Climate change mitigation technologies in Europe – evidence from patent and economic data

UNEP
United Nations Environment Programme

Europäisches Patentamt
European Patent Office
Office européen des brevets

The full report can be downloaded from:
www.epo.org/climate-europe

This study has been conducted in co-operation with the Grantham Research Institute on Climate Change and the Environment at the London School of Economics and Political Science (http://www.lse.ac.uk/GranthamInstitute)

Grantham Research Institute on Climate Change and the Environment

LSE The London School of Economics and Political Science

Cover
Solar, wind and biomass energy sources, Germany

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FOREWORD

"We must act now to slow the alarming pace of climate change and environmental degradation, which pose unprecedented threats to humanity"
(United Nations Post-2015 Development Agenda).

Climate change is one of today's truly global challenges, affecting all aspects of socio-economic development in every region of the world. Limiting the emissions of greenhouse gases (GHG) while achieving the other 16 goals of the UN Post-2015 Development Agenda, which include eradicating hunger and poverty, and ensuring access to modern energy for all, is all the more challenging. The problem is further exacerbated by a constantly increasing world population, expected to reach 9 billion people by 2050, with an ever-larger emerging middle class, whose standards of living involve higher energy consumption.

The 21st Conference of Parties of the United Nations Framework Convention on Climate Change (UNFCCC) represents a milestone in over 20 years of negotiations. The Parties aim to conclude an international legally binding agreement to replace the Kyoto Protocol of 1997, designed to limit GHG emissions in all signatory states.

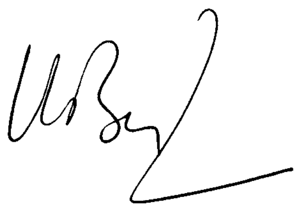
Technology and innovation have a key role to play in meeting these requirements, as shown by the decision taken in Cancún in 2010 to establish the "Technology Mechanism" in support of innovation and global technology dissemination.

As an innovation support system for technology, the patent system contributes to this scenario. It is designed to promote innovation and the diffusion of new technology. Moreover, it is an extremely powerful tool for measuring innovation and disseminating information, ultimately contributing to a more transparent and balanced knowledge economy.

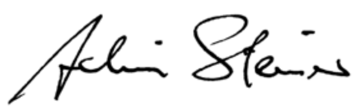
The European Patent Office (EPO) joined forces with the United Nations Environment Programme (UNEP) and the International Centre for Trade and Sustainable Development (ICTSD) in 2009 to investigate the role of the patent system in climate change-related technologies and provide evidence to support an informed debate. A first study, on "Patents and clean energy technologies" (CETs), was published in 2010. This was followed by two EPO-UNEP studies with a regional focus on Africa and Latin America, in 2013 and 2014 respectively.

These studies were made possible through the development of the Y02/Y04S, a dedicated tagging scheme and searchable database for CETs. This has since been expanded to cover all significant climate change mitigation technologies (CCMTs) in energy, carbon capture, transport, buildings, waste, energy-intensive industries and smart grids. The scheme has also supported numerous climate-related research projects in academia and has facilitated public access to information on climate change-related technologies through its user-friendly structure. Over 2.8 million patent documents and their technical disclosures are now readily available, worldwide and free of charge, via the internet, providing the world's most comprehensive documentation of technological solutions relevant to climate change.

This most recent EPO-UNEP study focuses on Europe, linking patent trends with relevant economic data on investments, trade and technology transfer in CCMTs. The report provides a clear and comprehensive picture of the contribution of Europe to CCMT development and dissemination. It is hoped that this wealth of data, some of which is published here for the first time, can provide useful input for a constructive policy debate on technology.



Benoît Battistelli,
President, European Patent Office



Achim Steiner,
Under Secretary General of the United Nations and Executive Director, United Nations Environment Programme

EXECUTIVE SUMMARY

In October 2014, the European Union committed to reduce greenhouse gas emissions by at least 40% by 2030 compared to 1990 levels. This represents a significant challenge, which can only be met through the development and deployment of new climate change mitigation technologies (CCMTs).

The present study analyses the position of Europe in the global race to develop new CCMTs, using data on patent applications, trade in CCMT capital goods, foreign direct investment in CCMTs, climate change policy stringency, carbon emissions and public expenditure on CCMT research and development activities, to investigate inventive and associated economic activity in CCMTs in Europe.

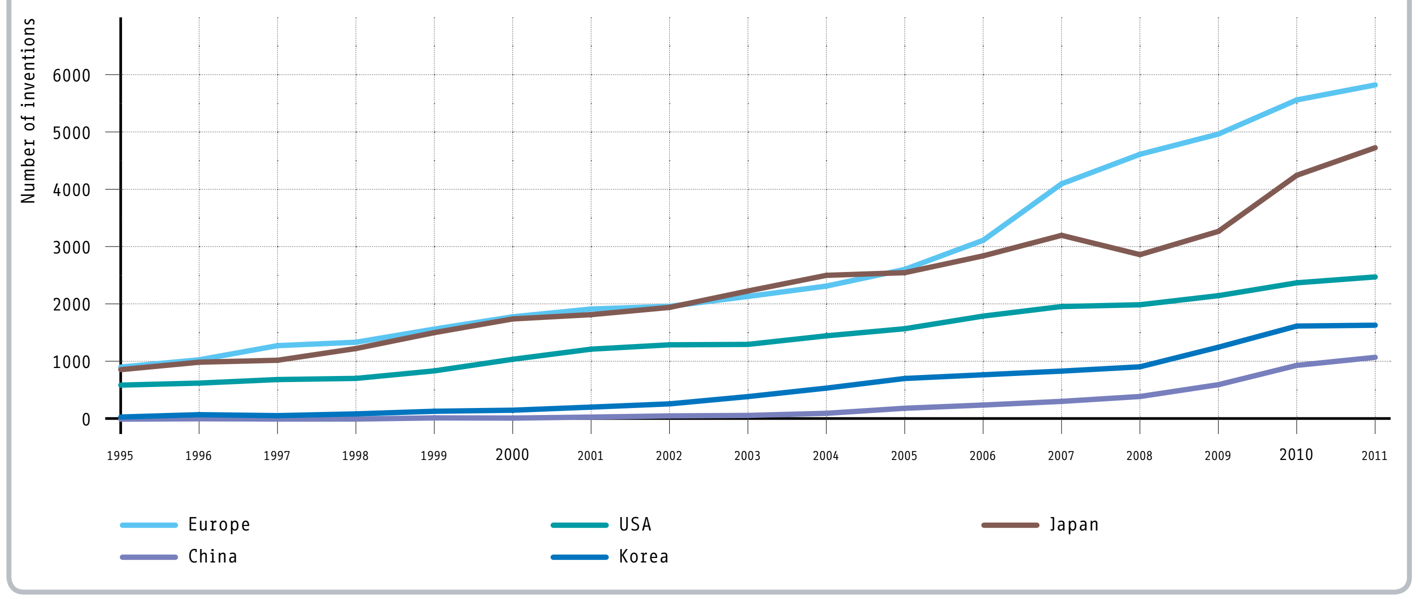
The main source of data was the Worldwide Patent Statistical Database (PATSTAT), developed by the European Patent Office (EPO). This publicly available database is the world's largest repository of patent information, containing data on over 82 million patent applications. The EPO has developed a dedicated classification scheme for CCMTs (using the Y02 and Y04S tags) that makes it possible to analyse CCMT-related trends in inventive activity and in the global technology market, and to provide evidence to support public and private decision-making.

