity. The lowest number of patents is in the technologies of SCWR, R&D in LWR, Risk assessment and FBR. In contrast, the EU leads in terms of number of publications on FBR. Similarly, there is a high number of patents related to fusion reactors, but this is not reflected in the number of publications. Research and iinovation in nuclear safety and waste discposal is primarily carried out by national government agencies. Hence, the table below does not list industry players and publications(which are predominantly from academic insitutions).

Table IV-III: Strengths and Weaknesses by country and category of measure listed in Theme 12

Category		US	China	France	Japan	Rest of EU	S. Korea	Other
Operation in nuclear reactors	Accident management	•	••••	•		••••	•	•
	Risk Assessment	••	••••	•	•	••	••	
	Radiation protection		••••		•	•••		
	Plant safety and integrity		••		•	••••		
Innovative reactor concepts	HTR	•	•••	•	•••	••••		
	FBR				••••	•		
	Data Fusion	•	••		••••	••		
	R. Handling	•	•		••••	••		
	Plasma and advanced materials		•	•	••••	••••		•
	R&D in LWR	•	••••		•••	•••		
	SCWR	•	••••	•	••••	•••		
Management of fissile materials and radioactive waste	Decommissioning					••••		
	Reprocessing	••	•		••••	••••		
	P&T	••	•		••••	••••		
	Fuel disposal	•			••••	••••		

IV.D. Theme 13: Developing sustainable biofuels, fuel cells and hydrogen and alternative fuels for the European transport fuel mix

Theme 13 investigates alternative fuel sources that can be replacement to conventional fuels in transport. Transport produces large amount of CO_2 emission and, especially in cities, has large impact to health and quality of inhabitants. In this theme, we will investigate possible solutions for replacement of conventional fuels with biofuels, hydrogen, fuel cells and advance alternative fuels.

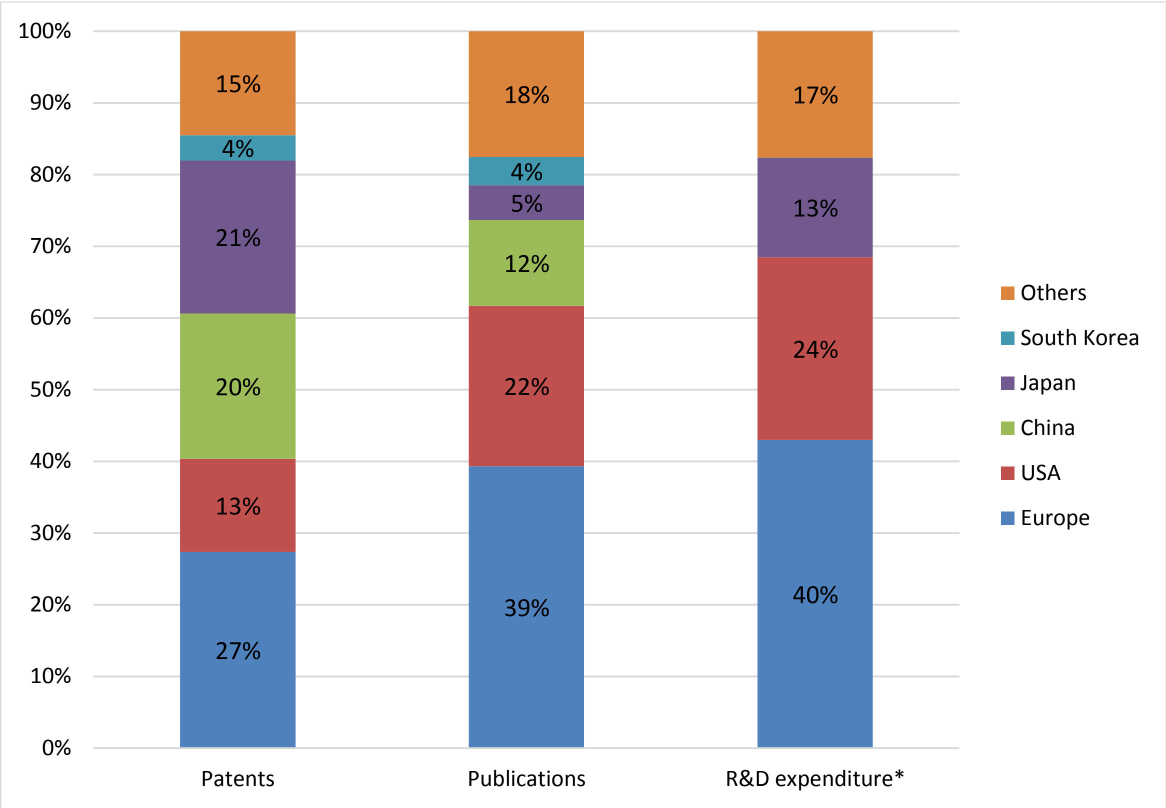


Figure IV-XV Overall representation of the relative results for the Theme 13

Analysed categories of technologies and measures

Sustainable Advanced Biofuels	Novel integrated process concepts for biofuel production
Hydrogen and Fuel Cells	Novel materials and components for fuel cell and hydrogen technologies
	Fuel cell electric vehicles
Advanced Alternative Fuels	Sustainable catalysts and process technologies for CO_2-based and CO_2-neutral liquid and gaseous fuels
	Artificial photosynthesis
	Plants for CO_2-based and CO_2-neutral fuels

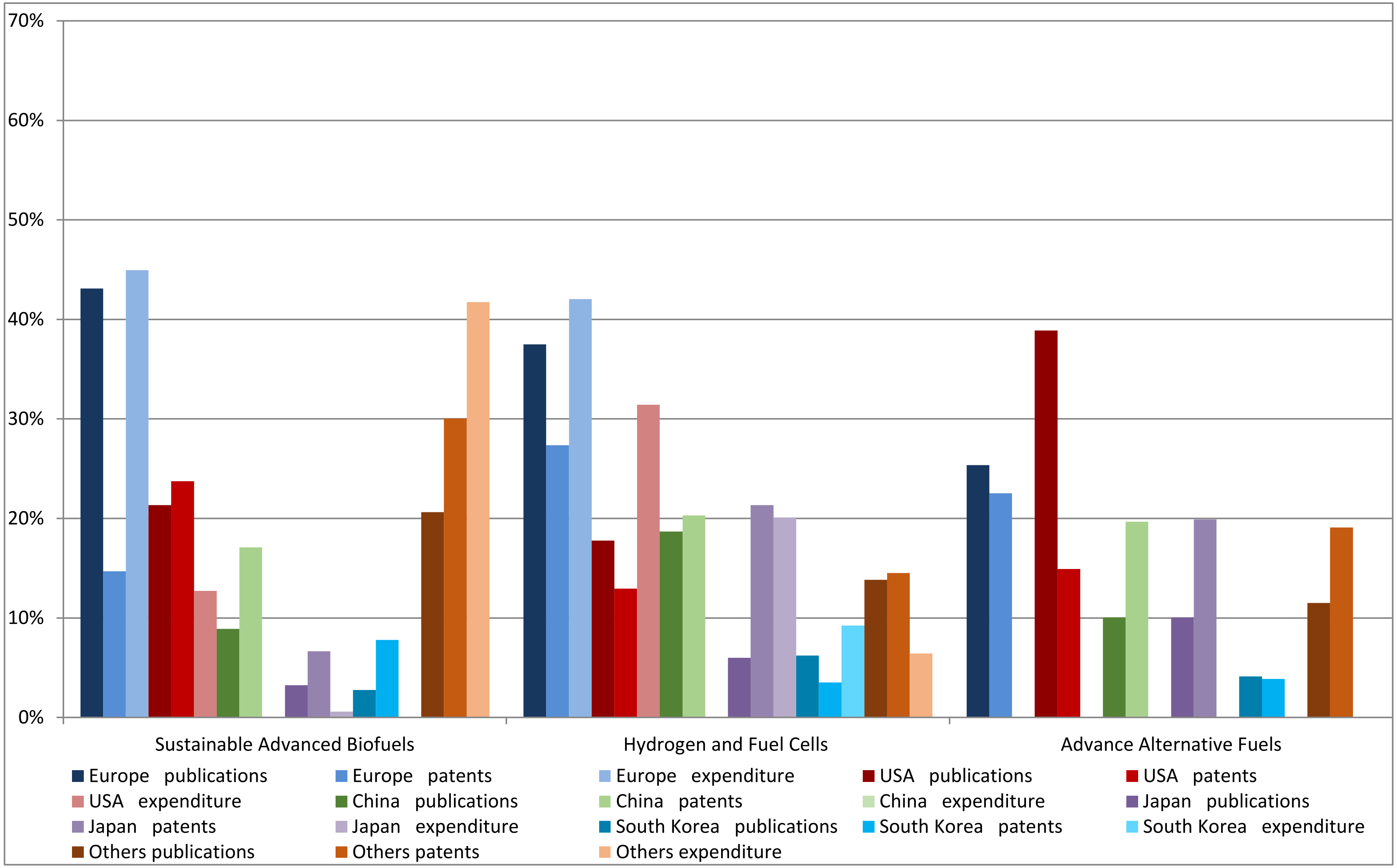


Figure IV-XVI: Total ratio of patents, publications and R&D expenditure (in Mio. €) by country and solution for Theme 13