At the global level, the last decades have seen a continuous expansion of inventive activity in climate change mitigation technologies. The growth in CCMT inventions has been much faster than in other technologies, and CCMTs today represent nearly 6% of global invention activity, up from 1.5% in 1990. There is good reason to believe that the implementation of climate change policies in many countries – such as taxes on polluting emissions, or feed-in tariffs for renewable energy – has played a key role in this development.

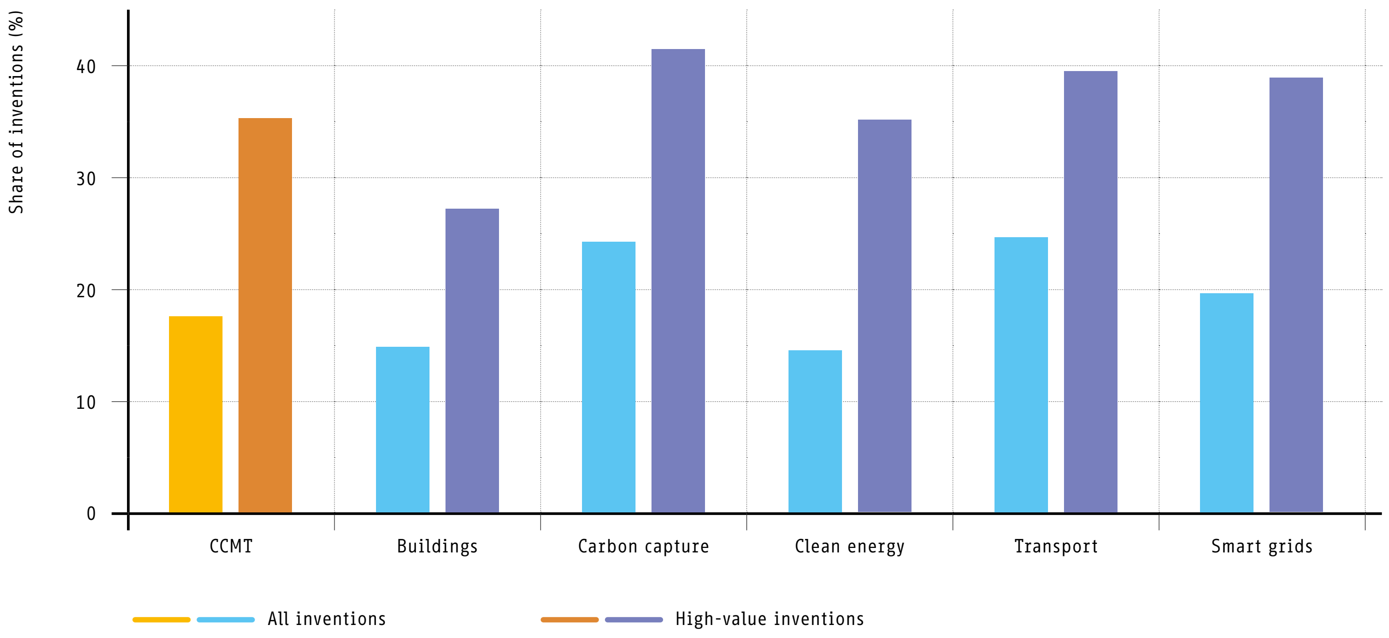
Europe appears as a major centre for CCMT invention activity. The data indicates that Europe is now a global leader in CCMT inventions, together with Japan, the US, Korea and China. European inventors were responsible for around 18% of CCMT inventions developed in the world during the period studied, despite the increasing competition from China and Korea. Most importantly, in CCMT inventions for which patent protection is sought in at least two jurisdictions, reflecting their higher value, the European share rose sharply, to almost 40% (Figure 1). Europe's contribution to global inventive efforts is highly significant across all CCMT areas (Figure 2). Comparing CCMT invention activity with general inventive performance, Europe also appears as the most CCMT-specialised region in the world.

The data suggests that public policies have been successful in encouraging the development of CCMTs in Europe. Probably as a consequence of these policies and of the induced inventive response, the carbon intensity of Europe's GDP has fallen by 30% in the last decades (Figure 3) and has remained the world's lowest since 2000.

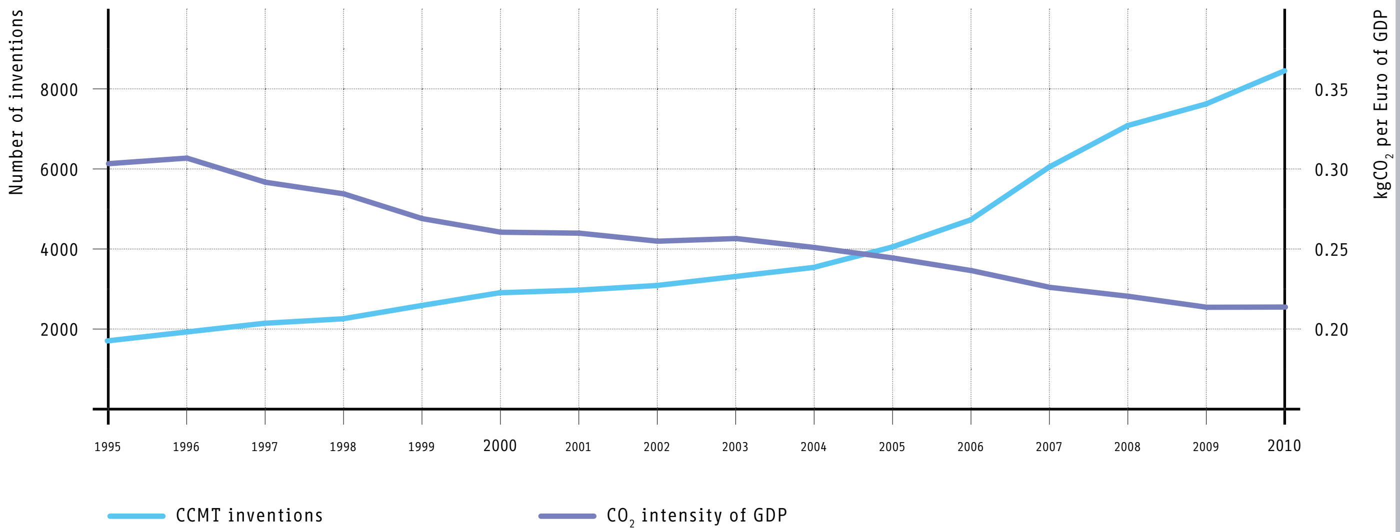
01 "High-value" CCMT inventions in the major innovation centres 1995-2011



02 European share of global CCMT inventions 1995–2011



03 CCMT inventions and CO_2 intensity of GDP in Europe 1995–2010



Within Europe, inventive activity in CCMTs appears highly concentrated, with five countries accounting for 80% of overall activity. It is clearly dominated by Germany, with almost half of Europe's CCMT inventions in the most recent period, followed by France, Italy, Spain and the UK. Germany's performance is partly a reflection of its economic size, but it also has the highest number of CCMT inventions per unit of GDP. In terms of this indicator, it is followed by Sweden, France and Finland. Interestingly, the data reveals that countries such as Greece and Portugal, which show less inventive activity overall, nevertheless appear highly specialised in CCMTs.

Europe also appears as the world's main market for CCMTs, measured by patents filed in Europe. Although European countries, in particular Germany, France and the UK, are the main sources of European patent applications, the origin of European filings is much broader. Inventors from the US, Japan and Korea are among the top ten contributors to CCMT patent filings in Europe. Furthermore, Europe has been the main destination for worldwide exports of CCMT goods and CCMT-related foreign direct investment.

Patent rights associated with European inventions are primarily protected in Europe, but protection is also increasingly sought around the world. For example, in 2010, 38% of European CCMT inventions led to patent applications in the US, 25% in China, 14% in Japan and 10% in Korea. Hence, the market for European CCMT inventions is by no means limited to Europe.

With its strong inventive activity, Europe is one of the world's main exporters of CCMT products, such as wind turbines, solar panels and batteries. Europe is also a major source of foreign direct investment in CCMT, with investment spanning all continents. However, Europe has a trade deficit in CCMTs, importing even more CCMT capital goods than it exports. A possible explanation lies in the persisting discrepancy between high tariffs on European CCMT exports (4% on average) and low tariffs on European CCMT imports (less than 1% on average).

Importantly, the analysis reveals a strong statistical relationship between cross-border patent filings and trade flows, as well as cross-border patent filings and foreign direct investment. This provides evidence that patent protection is conducive to incoming trade and investment flows, and may thus encourage the international transfer of CCMTs through these channels. As international diffusion of CCMTs is considered a key objective under the United Nations Framework Convention on Climate Change (UNFCCC), policies that facilitate trade, investment and patent flows should be supported. The provision of effective patent protection and the improvement of technological absorptive capacities are policies that could promote the diffusion of CCMTs and have important benefits in terms of mitigated climate change, as well as enhancing the prospects for growth and jobs.

The study also provides an overview of the current level of deployment of renewable energy (RE) in Europe, against its potential, analysed by the main types of RE and by different geographical areas within Europe. Policy has had a marked impact on European RE developments. Solar and thermal photovoltaic energy has been strongly supported in Germany and Spain, and many regions have backed the use of wind power. Biofuels have also had pan-European support.

RE accounted for some 15% of energy in the European Union (EU-28) in 2013, and the EU can already claim three times more renewable power per capita than anywhere else in the world. It has further ambitious goals to reduce CO_2 emissions, by 20% in 2020, and 80% by 2050. Over 50% of the European Union's RE is currently derived from biomass, followed by hydro (18%), wind (10%), solar (5%), heat pumps (4%) and geothermal (nearly 1%), but all of the European regions still have huge untapped potential in different RE mixes. For instance, biomass could account for two-thirds of the RE target in 2020, while wind power is projected to supply half of Denmark's electricity by 2020 – and the raw potential of this source alone could meet the EU's energy needs 20 times over.

Introduction

Hydroelectric power station, Wales, UK

Context and background

In December 2015, government leaders from around the globe gathered in Paris for the 21st session of the Conference of the Parties (COP 21) to the 1992 United Nations Framework Convention on Climate Change (UNFCCC), with the objective of concluding a legally binding international agreement aimed at limiting the average global temperature increase to 2°C above pre-industrial levels. The reductions in greenhouse gas (GHG) emissions entailed by this goal pose a significant challenge. Achieving this target while meeting growing global energy demands will require major changes in the technology used around the world. Technological developments are needed not only in energy generation and storage, but also in how energy, including in transport, buildings, industry and waste treatment, is used.

If the economic impact of this change is to remain acceptable, the cost of low-carbon technologies will have to be brought down, by breakthroughs emerging from research and innovation activities. This in turn depends on the allocation of resources. According to the last IPCC report, future investments in research, development and deployment (RD&D) will be the determining factor for the cost of emission reduction policies (IPCC, 2014). Importantly, the diversity of energy uses, systems, resources and national contexts means that addressing climate change and other environmental issues will require innovation across the whole range of existing and potential clean technologies, as well as the development of solutions adapted to local situations. Innovation could reduce the cost of existing climate change mitigation technologies, such as wind turbines and electric cars, and enable them to be deployed on a large scale, while investment in fundamental research will help to advance the frontiers of technologies such as smart grids, energy storage, and carbon capture.

Massive reductions in global carbon emissions represent not only a challenge but also an immense opportunity for current and future owners of low-carbon technologies, which offer real potential for growth and employment. European companies are well positioned in this respect. The European Union (EU) has long been at the forefront of global action to reduce carbon emissions. For example, in October 2014, EU leaders adopted a commitment to reduce domestic GHG emissions by 40% in 2030 relative to 1990. In 2012, GHG emissions were already 19% lower than in 1990 (at 4.5 Gt CO_2eq) and the new target set in 2014 represents a significant further commitment.

Scope and objectives of this study

Given this background, the objective of this study is to analyse

- Europe's position in the **global development** of new climate change mitigation technologies (CCMTs)
- Europe's role in the **dissemination of CCMTs**, measured by patent and economic data, and
- the importance of **European climate change policies** in explaining Europe's contribution to the global innovation and diffusion of CCMTs.

Development activity in this field is measured using patent data as a proxy for inventions in CCMTs. The EPO has developed a dedicated classification scheme (referred to as the Y02/Y04S tagging scheme[1]) to identify inventions related to climate change mitigation technologies. This makes it possible to analyse CCMT-related activity in Europe and compare it with developments in other key innovation regions in the world. Europe's inventive performance is looked at from several angles, analysing trends in different climate change mitigation technologies, comparing the levels of specialisation in CCMT across countries and highlighting to the importance of international collaboration between inventors.

Global dissemination of CCMTs from and to Europe is analysed using data on patent filings worldwide as well as on trade activities and foreign direct investment (FDI). The destination of patent filings is used to identify target markets for CCMT inventions. This makes it possible to identify the regions in which European inventions are protected and to examine the origins of inventions that target Europe as a market. Since dissemination of CCMTs also occurs through trade and FDI, the flows in patent filings are complemented with statistics on the main importing and exporting countries of CCMT goods and on foreign investment by companies active in CCMT R&D. To investigate the role of patent protection in international diffusion of CCMTs, the relationship between cross-border patent filing trends and trade and foreign investment stocks is also analysed.

Finally, **European policy** relevant to the innovation and dissemination of CCMTs is reviewed. In addition, an analysis of the relationship between the trends in climate change policy stringency, carbon emissions, public expenditure on CCMT research and development and Europe's inventive activity is performed. This is complemented by a mapping of the EU's renewable energy deployment and potential.

To the best of the authors' knowledge, this is the first time that such a comprehensive dataset has been put together to investigate inventive and associated economic activity relating to climate change mitigation in Europe.