IV.D.1. **Number and Ratio of Publications**

The following diagrams show the geographic allocation of publications from academic institutions in the last 5 years for the analysed categories.

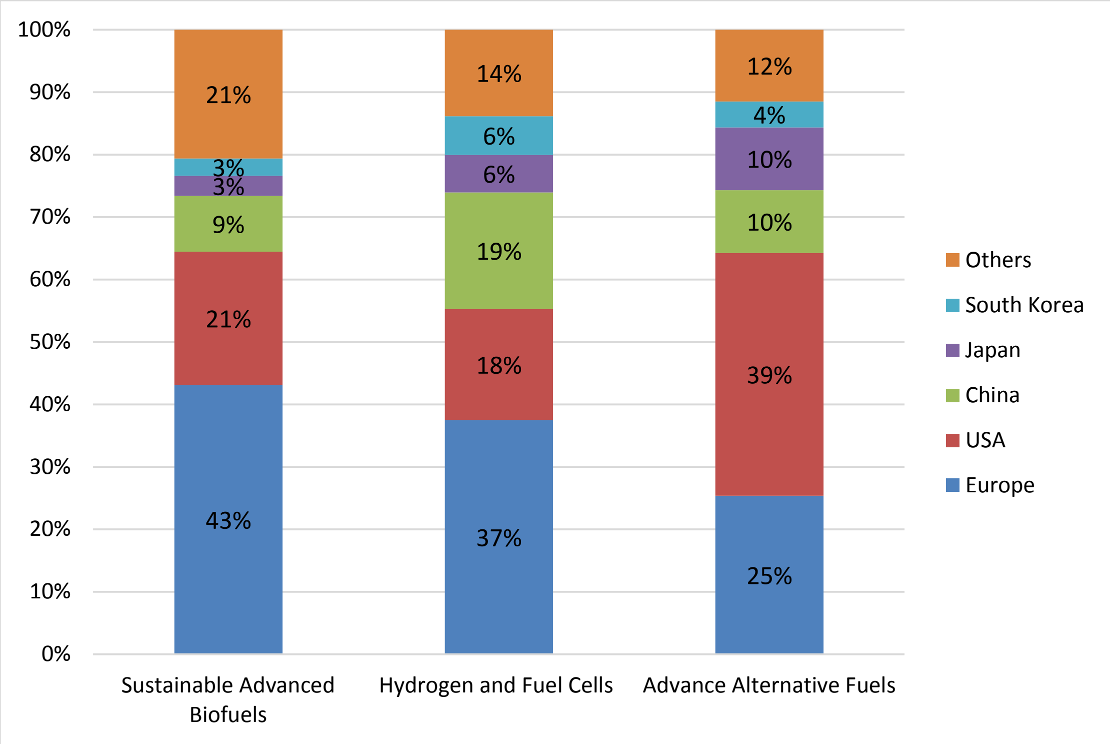


Figure IV-XVII: Number and ratio of publications by country and category of technologies listed in Theme 13

In terms of publications for developing sustainable biofuels, fuel cells and hydrogen and alternative fuels, **the EU is overall the most dominant contributor** although, it is the second largest contributor in the category of advanced alternative fuels. USA is the second largest publisher overall by having the highest number of publications in the category of advanced alternative fuels, second largest in terms of sustainable advanced biofuels and third largest for hydrogen and fuel cells. China and the combined publishing efforts of other nations are the next largest contributors with China having a slight advantage. Japan and South Korea both have equally the lowest contribution.

IV.D.2. **Number and Ratio of Patents**

The following diagrams show the geographic allocation of patents issues in the last 5 years for developing sustainable biofuels, fuel cells and hydrogen and alternative fuels for the European transport fuel mix.

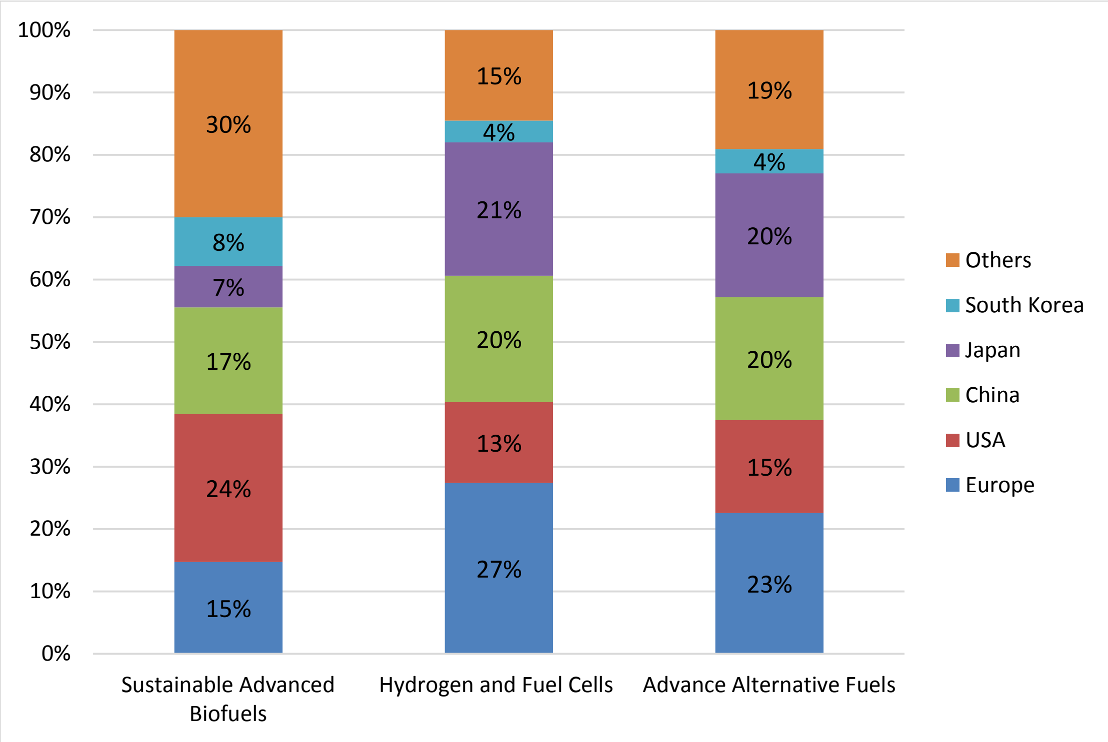


Figure IV-XVIII: Number and ratio of patents by country and category of technologies listed in Theme 13

The USA is the clear leader in the number of patents across all categories and is closely followed by the publications of Other nations. The EU is the third largest contributor overall followed by China. Once again, Japan and South Korea have the lowest contributions with the exception of Japan having a higher contribution that China in the category of hydrogen and fuel cells.

IV.D.3. **Volume and Ratio of Research and Development**

The following diagram (Figure IV-XVIII) shows the average volume and ratio of research and development expenditure in the last 5 years for the analysed categories.