1 For a description of the Y02/Y04S tagging scheme for CCMTs, see Chapter 3.

The study serves to inform policymakers, at the UNFCCC and in other international fora such as the World Trade Organization (WTO) and the associated TRIPS Council, and to provide evidence for the European representatives involved in these policy deliberations. It demonstrates how the EPO's publicly available Worldwide Patent Statistical Database (PATSTAT) can be used to analyse technology trends, in this case pertaining to CCMTs in Europe, with data from over 82 million patent applications from nearly 100 patent filing authorities. Policymakers and business strategists interested in particular geographical areas and specific technologies can conduct similar analyses to provide evidence as a basis for future policy and strategic business decisions.

Previous studies

The first study looking at a wide array of CCMTs on a global scale based on patent data was the initial joint EPO-UNEP-ICTSD[2] report on "Patents and clean energy technologies: bridging the gap between energy and policy", published in 2010 and using the EPO's PATSTAT services and its Y02/Y04S tagging scheme for CCMTs. The report found that the majority of CCMT patent filings in the period 1980-2009 originated from six OECD countries: the US, Japan, Korea, France, Germany and the UK. This was closely followed by a paper by Dechezleprêtre et al. (2011), which also used PATSTAT to examine the dynamics, distribution, and international transfer of patented inventions in 13 climate change mitigation technologies between 1978 and 2005. The authors also found that innovation in climate change technologies was highly concentrated in Japan, Germany, and the US (together accounting for 60% of total CCMT innovations globally), but that the innovation performance of certain emerging economies, particularly China and Russia, as well as Korea, was far from negligible. Their data suggested that, up to 1990, innovation had mostly been driven by energy prices. After 1990, environmental policies and climate policies appeared to have induced more innovation, with the pace accelerating after the signing of the Kyoto Protocol in 1997.

With regard to technology transfer, Dechezleprêtre et al. found that, historically, international transfers of CCMTs had occurred mostly between developed countries. However, there appeared to be tremendous potential for transfers between developed and developing countries, as well as for exchanges among developing countries only, particularly since these countries may have developed inventions that are better tailored to their specific needs. This was confirmed by a follow-up study by Glachant et al. (2013) and by another major review carried out by Haščič et al. (2012). Several further studies have been conducted that describe innovation activity and/or international technology diffusion in CCMTs, but with a more restricted focus. For example, Johnstone et al. (2010) focus on renewable energy patents in the OECD.

The EPO and UNEP have conducted further analyses of CCMT development and transfer in Africa (2013) and Latin America (2014), indicating that there are very few CCMT patent filings in the majority of developing countries, but no study on Europe has been published so far. The above-mentioned studies by Dechezleprêtre et al. (2011), Glachant et al. (2013) and Haščič et al. (2012) look at European countries individually but do not consider the overall contribution of Europe as a region to CCMT development and transfer.

Structure of the report

Chapter 2 of the report gives an overview of the European patent system, including national patent offices and the European Patent Office (EPO), and the patent application procedure under the Patent Cooperation Treaty (PCT).

Chapter 3 presents the data and methodologies used for the analysis in the subsequent chapters.

Chapter 4 analyses inventive activity in CCMTs of Europe-based inventors. It investigates where European CCMT research and development strengths lie, and compares Europe's performance with that of other main centres of innovation, in particular the US, Japan, China and Korea.

Chapter 5 presents a global analysis of technology markets where inventions developed in Europe are protected in other regions through the patent system. It further looks at the origin of patent applications filed in Europe, indicating global interest in Europe as a market for CCMTs. The patent data analysis is complemented with an investigation of international trade flows in CCMT goods and of foreign direct investments.

An examination of the connections between inventive activity and policies directed at climate change mitigation, together with relevant government expenditure on R&D, is performed in Chapter 6.

Chapter 7, written by UNEP, surveys the potential for use of clean energy in Europe, both by type of energy and by geographical region, against the goals defined by the EU, and gives an overview of current levels of implementation.

Key findings and conclusions are presented in Chapter 8.

2 UNEP – United Nations Environment Programme. ICTSD – International Centre for Trade and Sustainable Development

The European patent system

2
THE EUROPEAN PATENT SYSTEM

Marine current turbines, Strangford Lough, Northern Ireland

2.1
Patent protection in Europe

The objective of the patent system

Investing in innovation often involves high levels of risk and uncertainty. Patents provide an incentive to invest by granting patentees a temporary exclusive right to prevent others from exploiting the results of their R&D. This helps them to recoup their development costs and market their inventions without interference from competitors. Third parties must either license these technological solutions from the patent holders, or wait until the exclusive rights expire.

In return for this period of protection, applicants must disclose their invention in a manner sufficiently clear for it to be carried out by a person skilled in the art. Patent applications are published 18 months after the initial filing, providing a timely source of technical information, which is readily available, free of charge, on the internet. Patent literature lays the foundation for further technological developments, informing all stakeholders of the latest developments and preventing researchers from "re-inventing the wheel".

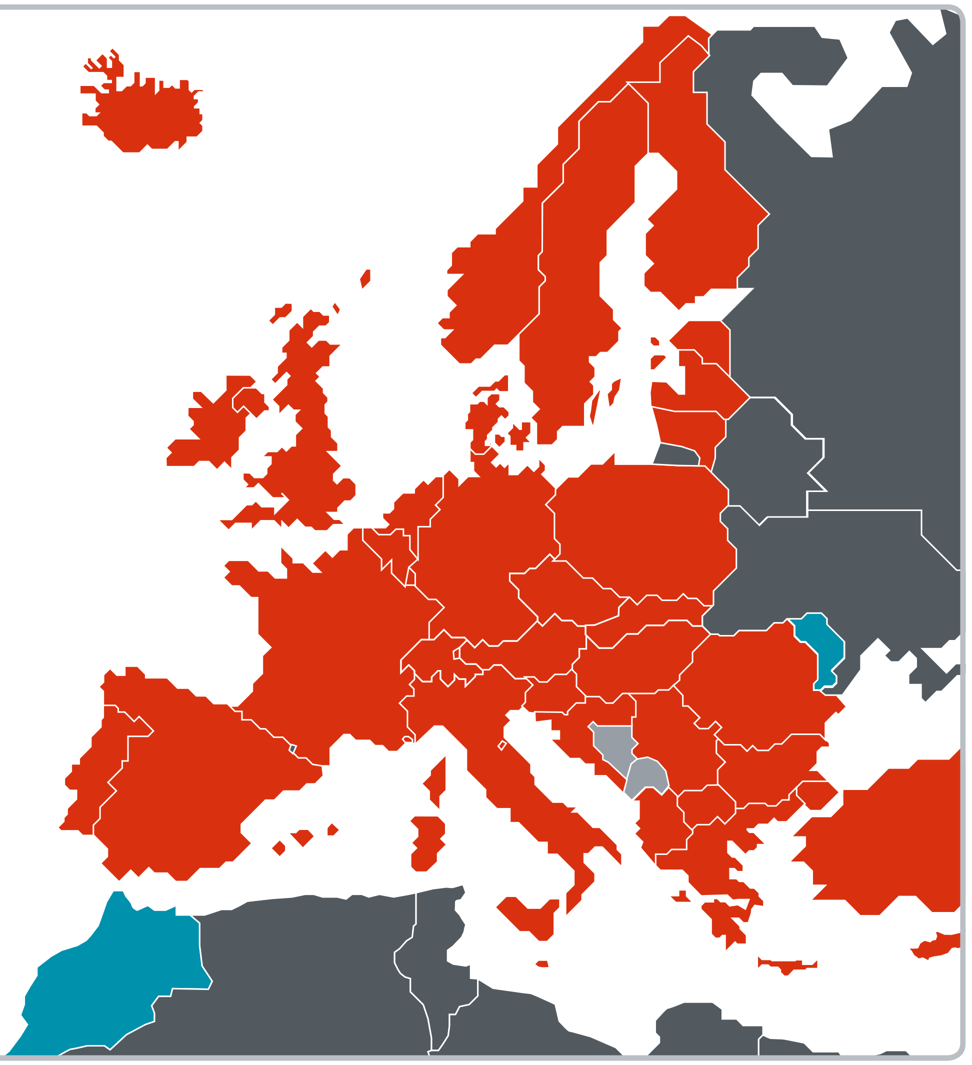
Overall, the objective of the patent system is to promote technological innovation and the dissemination of technical information, to the mutual benefit of inventors and the public, "in a manner that is conducive to social and economic welfare" (Article 7 of the Agreement on Trade-Related Aspects of Intellectual Property Rights – TRIPS). To fulfil its purpose, the patent system must offer fair and sound protection and facilitate the wide diffusion of knowledge.