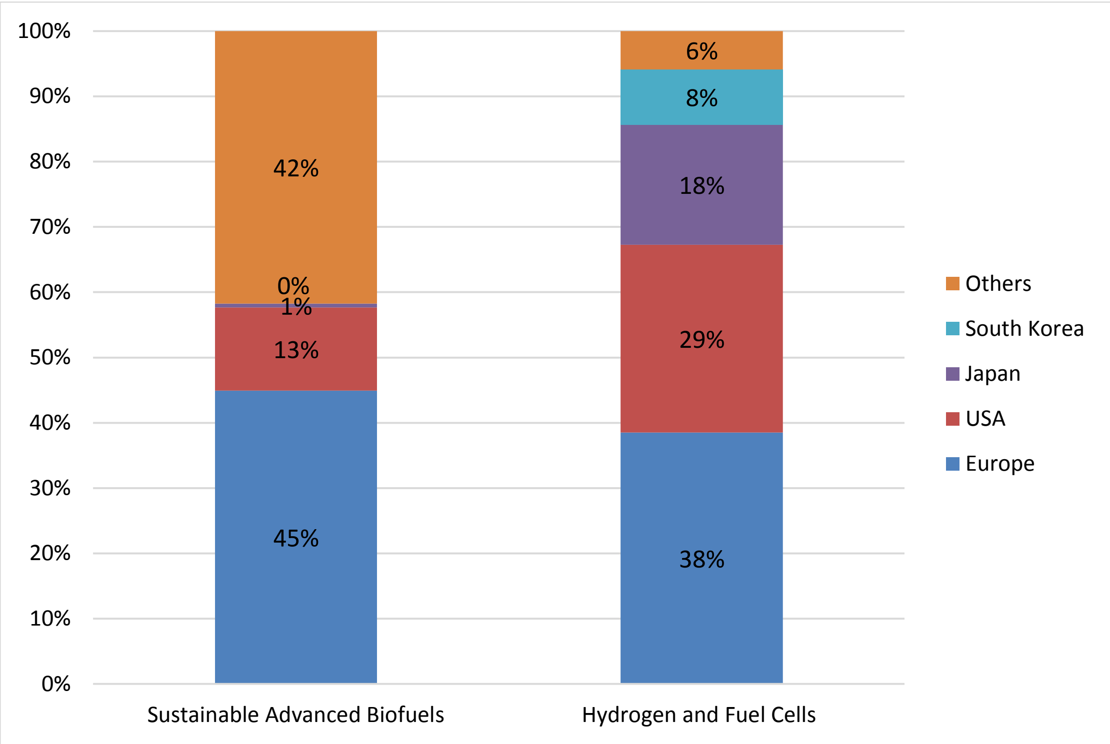


Figure IV-XIX: Volume and ratio of research and development by country and category listed in Theme 13

The EU has the greatest volume and ratio of research and development expenditure for all categories. The USA is the overall second largest contributor followed by the combined expenditure of other nations. Japan is the fourth highest contributor overall, although it is the third largest contributor for the category of hydrogen and fuel cells.

IV.D.4. **Conclusions on Strengths and Weaknesses of the EU**

The following table provides an overview of the geographical allocation of strengths and weaknesses regarding patents (•) and publications (◦) and industry key players (◇).

Table IV-IV: Strengths and Weaknesses by country and category of measures listed in Theme 13

Category		Europe		USA		China		Japan		S. Korea		Others	
Sustain-able Advanced Biofuels	Novel integrated process concepts for biofuel production	●● ○○○ ○		●● ● ○○	◇◇◇ ◇◇◇ ◇◇◇ ◇	● ● ○		● ○		● ○		●● ● ○○	
Hydrogen and Fuel Cells	Novel materials and components for fuel cell and hydrogen technologies	●● ○○○ ○	◇◇	●● ● ○○	◇	● ● ○		● ● ○	◇◇◇◇ ◇◇	● ○	◇	●● ○○	
	Fuel cell electric vehicles	●● ○○○ ○		●● ● ○○		● ○ ○		● ○		● ○		●● ○○	
Advance Alternative Fuels	Sustainable catalysts and process technologies for CO_2-based and CO_2-neutral liquid and gaseous fuels	 ○○○	◇◇◇ ◇◇◇	 ○○	◇	 ○		 ○	◇◇◇	 ○		 ○○	
	Artificial photo-synthesis	●● ○○		●● ● ○○ ○		● ● ○		 ○		● ● ○		●● ○	
	Plants for CO_2-based and CO_2-neutral fuels	 ○○○		 ○○ ○		 ○ ○		 ○		 ○		 ○○	

The overall strength of the EU in terms of patents is moderate across all categories. In terms of publications it is moderate to strong, although it is a bit lacking in the category of artificial photosynthesis. As for the number of key industrial players, the position of the EU varies from industry to industry. In the industry of sustainable advanced biofuels the EU has no key players, in the hydrogen and fuel cells industry it has three key industry players and in the advanced alternative fuels it has six key players. Overall it has a weak to moderate position in terms of key industry players.

V. CONCLUSIONS

The main overall conclusion related to patent activity can be that Europe is behind its main competitor China. However, Europe is still leading in publications and academic activity.

The following initial conclusions can be drawn within each of the integrated challenges:

Active consumer at the centre on energy system

European activity is strong in publications, but weak in patent filings. China is the clear leader in exports for these solutions.

Increasing energy efficiency across the energy systems

Generally, Europe is strong in publications, but has a low share of patents. For some technologies like heat and cold storage, Japan is better than Europe. China maintains the absolute leadership in lighting technologies with 95% of LED patents and exports of €14 billion in comparison to the €2 billion exported and €6.5 billion imported by Europe.

Europe is well positioned in energy efficiency in heating and cooling, especially in heat pump technology (closely followed by China with regard to absorption and compression heat pumps in comparison to publications and patents). Europe is also strong in publications and patents on condensing boilers (but not on exports, which is led by China), on cooling supply technologies (where Europe follows with a strong export position) and on heating supply technologies and low temperature boilers[37]. While South Korea leads in terms of patents for wood pellet boilers, the EU is very strong in publications as well as in exports.

For energy efficiency in industry, Europe is also strong in publications, but much weaker in patents. Where Europe is strong in export, it continues to import more than it exports.

System optimisation

Japan invests more in the development of electrical/electrochemical technologies for energy storage in recent years (two times the investments in EU, three times the investments in US), and it also leads in patent filings for electrochemical storage and heat storage. The EU is strong in mechanical storage patents, flow batteries and syngas technologies, as well as being strong in publications on chemical storage and power-to-X.

Regarding large-scale storage, Japan leads in patents on H_2 and on large-scale storage, but Europe is very active from a research perspective. Europe has a strong trade deficit on batteries, while Japan clearly exports more than it imports. The US emerges as the biggest exporter.

With respect to flexibility, Europe is much stronger in publications than in patents, with the exception of technologies related to innovative transmission network control and protection and DC grids with voltage source convertors. China is leading in most patentable areas, in particular smart

[37] There was no information available on exports for this category

substations, ICT systems and monitoring systems. Europe is, on the other hand, the global first player in the field of “smart cities”.

Secure, cost-effective, clean and competitive supply

Europe is strong only in RES technologies, while China and USA are the leaders for the other technologies (CCS, nuclear, biofuels, FCH and alternative fuels).

Except for hydropower, where EU has almost the same number of patents as China, the Chinese clearly lead in all the various technologies with regards to patents. The EU invests heavily in R&D in all areas. The only areas where the Americans invest almost as much is PV and ocean energy. In CSP and in geothermal, the USA and Japan perform slightly better than the EU in patents. EU is second in patents (after China) in the areas related to wind energy (Europe is a leader in advanced turbines and components), solar H&C and CHP from biomass.

Regarding Nuclear energy EU has the largest number of publications in all areas. Japan is leading with regards to R&D investments for management of materials and waste (also leading on patents) and operation of reactors (here, patents are dominated by China, with Europe second). Japan invests in R&D as much as Europe in developing innovative reactor concepts.

In terms of publications for the biofuels, FCH and alternative fuels, the EU is overall the most dominant contributor, only preceded by the USA as regards advanced alternative fuels, but the USA is the clear leader in the number of patents across all categories. This is despite the fact that the EU invests much more than the USA in R&D on sustainable advanced biofuels, and slightly more in FCH.

To further investigate the main European strengths and weaknesses across all themes, additional steps are needed. This report represents just a first insight into the innovation capacity of the Europe based on the Integrated Roadmap themes based on available public data.

Additional steps are to be initiated such as, for example, verification of the results presented, through further database searches and data comparison if one is to follow the insight and more detailed information. Additional professional databases should be consulted related to patent filing as well as the activity in scientific publications. Further effort is needed to find appropriate economic data for all countries involved and analyse the ability of transition of ideas and innovation into financial activity. Therefore, a series of investigations like questionnaires and contacts with relevant subjects should be pursued.

VI. Appendices

VI.A. Ranking of Industrial Players

The following table gives an overview about the top 10 industrial key players in each category ranked by number of patents. (Geographical assignment by site of head office.)

Themes 1&2

Rank	Assignee	Region
Grid Networking Systems		
1.	GEN ELECTRIC	USA
2.	ITRON INC	USA
3.	HONEYWELL INT INC	USA
4.	STATE GRID CORP CHINA	China
5.	KOREA ELECTRONICS TELECOMM	South Korea
6.	LG ELECTRONICS INC	South Korea
7.	ELSTER SOLUTIONS LLC	USA
8.	AREVA T D INC	EU
9.	LUTRON ELECTRONICS CO	USA
10.	SAMSUNG ELECTRONICS CO LTD	South Korea

Home Networking Systems

1.	HOLLISTER JAMES	USA
2.	GEN ELECTRIC	USA
3.	IMES KEVIN R	USA
4.	ALLURE ENERGY INC	USA
5.	UCENTRIC HOLDINGS INC	USA
6.	LG ELECTRONICS INC	South Korea
7.	LSIS CO LTD	South Korea
8.	SONY CORP	Japan
9.	KYOCERA CORP	Japan
10.	KONINKL PHILIPS ELECTRONICS NV	EU

Smart Homes & Buildings

1.	LG ELECTRONICS INC	South Korea
2.	SAMSUNG ELECTRONICS CO LTD	South Korea
3.	MATSUSHITA ELECTRIC IND CO LTD	Japan
4.	UNIVERSAL ELECTRONICS INC	USA
5.	LEE KOON SEOK	South Korea
6.	BAEK SEUNG MYUN	South Korea

7.	CHOI HWAN JONG	South Korea
8.	KOO JA IN	South Korea
9.	KOO FEEL YOUNG	South Korea
10.	KIM YONG TAE	South Korea

Theme 3

Rank	Assignee	Region

Thermal storages

1.	BETEILIGUNGS AG HAUSTECHNIK	EU
2.	WST WAERMESPEICHERTECH SA	EU
3.	MERCK PATENT GMBH	EU
4.	WIZARD POWER PTY LTD	Others (Australia)
5.	Univ SHANGHAI JIAOTONG	China
6.	MATSUSHITA ELECTRIC (Panasonic)	Japan
7.	SEKISUI CHEMICAL CO LTD	Japan
8.	OREGON STATE	USA
9.	GRIMM ARNOLD	EU
10.	DAUME JOCHEN	EU

Building envelope

1.	LUTRON ELECTRONICS CO	USA
2.	GOODYEAR TIRE RUBBER	USA
3.	HILTI AG	EU
4.	RAVENBRICK LLC	USA
5.	JOHNS MANVILLE	USA
6.	SIEMENS AG	EU
7.	HARBIN SAYYAS WINDOWS CO LTD	China
8.	YU XIANGYANG	China
9.	FISCHER ARTUR WERKE GMBH	EU
10.	GREEN TECHNOLOGY CONSTRUCTION	n.a.

Lighting

1.	USHIO ELECTRIC INC	Japan
2.	TOSHIBA CORP	Japan
3.	CANON KK	Japan
4.	GUIZHOU GUANGPUSEN PHOTOELECTR	China
5.	Siemens (PATENT TREUHAND GmbH)	EU
6.	MATSUSHITA ELECTRIC LTD (Panasonic)	Japan

7.	THORN LIGHTING LTD	EU
8.	HARISON TOSHIBA LIGHTING CORP (Toshiba)	Japan
9.	PANASONIC CORP	Japan
10.	IWASAKI ELECTRIC CO LTD	Japan

Building Ventilation

1.	DAEWOO ELECTRONICS CORP	South Korea
2.	ABB INSTALLAATIOT OY	Others (Switzerland)
3.	SVENSKA FLAEKTFABRIKEN AB	EU
4.	VALLOX OY	EU
5.	SANYO ELECTRIC CO (Panasonic)	Japan
6.	METSO PAPER INC	EU
7.	UNIV SHANDONG TECHNOLOGY	China
8.	MITSUBISHI HEAVY IND LTD	Japan
9.	VENT AXIA GROUP LTD	EU
10.	SIEGENIA FRANK KG	EU

Building monitoring and control systems

1.	KATES LAWRENCE	USA
2.	YORK INT CORP (Johnson Controls Inc.)	USA
3.	VISTEON GLOBAL TECH INC	USA
4.	FORD MOTOR CO	USA
5.	EMERSON ELECTRIC CO	USA
6.	CARRIER CORP (UTC)	USA
7.	FORD GLOBAL TECH LLC (Ford Motor)	USA
8.	TOSHIBA LIGHTING TECHNOLOGY	Japan
9.	TRANE INT INC (Ingersoll Rand)	EU
10.	NEST LABS INC (Google)	USA

Theme 6

Rank	Assignee	Region

Flexible AC transmission systems

1.	ABB	Switzerland
2.	Alstom	France
3.	Siemens	Germany
4.	State Grid Corp China	China
5.	General Electric	USA
6.	Hitachi	Japan
7.	KEPCO - Korea Electric Power	South Korea
8.	LS Industrial Systems	South Korea
9.	China Southern Power Grid	China
10.	NR Electric	China

Optimization models for asset management

1.	ABB	Switzerland
2.	General Electric	USA
3.	Toshiba	Japan
4.	Hitachi	Japan
5.	Mitsubishi Electric	Japan
6.	Siemens	Germany
7.	Schneider Electric	France
8.	State Grid Corp China	China
9.	China Southern Power Grid	China
10.	Huawei	China

Network monitoring

1	ABB	Switzerland
2	General Electric	USA
3	Toshiba	Japan
4	Hitachi	Japan
5	Alstom	France
6	Siemens	Germany
7	State Grid Corp China	China
8	Silver Spring Network	USA
9	Schneider Electric	France
10	KEPCO - Korea Electric Power	South Korea

DC grids with voltage source converters

1.	ABB	Switzerland
2.	Siemens	Germany
3.	Alstom	France
4.	General Electric	USA
5.	State Grid Corp China	China
6.	Hitachi	Japan
7.	Toshiba	Japan
8.	Mitsubishi Electric	Japan
9.	Matsushita - Panasonic	Japan
10.	Fuji Electric	Japan

Control and protection systems

1.	ABB	Switzerland
2.	General Electric	USA
3.	Schneider Electric	France
4.	Toshiba	Japan
5.	Siemens	Germany
6.	KEPCO - Korea Electric Power	South Korea
7.	State Grid Corp China	China
8.	Mitsubishi Electric	Japan
9.	Alstom	France
10.	LS Industrial Systems	South Korea

Smart substations

1.	ABB	Switzerland
2.	General Electric	USA
3.	Siemens	Germany
4.	State Grid Corp China	China
5.	Toshiba	Japan
6.	Hitachi	Japan
7.	Fuji Electric	Japan
8.	Schneider Electric	France
9.	Beijing Sifang Automation	China
10.	Schweitzer Engineering Lab	USA

Innovative controllable power components

1	ABB	Switzerland
2	General Electric	USA
3	Schneider Electric	France
4	Siemens	Germany
5	Toshiba	Japan
6	KEPCO - Korea Electric Power	South Korea
7	Fuji Electric	Japan
8	Mitsubishi Electric	Japan
9	Chugoku Epco	Japan
10	Hitachi	Japan