Protection of inventions in Europe

In Europe, inventors can apply for patent protection in the individual European states via the national patent systems and/or seek regional protection through a centralised European procedure at the European Patent Office (EPO).

The EPO is the operating arm of the European Patent Organisation, set up on the basis of the European Patent Convention (EPC) signed in Munich in 1973. Over the years, the Organisation has grown to include 38 member states, two extension states and two validation states, covering an area with more than 600 million inhabitants.

Today, the European Patent Organisation includes 38 member states (red), 2 extension states (grey) and 2 validation states (blue)



The EPC makes it possible to obtain patent protection in up to 42 countries with a single application. European patent applications undergo rigorous substantive examination, thus providing a high degree of legal certainty throughout Europe. Once granted, the European patent can be validated in the individual EPC contracting states, as well as in the extension states and validation states where protection is sought.

A European patent application can also result from an international application filed under the Patent Cooperation Treaty (PCT). This international agreement offers a simplified patent application procedure for 148 countries worldwide. It enables inventors to file a single international application designating many countries, instead of having to apply separately for national or regional patents. In this international phase, an international search is carried out and – upon request – an international preliminary examination. The EPO is one of the largest International Searching Authorities under the PCT system, performing almost 40% of the international searches and around 55% of preliminary examinations requested by applicants all over the world. Within 30 months of filing the international application, the applicant decides in which of the 148 PCT countries to pursue the patent grant procedure, carried out by the relevant national patent offices and/or by regional patent offices such as the EPO.

The unitary patent

When the ratification of the Agreement on the Unified Patent Court is sufficiently far advanced, the European patent with unitary effect ("unitary patent") will be a further option available to inventors in Europe. A unitary patent will be a European patent granted by the EPO under the provisions of the EPC, to which unitary effect for the territory of the European Union (except Spain and Croatia) is given after grant, at the patentee's request.

Together with a dedicated unified patent litigation system, the unitary patent will simplify post-grant administration and litigation procedures and significantly lower the costs for patent owners. The streamlining of formalities and reduction of costs will benefit inventors in Europe, especially SMEs and research institutions. The new patent will also provide greater certainty to the market, thanks to the unitary protection effect and the creation of a specialised patent court ruling with Europe-wide effect on patent infringement and validity.

Patent quality

To optimise the impact of the patent system on innovation, it is essential to grant patents of high quality. Thorough search and examination procedures ensure that temporary exclusive rights are granted only for genuine inventions.

High-quality patents must clearly define the scope of intellectual property protection for their owners and be capable of withstanding invalidity proceedings in court or before any other administrative body. High quality brings legal certainty to the market, increasing the confidence of innovators to trade, transfer and license their inventions, in the knowledge that their exclusive rights are strong.

To provide certainty to the market at an early stage and avoid delays in patent procedures, the EPO recently introduced the "Early Certainty from Search" scheme. The aim of this initiative is to issue all search reports and written opinions on patentability within six months of filing the application at the EPO. The scheme supports innovators by providing them with a sound and timely basis for making strategic decisions, as well as benefiting the public by enhancing the transparency of pending patent rights in Europe.

Delivering high quality is a continual challenge in the modern patent system. The number of patent filings is rising steadily, with corresponding growth in the volumes of prior art to be searched when assessing patentability. Technologies are ever more interconnected and complex, requiring a highly specialised workforce. The EPO provides scope for the public to contribute to the quality of the patent system by allowing any third party to file observations concerning the patentability of an invention claimed in a published European patent application. This can be done free of charge on the EPO's website. In addition, any EPO patent may be challenged through the opposition procedure within nine months of the date of grant.

Validating European patents in Morocco and Moldova

Since 2010, the European Patent Organisation has concluded validation agreements with three non-member states: Morocco, the Republic of Moldova and Tunisia. In Morocco, the agreement entered into force on 1 March 2015, allowing, for the first time, validation of European patents outside Europe. This was followed by Moldova, where the validation agreement entered into force on 1 November 2015.

The validation procedure allows a granted European patent to be validated as a national patent without further search or examination by the IP office of the validation state. This greatly simplifies the procedures for patent protection for the holders of European patents; meanwhile, the Moroccan and Moldovan IP offices can focus their resources on the examination of local patent applications.

2.2 Transparency and patent information

Patent disclosure and knowledge dissemination

Disclosure, publication and dissemination of patent information play a fundamental role in maintaining the balance of rights and obligations in the patent system. These three steps ensure that the major part of the technical knowledge produced every day by the world's innovators is made available to the public. Without the patent system, most of this information would probably remain secret.

Patent information is, first and foremost, an invaluable source of technical knowledge and a sensitive indicator of developments in the technology market. Patent literature can be searched to find one or more solutions to a technical problem, to learn from the research and development of other innovators, and to identify emerging trends in a particular field of interest, such as climate change mitigation technologies.

Digitisation and publication of patent data over the internet has greatly enhanced the potential for knowledge dissemination. Some large IP organisations, such as the EPO, major national patent offices (e.g. the IP5) and WIPO, have assumed a proactive role as global information providers, developing tools that remove barriers to access for the general public, while continuing to expand their data collections to guarantee maximum geographical coverage. The EPO's Espacenet[3] service provides free access to the world's largest repository of patents and patent applications, comprising over 90 million documents.

Although Espacenet enables complex searches with a combination of key words and filters, the search process remains dependent on patent classification, i.e. the system of codes that serve to group inventions according to technical areas. The classification system common to all patent offices, with 70 000 technology codes, is the International Patent Classification (IPC). The patent classification now used by the EPO is the Cooperative Patent Classification (CPC), a new system jointly managed with the United States Patent and Trademark Office (USPTO). With over 250 000 codes, the CPC is an extension of the IPC that combines the best practices of both offices and allows for more accurate and efficient searching. Since its introduction in 2013, it has been adopted by several large IP offices, including those of Korea (KIPO), China (SIPO), Russia (ROSPATENT) and Brazil (INPI), as well as by the EPO's member states, and is rapidly becoming the de facto global refined classification system.

Integrated into the CPC is the Y02/Y04S tagging scheme, specially developed by the EPO for searching documents relating to climate change mitigation technologies (CCMTs). This brings together under one umbrella many different CCMTs traditionally classified under a wide range of technology fields. The aim is to increase the transparency of patent information and enhance the accessibility of these technologies to the general public. The Y02/Y04S scheme currently contains over 900 searchable codes with nearly 2.3 million patent publications.

A further initiative, to aid monitoring the status of patent proceedings on the same patent application filed at different patent offices, is the IP5 "Global Dossier" service, provided by the EPO with data from the JPO, KIPO, SIPO and the USPTO, which allows users to access, from a single entry point, information on how their applications are progressing in the various patent offices around the world.

Overcoming the language barrier with Patent Translate

In order to improve accessibility and transparency of multilingual patent information, the EPO has equipped its vast free-of-charge patent database Espacenet with a high-quality machine translation tool, called Patent Translate.

Patent Translate is a very effective, practical and user-friendly information tool (powered by Google) that allows users to simultaneously compare the original text with the translations in different languages, and quickly get an understanding of the invention described in the patent.

Patent Translate is now complete and provides on-the-fly-translation between English and the other 27 official languages of the EPO member states, plus Chinese, Japanese, Korean and Russian. Translation from and into French and German is also available for all of the EPO languages.

3 See www.espacenet.com

Patent statistics for decision makers

Industry has long made use of patent statistics in support of strategic decisions on R&D investments, competitors' behaviour and "freedom to operate". Today, growing IP awareness and training have also made patent data more accessible to a large range of actors in the public sector, where reliable concrete evidence is required to guide policy-making. Patents are well-suited to meet this need: they represent a high-quality source of information that can be used to address a wide range of policy issues in the fields of science and technology, R&D and innovation, entrepreneurship, global value chains, development and economic growth.

Both the technical and legal aspects of patent information are important to policy-makers; they provide input on the development of emerging technologies, their origin and ownership, and the transfer flows between countries. Patent landscaping studies, such as the one presented in this report, can provide a clear picture of developments in technological areas at a national, regional and international level through visualisation in maps and graphs of large amounts of complex data.

One of the most widely used tools for statistical research is the EPO Worldwide Patent Statistical Database (PATSTAT), which is publicly available and contains over 82 million patent applications from nearly 100 countries. Interestingly, today 40% of PATSTAT users come from governmental research and policy-making.

Finding sustainable technologies in patents: the Y02/Y04S tagging scheme

In response to the requirements of external organisations, the EPO has developed a dedicated classification scheme for CCMTs, termed the Y02/Y04S tagging scheme. This scheme is part of the Cooperative Patent Classification (CPC) and available for public use within the EPO's Espacenet and PATSTAT services. It presents an overview of key CCMT areas, increasing the transparency of patenting activity and accessibility of these technologies, while also allowing trends and statistics to be derived.

The Y02/Y04S scheme covers:

- Y02B – CCMTs related to buildings
- Y02C – Capture, storage, sequestration or disposal of greenhouse gases
- Y02E – Reduction of greenhouse gas emissions, related to energy generation, transmission or distribution
- Y02P – CCMTs relating to production in energy intensive industries[4]
- Y02T – CCMTs related to transportation
- Y02W – CCMTs related to wastewater treatment or waste management
- Y04S – Systems integrating technologies related to power network operation, communication or information technologies for improving electrical power generation, transmission, distribution, management or usage, i.e. smart grids

Farouk Tedjar and Jean-Claude Foudraz (France)

Finalists of the European Inventor Award 2012 in the category of SMEs, in the area of technologies for solid waste management (Y02W30)

Invention: Method for recycling batteries

Billions of lithium-ion-based rechargeable batteries are produced every year to power cell phones, laptops and MP3 players. Discarding them can create huge amounts of waste. French scientists Farouk Tedjar and Jean-Claude Foudraz developed a novel solution – which is fast, effective, inexpensive and uses less energy – to recycle these batteries and recover 98% of the valuable metals they contain.

4 Completion is expected at the end of 2015.

Data sources and methodology

3 DATA SOURCES AND METHODOLOGY

Offshore wind farm, North Sea

For this study, data from five main sources has been gathered: the EPO Worldwide Patent Statistical Database (PATSTAT), the United Nations Commodity Trade Statistics Database, the UNCTAD TRAINS database, Bureau van Dijk's ORBIS database, and the World Bank World Development Indicators.

Patent data

The patent data used in the study is drawn from the Worldwide Patent Statistical Database[5] (PATSTAT) maintained by the European Patent Office. PATSTAT is the largest international patent database available to the research community, with over 82 million patent applications included. Patent documents are categorised using the Cooperative Patent Classification (CPC), the International Patent Classification (IPC) and national classification systems. In particular, the new Y02/Y04S tagging scheme of the CPC, developed by the EPO to identify patents in PATSTAT pertaining to "technologies or applications for mitigation against climate change", is used. This scheme is the result of an unprecedented effort by the EPO, whereby patent examiners specialised in each technology, with the help of external experts, have developed a tagging scheme for patents related to CCMTs. The Y02/Y04S categories provide the most reliable method available today for identifying CCMT patent filings, and the scheme is becoming the de facto international standard for clean innovation studies.

CCMTs include technologies that reduce the amount of greenhouse gas emitted into the atmosphere when producing or consuming energy: for example, renewable energy technologies, carbon capture and storage or electric vehicles. They also include technologies, such as batteries, that do not directly contribute to carbon emissions reduction but are complementary to low-carbon technologies. Thus, climate change mitigation technologies are a subset of "green" technologies, which also include technologies such as those relating to water or air pollution control. The Y02/Y04S tagging scheme has now been extended to include Y02W for CCMTs in solid and liquid waste treatment (not available in PATSTAT at the time of this analysis), and will be further extended to include Y02P for production, covering CCMTs in energy-intensive industries. The categories included in this study are listed in Table 1. A detailed list of all sub-classifications is available on the EPO website.[6]

To introduce the indicators used in this and other studies, it is useful to briefly review how the patent system works. A patent is a legal title protecting an invention. To be patented, a product or process must be new, involve an inventive step and be susceptible of industrial application. The legal protection conferred by a patent gives its owner the right to exclude others from making, using, selling, offering for sale or importing the patented invention for the term of the patent, which is usually 20 years from the filing date, and in the country or countries where the patent has been filed (and subsequently granted). This set of rights provides the patentee with a competitive advantage. The cost to the inventor, in return, is the mandatory public disclosure of the technology for which protection is sought. Disclosure makes subsequent imitation easier and facilitates other future technological developments.