ICT systems

1	General Electric	USA
2	ABB	Switzerland
3	Siemens	Germany
4	Toshiba	Japan
5	Schneider Electric	France
6	Mitsubishi Electric	Japan
7	ITRON	USA
8	KEPCO - Korea Electric Power	South Korea
9	LG	South Korea
10	Hitachi	Japan

Power electronics

1	Matsushita - Panasonic	Japan
2	Siemens	Germany
3	Infineon Technologies	Germany
4	Fuji Electric	Japan
5	Mitsubishi Electric	Japan
6	Hitachi	Japan
7	ABB	Switzerland
8	CREE Inc	USA
9	Fujitsu	Japan
10	NXP Semiconductors	The Netherlands

Demand-response applications

1	Toshiba	Japan
2	Schneider Electric	France
3	Emerson Electric	USA
4	Responsive Load	United Kingdom
5	Ecofactor	USA
6	General Electric	USA
7	Whirpool	USA
8	Lutron Electronics	USA
9	Mitsubishi Electric	Japan
10	Nest Labs (Now within Google)	USA

Theme 10

Rank	Assignee	Region

Wind energy

1.	WOBBEN ALOYS	EU
2.	VESTAS WIND SYS AS	EU
3.	GEN ELECTRIC	USA
4.	REPOWER SYSTEMS AG	EU
5.	NORDEX ENERGY GMBH	EU
6.	SIEMENS AG	EU
7.	STATE GRID CORP CHINA	China
8.	WOBBEN PROPERTIES GMBH	EU
9.	MITSUBISHI HEAVY IND LTD	Japan
10.	REPOWER SYSTEMS SE	EU

Solar Heating and Cooling

1.	MATSUSHITA ELECTRIC IND CO LTD	Japan
2.	TANIGAWA KAZUNAGA	Japan
3.	TANIGAWA HIROYASU	Japan
4.	MATSUSHITA ELECTRIC WORKS LTD	Japan
5.	OWENS ILLINOIS INC	USA
6.	SANYO ELECTRIC CO	Japan
7.	UNIV KUNMING SCIENCE TECH	China
8.	FUZHOU AQUAPOWER ELECTRIC WATER HEATER CO LTD	China
9.	UNIV SOUTHEAST	China
10.	SIEMENS AG	EU

Hydropower

1.	ACCESS BUSINESS GROUP INT LLC	USA
2.	PYROPHASE INC	USA
3.	BOSCH GMBH ROBERT	EU
4.	GEN ELECTRIC	USA
5.	PARK SEONG SOO	South Korea
6.	WRIGHT MFG INC	USA
7.	UNIV VINNYTSIA NAT TECH	Others (Ukraine)
8.	RAVEN ENERGY ALTERNATIVES LLC	USA
9.	VOITH SIEMENS HYDRO POWER	EU
10.	UNIV VINNYTSIA NAT TECH	USA

Photovoltaic Energy

1.	CANON KK	Japan
2.	COMMISSARIAT ENERGIE ATOMIQUE	EU
3.	DU PONT	USA
4.	SANYO ELECTRIC CO	Japan
5.	IBM	USA
6.	SHARP KK	Japan
7.	GEN ELECTRIC	USA
8.	SAINT GOBAIN	EU
9.	KONARKA TECHNOLOGIES INC	Japan
10.	HITACHI CHEMICAL CO LTD	Japan

Ocean Energy

1.	CAMERON INT CORP	USA
2.	HYDAM TECHNOLOGY LTD	EU
3.	OTTERSEN HANS OLAV	Norway
4.	AUSTRALIAN SUSTAINABLE ENERGY	Others (Australia)
5.	PETROLEO BRASILEIRO SA	EU
6.	OCEAN POWER TECHNOLOGIES INC	USA
7.	WAVEPISTON APS	EU
8.	SEA ENERGY CORP	EU
9.	PHILLIPS REED E	USA
10.	MICHAELIS DOMINIC	EU

Combined Heat and Power from Biomass

1.	UNIV NORTH CHINA ELEC POWER	China
2.	CENTRAL RES INST ELECT	Japan
3.	COMMUNITY POWER CORP	USA
4.	IND ECOSYSTEMS PTY LTD	Others (Australia)
5.	UPM KYMMENE OYJ	Others (Finland)
6.	QIN CAIDONG	China
7.	FERGUSON ROGER	EU
8.	WUHAN KAIDI ENG TECH RES INST	China
9.	VATTENFALL AB	EU
10.	KANAI OFFICE CORP	Japan

Concentrating Solar Power

1.	YEOMANS ALLAN JAMES	Others (Australia)

2.	CARDING SPEC CANADA	Others (Canada)
3.	ENVIRONMENTAL SECURITY INC	USA
4.	STARK VIRGIL	USA
5.	MITSUBISHI HEAVY IND LTD	Japan
6.	JOST ALFRED	USA
7.	HARRISON JOHN	USA
8.	ABENGOA SOLAR NEW TECH SA	EU
9.	SOLOMON FRED D	USA
10.	PULSAR ENERGY INC	USA

Geothermal Energy

1.	MATSUSHITA ELECTRIC IND CO LTD	Japan
2.	HITACHI LTD	Japan
3.	MITSUBISHI ELECTRIC CORP	Japan
4.	TOSHIBA CORP	Japan
5.	CANON KK	Japan
6.	MITSUBISHI HEAVY IND LTD	Japan
7.	GEN ELECTRIC	USA
8.	SIEMENS AG	EU
9.	DENSO CORP	Japan
10.	SANYO ELECTRIC CO	Japan

Theme 11

Rank	Assignee	Region

Carbon Capture and Storage

1.	ALSTOM TECHNOLOGY LTD	EU
2.	ALSTOM TECHNOLOGY LTD	EU
3.	CALERA CORP	USA
4.	GEN ELECTRIC	USA
5.	EXXONMOBIL RES ENG CO	USA
6.	LANZATECH NEW ZEALAND LTD	Others (New Zealand)
7.	DOW CHEMICAL CO	USA
8.	LEWIS TYREE JR	USA
9.	BIOPROCESSORS CORP	USA
10.	NIPPON STEEL CORP	Japan

Conversion of captured CO_2 to useful products

1.	TANIGAWA KAZUNAGA	Japan
2.	TANIGAWA HIROYASU	Japan
3.	ALSTOM TECHNOLOGY LTD	EU
4.	TEXACO DEVELOPMENT CORP	USA
5.	NORSK HYDRO AS	EU
6.	SNAM PROGETTI	EU
7.	CHEVRON USA INC	USA
8.	MITSUBISHI HEAVY IND LTD	Japan
9.	ISHIKAWAJIMA HARIMA HEAVY IND	Japan
10.	GEN ELECTRIC	USA

Clean Coal and Flexible/Back-up Generation for conventional thermal power plants

1.	HITACHI LTD	Japan
2.	SIEMENS AG	EU
3.	MITSUBISHI HEAVY IND LTD	Japan
4.	TOSHIBA CORP	Japan
5.	GEN ELECTRIC	US
6.	MATSUSHITA ELECTRIC IND CO LTD	Japan
7.	MITSUBISHI ELECTRIC CORP	Japan
8.	STATE GRID CORP CHINA	China
9.	TOSHIBA KK	Japan
10.	G OBRAZOVATEL NOE UCHREZHDENIE	Others (Norway)

Unconventional Fossil Fuels

1.	HITACHI LTD	Japan
2.	SIEMENS AG	EU
3.	TOSHIBA CORP	Japan
4.	GEN ELECTRIC	Japan
5.	MITSUBISHI HEAVY IND LTD	Japan
6.	WESTINGHOUSE ELECTRIC CORP	USA
7.	ALSTOM TECHNOLOGY LTD	EU
8.	WOBBEN ALOYS	EU
9.	KVASENKOV OLEG IVANOVICH	Others (Russia)
10.	SHIMIZU CONSTRUCTION CO LTD	Japan

Theme 12

Rank	Assignee	Region
1.	Areva	Europe
2.	Westinghouse –GE	US
3.	Atomstroyexport	Russia
4.	Mitsubishi	Japan
5.	AECL	Canada
6.	KHNP	South Kore
7.	CNNC	China
8.	EON	Europe
9.	SSE	UK
10.	RWE	Europe
11.	Exelon	UK

Theme 13

Sustainable Advanced Biofuels

1.	SCRIPPS RESEARCH INST	USA
2.	SAPPHIRE ENERGY INC	USA
3.	CODEXIS INC	USA
4.	BIO ARCHITECTURE LAB INC	USA
5.	CHEVRON USA INC	USA
6.	SAPPHIRE ENERGY	USA
7.	GEOSYNFUELS LLC	USA
8.	UNIV MICHIGAN STATE	USA
9.	TEXAS A M UNIV SYS	USA
10.	ALLTECH INC	USA

Hydrogen and Fuel Cells

1.	MATSUSHITA ELECTRIC IND CO LTD	Japan
2.	SIEMENS AG	EU
3.	HITACHI LTD	Japan
4.	MITSUBISHI ELECTRIC CORP	Japan
5.	GEN ELECTRIC	USA
6.	CANON KK	Japan
7.	BOSCH GMBH ROBERT	EU
8.	SONY CORP	Japan
9.	TOSHIBA CORP	Japan

10.	SAMSUNG ELECTRONICS CO LTD	South Korea

Advance Alternative Fuels

1.	ALSTOM TECHNOLOGY LTD	EU
2.	ASHLAND OIL INC	USA
3.	SNAM PROGETTI	EU
4.	TANIGAWA KAZUNAGA	Japan
5.	TANIGAWA HIROYASU	Japan
6.	METALLGESELLSCHAFT AG	EU
7.	BASF AG	EU
8.	TOPSOE HALDOR AS	EU
9.	MITSUBISHI HEAVY IND LTD	Japan
10.	VOEST ALPINE IND ANLAGEN	EU

VI.B. **Consultation summaries for stakeholder engagement**

Integrated Challenge 1

Thanks to the support provided by the Stakeholder Forum, it was possible to formulate some questions to stakeholders[38] that helped to understand better which are the main technological fields involved, and to define the research area.

The following questions were submitted to the stakeholders:

1. What do you consider as part of a 'smart grid'?
    a. Everything that can be managed through ICT and electricity technologies, from the energy distribution network to the building facilities
    b. Just the energy supply side network infrastructure
    c. Just the electricity distribution network infrastructure at the consumer level
    d. Other
2. Which do you think are the latest/newest/'hottest' technologies, products and services that are currently being developed, and which could help to make consumers and prosumers more active in interacting with the energy market?
3. Which are the smart technologies, products and services you think should be deployed first, in order to establish large-scale smart grids? List three of them.
4. How influential/useful/fundamental would you consider to have an energy simulation software that allow to integrate data about a smart grids up to Home Energy Management Systems (HEMSs), to foster/support investments in the smart metering and technology sectors? Please, rate it with a number, from 0 to 5 (being 0 equal to 'not influential/useful at all', and 5 equal to 'very influential/useful').

Theme 1

Supplementary to the research undertaken by the consortium on Theme 1 of the SET Plan, a group of practitioners in the field of energy economics, renewable energy, energy efficiency, and other related disciplines provided insights on innovation and policy measures to increase consumer engagement in the energy system. In total 16 stakeholders participated in an online survey from 13 April-20 May. Participants were from a variety of different sectors, including Non-profit/Non-governmental (5), Business/Industry (4), Governmental (3), Academia (2), Scientific and Technological Community (1), and Intergovernmental (1). Between them, there was strong agreement that financial incentives and disincentives are generally the most effective programs in encouraging individuals and organisations to change their energy consumption behaviour. In particular, programs that provide subsidies or rebates for consumers to invest in energy saving technologies and adopt low-waste energy measures are regarded as effective ways to change consumer behaviour. To reinforce the principal of financial motivation, there was also recognition that taxing 'dirty' sources of energy or energy inefficient technologies can also lead to behaviour change. Other examples worth noting are: lightbulb replacement programs, which require or

[38] The stakeholders included targeted contacts from our stakeholder database of over 900 individuals as well as broader involvement through an online questionnaire response survey

encourage consumers to use more energy efficient lighting products; Ecolabeling; Energy audits; and household clean energy potential assessments, among others.

The general perception is that consumers are passive in energy systems because it is considered too expensive and 'too technical' to engage. It is widely cited by the sample that participation in energy systems requires high up-front costs and a deep understanding of energy markets. To improve consumer engagement, there is strong support for utility companies to provide service users with more user friendly information. In particular, it is suggested that they could do a better job of explaining the pros and cons of energy alternatives, and provide practical tips on how to conserve energy. One way utility companies can meaningfully inform their customers is to provide more user friendly invoices that clearly explain the costs embedded in the bill. Another common suggestion is to make smart meters more widely available to inform customers about their household energy use. Key ways in which governments can encourage consumers to participate in energy systems is to provide tax incentives for people to use energy saving measures and install their own renewable energy technologies. In addition, governments can help invest in local/decentralised energy markets that enable communities to generate and share their own energy. Other common suggestions is for governments to remove barriers in implementing renewable energy projects, use market mechanisms to make carbon intensive sources of energy uncompetitive, and use education campaigns to raise awareness about the social, economic and environmental benefits of a clean energy transition.

Theme 2

Supplementary to the research undertaken by the consortium for theme 2 of the SET Plan, a group of practitioners in traditional and renewable energy provided insights on innovation and policy measures to activate consumers through new technologies, products and services. In total, 10 stakeholders participated in an online survey from 13 April - 20 May. Participants were from a variety of different sectors, including Academia (3), Business/Industry (2), Intergovernmental (2), Non-Profit/Non-Governmental (1), and Scientific and Technological Community (1). The participants identified the following institutions as international leaders for the theme:

Academia	**Private Sector**
1.Fraunhofer Institute	1.Schneider
2.Environmental Research Institute, UCC, Cork	1.Siemens
2.Massachusetts Institute of Technology	2.American Council On Renewable Energy
3.Lappeenranta University of Technology	2.ABB
3.Aalto University	2.China Renewable Energy group of Industry
4.Cambridge University	2.Eco-Business.com
4.Chemnitz Technical University	2.ECOFYS
4.Energy Research Centre of The	2.Elster

Netherlands

4.Harvard	2.Elk: Passive houses, zero energy houses
4.Imperial College London	2.Enercon: Windmill
4.Karlsruhe Institute of Technology	2.Fronius: PV
4.Leonardo Energy	2.Green,Ethical, Fire
4.Massachusetts Institute of Technology	2.Honeywell
4.National University of Ireland, Galway	2.MAC Energy
4.Oxford	2.Naturstrom
4.Queens University, Belfast	2.Opower
4.TU Wien	2.Plan ET
4.UKerc	2.SEAM group
4.University of California, Berkeley	2.Tesla
	2.There Corporation
	2.Vestas
	2.Yahoo

In addition, survey participants were asked **to rank the level of involvement by the European Union** in developing innovative technologies, products and services. The sample clearly believes that the EU is proactively engaged in this field. Answers ranged from 'Moderately involved' to 'Very Highly involved', with the median level assessed being "Moderately High". The survey also evaluated stakeholder perceptions of the **EU's capacity to advance innovation in the field**. Answers ranged from 'Moderate Capacity' to 'Very High Capacity', with the median being 'High Capacity'.