To make things clearer, consider a simplified invention process. In the first stage, an inventor from a particular country "invents" a new technology. The inventor then decides how to protect the intellectual property associated with this invention and where to market it. A patent application is filed in country 1 (thereby establishing "priority"), which may grant the applicant an exclusive right to commercially exploit the invention in that country if the subject-matter meets the requirements for patentability. Usually, a patent will be sought in country 1 if the invention is to be marketed there, or if there may be a possibility of licensing it to others. The patent applicant also has the right to submit a patent application for the same invention to other national or regional patent offices (or WIPO[7]) within 12 months, claiming the original filing date as the legally valid date of filing. The set of patents in different countries relating to the same invention is called a patent family. The vast majority of patent families include only one filing (usually in the home country of the inventor, particularly for large countries such as the US). When a patent is sought in several countries, the first filing date worldwide is called the priority date. Accordingly, the first patent filing is called the priority application and the first patent office is referred to as the priority office.

In this study, patent applications are sorted by priority year.[8] Because they are first published 18 months after filing, there is a lag between the filing date and the time at which they are observed in the PATSTAT database. For this reason, analysis of the data beyond 2011, which is the latest comprehensive year in the June 2015 version of PATSTAT, is not possible. The number of patent families[9] is used as an indicator of the number of inventions, and the number of technologies invented in country A and also filed in country B is used as an indicator of the number of inventions transferred from country A to country B. This approach has been used extensively in recent years, particularly in the environmental field (Lanjouw and Mody, 1996; Eaton and Kortum, 1999; Dechezleprêtre et al., 2011; Dechezleprêtre et al., 2013).

5 Latest version, dated June 2015.
6 See http://worldwide.espacenet.com/classification.

7 See an explanation of PCT filings in Chapter 2.
8 NB: previous EPO-UNEP studies have defined filings by publication year.
9 The simpler form of the patent family (DOCDB) is used, not the wider INPADOC family definition. In the simpler definition, each patent document in the family must have the same priority document or set of priority documents.

Data sources and methodology

01 Patent classification codes used in the study

Classification code	Description
Y02B	**CLIMATE CHANGE MITIGATION TECHNOLOGIES RELATED TO BUILDINGS, e.g. INCLUDING HOUSING AND APPLIANCES OR RELATED END-USER APPLICATIONS**
Y02B10	Integration of renewable energy sources in buildings
Y02B20	Energy efficient lighting technologies
Y02B30	Energy efficient heating, ventilation or air conditioning [HVAC]
Y02B40	Technologies aiming at improving the efficiency of home appliances
Y02B50	Energy efficient technologies in elevators, escalators and moving walkways
Y02B60	Information and communication technologies [ICT] aiming at the reduction of own energy use
Y02B70	Technologies for an efficient end-user side electric power management and consumption
Y02B80	Architectural or constructional elements improving the thermal performance of buildings
Y02B90	Enabling technologies or technologies with a potential or indirect contribution to GHG emissions mitigation
Y02C	**CAPTURE, STORAGE, SEQUESTRATION OR DISPOSAL OF GREENHOUSE GASES [GHG]**
Y02C10	CO_2 capture or storage (not used, see subgroups)
Y02C20	Capture or disposal of greenhouse gases [GHG] other than CO_2 (not used, see subgroups)
Y02E	**REDUCTION OF GREENHOUSE GAS [GHG] EMISSIONS, RELATED TO ENERGY GENERATION, TRANSMISSION OR DISTRIBUTION**
Y02E10	Energy generation through renewable energy sources
Y02E20	Combustion technologies with mitigation potential
Y02E30	Energy generation of nuclear origin
Y02E40	Technologies for efficient electrical power generation, transmission or distribution
Y02E50	Technologies for the production of fuel of non-fossil origin
Y02E60	Enabling technologies or technologies with a potential or indirect contribution to GHG emissions mitigation
Y02E70	Other energy conversion or management systems reducing GHG emissions
Y02T	**CLIMATE CHANGE MITIGATION TECHNOLOGIES RELATED TO TRANSPORTATION**
Y02T10	Road transport of goods or passengers
Y02T30	Transportation of goods or passengers via railways
Y02T50	Aeronautics or air transport
Y02T70	Maritime or waterways transport
Y02T90	Enabling technologies or technologies with a potential or indirect contribution to GHG emissions mitigation
Y04S	**SYSTEMS INTEGRATING TECHNOLOGIES RELATED TO POWER NETWORK OPERATION, COMMUNICATION OR INFORMATION TECHNOLOGIES FOR IMPROVING ELECTRICAL POWER GENERATION, TRANSMISSION, DISTRIBUTION, MANAGEMENT OR USAGE, i.e. SMART GRIDS**
Y04S10	Systems supporting electrical power generation, transmission or distribution
Y04S20	Systems supporting the management or operation of end-user stationary applications
Y04S30	Systems supporting specific end-user applications in the transportation sector
Y04S40	Smart grids, communication or information technology specific aspects supporting electrical power generation, transmission or distribution

To determine in which country a patented invention has been developed, information on the inventor's country of residence is used. A patent application must always name an inventor, who must be a physical person. In contrast, the applicant can be a legal person, and in practice the application fees are normally paid by a company or institution. PATSTAT includes information on both the inventor and the applicant. Inventor information is used to determine where inventions are developed, and applicant information to determine the legal owner of the patent. In practice, the inventor country and the applicant country are almost always the same, but nothing prevents a US-based company from filing a patent application for an invention developed in its Europe-based research lab. In this case, the patent will be considered as a European invention. When a patented technology has been developed jointly between inventors located in different countries, fractional counting is applied. For example, if the technology was developed by inventors located in Germany and France, one half of a patent is counted for each inventor country.

In all the patent statistics presented below, "Europe" is defined as the member and extension states of the European Patent Organisation, which are listed in Annex 1. Where the analysis or statistic is limited to countries that are also members of the European Union, this group of countries is referred to as the EU.

Despite the recent profusion of studies using patent data, patent-based indicators are imperfect proxies for technological invention and technology transfer, and have several limitations (see OECD, 2009, for a recent overview). Firstly, patents are only one of several means of protecting inventions, along with lead time, industrial secrecy, or purposefully complex specifications (Cohen et al., 2000; Frietsch and Schmoch, 2006). In particular, some inventors may prefer secrecy to prevent public disclosure of the invention imposed by patent law or to save costs relating to patenting. However, there are very few examples of economically significant inventions that have not been patented (Dernis et al., 2001).

Secondly, the propensity to patent differs between sectors, depending on the nature of the technology (Cohen, Nelson and Walsh, 2000). It also depends on the risk of imitation in a particular country. Accordingly, inventions are more likely to be patented in countries with technological capabilities and effective enforcement of IPRs. This means that greater patenting activity could reflect either greater inventive activity or a greater propensity to file patents in that country. Some methods used in this paper and described below allow to partly control for this problem.