Theme 3

Supplementary to the research undertaken by the consortium for theme 3 of the SET Plan, a group of practitioners from the fields of industrial development, renewable energy, energy efficiency, data analytics, climate change and other multi-disciplinary fields provided insights on innovation in building energy efficiency. In total, 10 stakeholders participated in an online survey from 13 April - 20 May. Participants were from a variety of different sectors, including: Intergovernmental (3), Academia (2), Governmental (2), Non-Profit/Non-Governmental (2), Scientific and Technological Community (1), and Bilateral Agency (1). The participants identified the following institutions as international leaders for the field in question:

Academia	**Private Sector**
1.ADICONSUM	1.Adene
1. Massachusetts Institute of Technology	1.Adiconsum

2. Chemnitz Technical University	1.BerlinBerlin's energy technology industry
2. European Network for the Energy Performance Certification of Buildings	1.American Council On Renewable Energy (ACORE)
2.Fraunhofer Institute	1.Apple
2.Heriot-Watt University	1.CBRE
2.Imperial College London	1.Confederation of British Industry (CBI)
2.IWU, Darmstadt	1.Eco-Business.com
2.Joint Research Centre (JRC)	1.Elk
2.Leonardo	1.Escan
2 Masdar Institute of Abu Dhabi	1.Google
2.Oxford University's Environmental Change Institute	1.Green,Ethical, Fire
2.Rutgers university	1.Ingra
2.TU Wien	1.Korea Energy Management Corporation
2.University College of London	1.Open Energy Efficiency
2.University of California, Berkeley	1 Renewable Funding
2.University of California, Davis	1.Retroficiency
2.University of California, Santa Barbara	1.Schnieder Electric
2. University of Chicago / Center for Data Science and Public Policy	1.ZRMK Institut
2.University of Dayton	

In addition, survey participants were asked to **rank the level of involvement by the European Union** in advancing energy efficiency in the building sector. An overwhelming majority feel the EU is proactive in this field. When asked to rank the level of involvement, most respondents provided answers ranging from 'Moderate' to 'Very High', with the median being: Moderately High. In regards to ranking the EU's level of capacity to advance building energy efficiency, answers ranged from 'Moderate' to 'Very High', with the median being the same as the previous question: Moderately High.

Theme 4

Supplementary to the research undertaken by the consortium for theme 4 of the SET Plan, a group of practitioners from a number of energy fields provided insights on innovation for energy efficiency in heating and cooling. In total, 4 stakeholders participated in an online survey from 13 April - 20 May. Participants were from a variety of different sectors, including Academia (1), Intergovernmental (1), Non-Profit/Non-Governmental (1), and Scientific and Technological Community (1). The participants identified the following institutions as international leaders for the theme:

Academia	Private Sector
1.Chalmers	1.Abb
1.Chemnitz Technical University	1.American Council On Renewable Energy (ACORE)
1.EPFL	1.China Renewable Energy group
1.Imperial College London	1.E.on
1.IRENA	1.Edf
1.Leonardo Energy	1.Nibe
1.Linköping University of Technology	1.Schneider Electric
1.Massachusetts Institute of Technology	
1.SP Technical Research Institute of Sweden	
1.T.U Delft	

In addition, survey participants were asked to **rank the level of involvement by the European Union** in advancing innovation in the field of energy efficiency for heating and cooling. With a small sample size it is hard to fully gauge stakeholder views on the EU's role in the sector. However, of the four respondents, three feel the **EU has "Very High" involvement** in advancing innovation in the field. The outlier evaluated the EU to have a "moderate" level of involvement in advancing innovation in heating and cooling and noted that the "EU plays a much larger role in developing technology breakthroughs for energy transmission and gas". When it came to assessing the **EU's capacity for advancing innovation in the field**, all stakeholders were in agreement that the EU has a 'Very High' capacity.

Theme 5

Supplementary to the research undertaken by the consortium for theme 5 of the SET Plan, a group of practitioners from the fields of industrial development, renewable energy, energy efficiency, data analytics, climate change and other multi-disciplinary fields provided insights on innovation in building energy efficiency. In total, 10 stakeholders participated in an online survey from 13 April - 20 May. Participants were from a variety of different sectors, including: Intergovernmental (3), Academia (2), Governmental (2), Non-Profit/Non-Governmental (2), Scientific and Technological Community (1), and Bilateral Agencies (1). The participants identified the following institutions as international leaders for the theme:

Academia	Private Sector
1. Fraunhofer Institutee	1.Johnson Controls

1. Massachusetts Institute of Technology	1.Siemens
2. Chemnitz Technical University	2.ABB
2. Energy University, Schneider Electric	2.American Council On Renewable Energy (ACORE)
2.Forschungsstelle Energiewirtschaft Ffe	2.China Renewable Energy group
2. IIT	2.Crupe
2.Imperial College London	2.DNV-GL Energy
2.International Energy Agency (IEA)	2.IIP
2.IREES Institute of Resource Efficiency and Energy Strategies, Karlsruhe	2.Osram
2.IRENA	2.Phillips
2 Joint Research Centre (JRC)	2.Reliance
2. Laboratory of Energy and Environment LEA, Portugal	2.Root3
2. Leonardo Energy	2.Schnieder Electric
2. Linköping University, Sweden	2.Swedish Steel Producers' Association/European Climate Foundation
2. Masdar Institute of Abu Dhabi	
2.National Technical University of Athens, Greece	
2. University of California, Berkeley	
2.University of Illinois, Chicago	
2. University of Texas, Austin	
2. Wuppertal Institute for Climate, Environment and Energy	

In addition, survey participants were asked to **rank the level of involvement by the European Union** in increasing energy efficiency in the industrial sector. The EU is considered to be highly engaged in the field, with a majority of respondents stating "Very High" involvement. Other answers ranged from "High" to "Moderate". Also, the stakeholders sampled in the survey believe the EU has a **large capacity to continue steering innovation in the industrial sector**. A majority of respondents believe the EU has a "High" level of capacity, while other answers ranged from "Very High" to "Moderate".

Theme 7

Supplementary to the research undertaken by the consortium for theme 7 of the SET Plan, a group of practitioners from the fields of renewable energy, energy storage, energy efficiency, and other multi-disciplinary fields provided insights on innovation in energy storage and the conversion of electricity to other energy carriers. In total, 12 stakeholders participated in an online survey from 13 April - 20 May. Participants were from a variety of different sectors, including: Business/Industry (6) Academia (2), Intergovernmental (1), Governmental (2), Non-Profit/Non-Governmental (1), and the Scientific and Technological Community (1). The participants identified the following institutions as international leaders for the theme:

Academia	**Private Sector**
1. Massachusetts Institute of Technology	1.Tesla
2. Fraunhofer Institutee	2. Siemens
3. NREL	3. SAFT
4.ACoRe	4.A123
4.CEA	4.ACoRe
4.Centre for Energy Technologies, Aarhus University Herning	4.Air Liquide for hydrogen
4.Department of Physics & Energy at University of Limerick	4.Alstorm
4.EASE or European Association for Storage of Energy	4.Andritz
4.ETH Zurich	4.BYD
4.Flensburg	4.DNV GL
4.HamburgTechnical Institute	4.E.ON
4.Harvard University	4.EDF
4.IISc, Bangalore	4.Elin
4. IIT Mumbai	4.Exide
4. MESC Consortium	4.GAELECTRIC
4.Technical University of Denmark	4.IRENA
4.Technion	4.LG Chemicals
4.Tel Aviv University	4.Panasonic
4.TU Delft	4.Samsung SDI

4.University of Toronto

4.University of Newcastle, Australia

In addition, survey participants were asked to **rank the level of involvement by the European Union** in advancing energy storage and the ability to convert electricity to other energy carriers. The overall feeling is that the EU's level of involvement in the field is between "moderate" to "high". In addition, the sample believes the EU has an even greater capacity to advance innovation in energy storage. All of the participants evaluate the EU's **capacity to support innovation to be "high" or "very high"**, suggesting the EU has the opportunity to play an even bigger role in supporting future developments in the field.

Theme 8

Supplementary to the research undertaken by the consortium for theme 8 of the SET Plan, a group of practitioners from the fields of renewable energy, energy efficiency, information systems and other multi-disciplinary fields provided insights on innovation in energy system flexibility, security and cost-effectiveness. In total, 6 stakeholders participated in an online survey from 13 April - 20 May. Participants were from a variety of different sectors; including Academia (2), Intergovernmental (1), Governmental (1), and Non-Profit/Non-Governmental (2). The participants identified the following institutions as international leaders for the theme:

Academia	**Private Sector**
1.ECL	1.Akuo Energy
1.ECN	1.Ankur Gassifiers
1.IER	1.EON
1.IISc	1.GDF Suez
1.IIT Delhi	1.IEA
1.IIT Mumbai	1.NREL
1.Rocky Mountain Institute	1.Siemens
1.TERI	1.Tata BP Solar
1.University of Oldenburg, Germany	

In addition, survey participants were asked to **rank the level of involvement by the European Union** in advancing innovation in the fields of energy system flexibility, security and cost-effectiveness. The general sentiment is that the EU's level of involvement is "moderate". For the future growth of the sector, the respondents gauge the EU to **have a "high" capacity** to advance change in the field.

Theme 9

Supplementary to the research undertaken by the consortium for theme 9 of the SET Plan, a group of practitioners from energy management, urban energy systems, clean tech and other multi-disciplinary fields provided insights on innovation in smart cities and communities. In total, 7 stakeholders participated in an online survey from 13 April - 20 May. Participants were from a variety of different sectors, including: Business/Industry (3), Scientific and Technological Community (2), Intergovernmental (1), Governmental (1), and Media (1).

Academia	**Private Sector**
1. Massachusetts Institute of Technology	1.Tesla
2. Fraunhofer Institutee	2. Siemens
3. NREL	3. SAFT
4.ACoRe	4.A123
4.CEA	4.ACoRe
4.Centre for Energy Technologies, Aarhus University Herning	4.Air Liquide for hydrogen
4.Department of Physics & Energy at University of Limerick	4.Alstorm
4.EASE or European Association for Storage of Energy	4.Andritz
4.ETH Zurich	4.BYD
4.Flensburg	4.DNV GL
4.HamburgTechnical Institute	4.E.ON
4.Harvard University	4.EDF
4.IISc, Bangalore	4.Elin
4. IIT Mumbai	4.Exide
4. MESC Consortium	4.GAELECTRIC
4.Technical University of Denmark	4.IRENA
4.Technion	4.LG Chemicals
4.Tel Aviv University	4.Panasonic
4.TU Delft	4.Samsung SDI
4.University of Toronto	
4.University of Newcastle, Australia	

To begin the survey, participants were asked to define the meaning of "holistic system optimisation" for smart cities. The general conjecture is that the term implies: Integrated planning of all technological and energy systems for the benefit of resource efficiency and social well-being. Once participants defined some principles associated with smart cities and communities, they were asked to rank which services have the greatest impact in making an urban/local area "smart". On a scale, participants ranked "Rate of energy "self-sufficiency" to be the most important followed evenly by "Strict local pollutant limits" and "public transportation network development". The fourth item on the list was geospatial information, which was regarded as "important", but did not have the same emphasis as the other options. In addition, respondents' comments stressed the role of local natural resources (i.e. food and energy) and its contributions to smart cities.

To complement views on factors that contribute to the development of smart cities, respondents were also asked to provide a list of barriers to the implementation of the concept on universal scale. The most common answers among the sample were in order 1) costs/funding, 2) lack of public knowledge/interest, and 3) special interests. Lastly, respondents were asked to evaluate the phase of development/demonstration of a holistic approach at the urban level in the EU. On a grading scale of "Highly un-advanced" to "Highly advanced", the general sentiment is that the EU is "Moderately advanced".

Theme 10

No information gathered

Theme 11

Supplementary to the research undertaken by the consortium for theme 11 of the SET Plan, a group of practitioners from the fields of carbon capture and storage, the oil and gas industry, renewable energy, and other multi-disciplinary fields provided insights on innovation related to carbon capture, and energy efficiency in the fossil-fuel sector. In total, 9 stakeholders participated in an online survey from 13 April - 20 May. Participants were from a variety of different sectors, including: Business/Industry (3), Non-profit/Non-governmental (3), Academia (2), and Intergovernmental (1).The participants identified the following institutions as international leaders for the theme:

Academia	**Private Sector**
1. University of Edinburgh	1.Shell
2. Massachusetts Institute of Technology	2.Summit Power
2. Stanford University	3.BP
2. University of Texas	3.Statolli
3.Fraunhofer Institutee	4.Alstom
3.Global CCS Institute	4.Arch Coal
3.IFPEN	4.Chevron
3.Imperial College	4.Ciuden

3.Princeton (CMI Programme)

3.University of Regina

3.SINTEF

3.TNO

3.UIT, India

3.University of Adelaide (Australia)

3.University of Nottingham

3.University of Regina

3. University of West Virginia

4.Denbury

4.E.ON Benelux in partnership with GDF Suez

4.Endesa

4.Exxon

4.Foster Wheeler

4.MHI

In addition, survey participants were asked to rank the **level of involvement by the European Union** in advancing carbon capture, CO_2 utilisation and GHG storage technologies. Overall, the sample evaluates the EU to have a "moderate" level of involvement in the field. It was also noted that the level of involvement has digressed over the past 5 years with the "failure of the European Energy Programme for Recovery and NER300 programmes". Based on the survey results, the EU's current involvement in the field is falling short of its capacity. The general sentiment is that the **EU has a "high capacity" to support innovation in the field.** Although there is a feeling that the EU could do more in this sector, compared to other regions of the world, there is a feeling that Europe is a leader in the design and deployment of carbon capture and sequestration projects.

Theme 12

Supplementary to the research undertaken by the consortium for theme 12 of the SET Plan, a group of practitioners from the fields of energy and infrastructure, science education, energy policy, and other multi-disciplinary fields provided insights on the efficient operation of nuclear systems, development of innovative reactor concepts and sustainable solutions for the management of fissile materials and radioactive waste. In total, 5 stakeholders participated in an online survey from 13 April - 20 May. Participants were from a variety of different sectors: Academia (3), Business/Industry (1), and Non-profit/Non-governmental (1).The participants identified the following institutions as international leaders for the theme:

Academia

1.American National Laboratories (Idaho, Pacific North, Sandia)

1.Commissariat à l'énergie atomique

1.Electric Power Research Institute

1.Massachusets Institute of Technology

Private Sector

1.Areva

1.Westinghouse

2.GE-Hitachi

2.NuScale

1.University of California, Berkeley	2.PG&E
	2.Rosatom

In addition, survey participants were asked to rank the **level of involvement** by the European Union in the efficient operation of nuclear systems, development of innovative reactor concepts and sustainable solutions for the management of fissile materials and radioactive waste. Overall, the sample believes the EU demonstrates a "low" level of involvement in the field and one participant went as far to say that the EU is "mostly thwarting any progress in this area". However, it was difficult to assess the sample's general assessment on the EU's **capacity to steer innovation** in the field. Answers were ranged on a scale from "high capacity" to "very low capacity". Based on the comments, there seems to be uncertainty among stakeholders about the direction of the sector. This could be attributed to commitments by a number of EU countries to phase-out nuclear power, while some other EU countries have decided to increase investment in the controversial energy.

Theme 13

Supplementary to the research undertaken by the consortium for theme 13 of the SET Plan, a group of practitioners from the fields of renewable energy, energy efficiency, engineering, public policy and other multi-disciplinary fields provided insights on the development of sustainable biofuels, fuel cells and hydrogen and alternative fuels. In total, 11 stakeholders participated in an online survey from 13 April - 20 May. Participants were from a variety of different sectors: Non-profit/Non-governmental (3), Academia (2), Business/Industry (2), Governmental (2) and the Scientific and technological community (2).The participants identified the following institutions as international leaders for the theme:

Academia	**Private Sector**
1.University of California	1.Addax
2.NREL	1.Biochemtex
3.Asian Institute for Technology, Bangkok	1.British Airways
3.Swiss Federal Institute of Technology Lausanne	1.Chemrec
3.Environmental and Energy Study Institute	1.Clariant
3.EU JRC IE	1.Greenergy
3.Gerogia Tech	1.IRENA
3.IFPRI	1.Lanzatech
3.Imperial College	1.Neste Oil
3.International Crop Research Institute	1.Sky NRG
3.South African National Energy Research	1.ST1 Finland

Institute	
3.Tsinghua University	1.Sustainable Solutions, LLC
3.University of Colorado	1.Virgin Air
3.University of Sao Paulo, Brazil	
3.Wageningen University	

In addition, survey participants were asked to rank the **level of involvement** by the European Union in developing sustainable biofuels, fuel cells and hydrogen and alternative fuels. Overall, the sample believes the EU demonstrates a "moderate" to "high" level of engagement in the field. For the future growth of the sector, the respondents gauge the EU to have a "high" to "very high" **capacity** to support the development of alternative fuel.

VI.C. **Data Tables**

Available as a separate document.