Another limitation is that, while a patent grants the exclusive right to use a technology in a given country, there is nothing to ensure that the patent owner will actually exercise this right. This could significantly bias the results if applying for patent protection were free, which could encourage inventors to patent widely and indiscriminately. However, patenting involves significant expense, in terms of both the costs of preparing the application and the administrative costs and fees associated with the grant procedure. In addition, the grant of a patent in a given country may be of limited value to the holder if that country's enforcement of intellectual property rights is weak, since publication of the patent can increase the risk of imitation (see Eaton and Kortum, 1996, 1999). Finally, patent infringement litigation usually takes place in the country where the technology is commercialised (as this is where the alleged infringement occurs). Thus, inventors will be reluctant to incur the cost of patent protection in a country unless they expect there to be a market for the technology concerned.

However, the fact remains that the value of individual patents is heterogeneous: many patents have low value, while other patents have a very high value. As a consequence, the absolute number of patents does not perfectly reflect the value of technological innovation. Methods have been developed to address this issue. In this report, data on international patent families is used to construct statistics for "high-value" inventions. Where appropriate, patents filed with at least two jurisdictions are used to screen out low-value patents, as has been done elsewhere (Dechezleprêtre et al 2011; Johnstone et al., 2012). Patents filed in at least two jurisdictions are referred to as "claimed priorities", because when applicants file additional patent applications abroad after the initial application they can claim the application date of the first application (the "priority date") as the starting date for patent protection in other jurisdictions.[10] Using patent applications filed in at least two jurisdictions helps to filter out low-value inventions, for which protection is typically sought at a single patent office (see Guellec and van Pottelsberghe, 2000, and Harhoff et al., 2003).[11] Since patent protection is costly, applicants are only likely to file in several jurisdictions if they see enough market potential for the invention.

10 For a discussion of the merits of the use of "claimed priorities", as well as a review of a number of applications, see Haščič and Migotto (2015). For a discussion of family size as a patent value indicator, see Harhoff et al. (2003).

11 All applications filed with the EPO and WIPO (so-called PCT filings) are treated as patent applications filed in at least two jurisdictions. Given the higher costs of EPO and PCT filings compared to the national route, applicants will only choose a European or international application if they intend to file in several jurisdictions simultaneously. Furthermore, the qualitative results do not change if the alternative definition is used.

A further complication arises from the fact that not all patent applications result in granted patents. Sometimes the patent application does not fulfil the patentability criteria, or the applicant loses commercial interest in seeking patent protection for the invention while the application is still pending. In addition, since the grant procedure takes time, there is usually a delay of several years between the filing date and the date of grant. This creates an additional timeliness problem when considering granted patents only. Therefore, unless stated otherwise, the analysis will focus on counting patent families, where a patent family represents a set of patent applications, granted or not granted in different countries, that are related to the same proposed invention. Throughout the report, the term "invention" refers to patent families.[12]

Trade data

Trade data in USD comes from the United Nations COMTRADE database, which reports bilateral trade between countries at a highly disaggregated product level. Trade data in the COMTRADE database covers between 70% and 90% of world trade obtained from the WTO Statistics Database, depending on the year.

As is the case with patent data, the very detailed classification system used in the COMTRADE database (a six-digit classification of commodities) makes it possible to specifically identify trade in equipment goods that incorporate technologies to cut GHG emissions (for example, wind turbines). To identify products incorporating CCMTs, the same approach as in Glachant et al. (2013) and Sugathan (2013) is taken. The list of commodity codes used in the study is presented in Table 2. Technology transfer is then measured by the value of trade in these goods between trading partners.

Dr. Mark van Loosdrecht and
Dr. Merle Krista de Kreuk (Netherlands)

Finalists of the European Inventor Award 2012 in the category of Research, in the area of technologies for wastewater treatment (Y02W10/15)

Invention: Waste-water treatment method

Dutch scientists Mark van Loosdrecht, Merle Krista de Kreuk and Joseph Heijnen invented a cutting-edge sewage purification system which uses aerobic granular biomass. Bridging biotechnology and civil engineering, their solution drastically improves the quality of waste-water going back into the water cycle, without relying on extra chemicals. It can also make water treatment much more efficient and cost-effective.

12 The simpler form of the patent family (DOCDB) is used.

02 Description and harmonised system (HS) codes of low carbon goods considered in the study

Technology class	HS code	Description
Hydro energy	841011	Hydraulic turbines & water wheels, of a power not >1 000 kW
	841012	Hydraulic turbines & water wheels, of a power >1 000 kW but not >10 000 kW
	841013	Hydraulic turbines & water wheels, of a power >10 000 kW
	841090	Parts (incl. regulators) of the hydraulic turbines & water wheels of 8410.11-8410.13
Nuclear energy	840110	Nuclear reactors
	840120	Machinery and apparatus for isotopic separation, and parts thereof
	840140	Parts of nuclear reactors
Solar thermal	841919	Instantaneous/storage water heaters, non-electric (excl. of 8419.11)
Solar photovoltaic	854140	Photosensitive semiconductor devices, incl. photovoltaic cells whether or not assembled in modules/made up into panels; light emitting diodes
Wind energy	850231	Wind-powered electric generating sets
	730820	Towers and lattice masts, of iron or steel
Energy storage	850710	Lead-acid electric accumulators (vehicle)
	850720	Lead-acid electric accumulators except for vehicles
	850730	Nickel-cadmium electric accumulators
	850740	Nickel-iron electric accumulators
	850780	Electric accumulators
	850790	Parts of electric accumulators, including separators
	853224	Fixed electrical capacitors, other than those of 8532.10, ceramic dielectric, multilayer
Electric and hybrid vehicles	870390	Vehicles principally designed for the transport of persons (excl. of 87.02 & 8703.10-8703.24), with C-I internal combustion piston engine (diesel/semi-diesel), n.e.s. in 87.03
Heating	903210	Thermostats
	841861	Compression-type refrigerating/freezing equipment whose condensers are heat exchangers, heat pumps other than air conditioning machines of heading 84.15
	841950	Heat exchange units, whether/not electrically heated
Insulation	680610	Slag wool, rock wool & similar mineral wools (incl. intermixtures thereof), in bulk/sheets/rolls
	680690	Mixtures & articles of heat-insulating/sound-insulating/sound-absorbing mineral materials (excl. of 68.11/68.12/Ch.69)
	700800	Multiple-walled insulating units of glass
	701939	Webs, mattresses, boards & similar non-woven products of glass fibres
Lighting	853931	Electric discharge lamps (excl. ultra-violet lamps), fluorescent, hot cathode
	853120	Indicator panels incorporating liquid crystal devices (chemically defined)/ light emitting diodes (LED)
Transportation	860120	Rail locomotives powered by electric accumulators
Smart grids	902830	Electricity meters
Biofuels	220720	Ethyl alcohol, other spirits (denatured)
	220710	Ethyl alcohol (alcoholic strength 80 degrees or more)
Clean coal & gas	841990	Parts of apparatus for treatment of materials by temperature
	841181	Other gas turbines of a power not exceeding 5 000 kw
	841199	Parts of other gas turbines
	841182	Other gas turbines of a power exceeding 5 000 kw
	841950	Heat exchange units
	840420	Condensers for steam or other vapour power units

Tariff data

Tariff data in percentage points comes from the United Nations Conference on Trade and Development (UNCTAD) Trade Analysis and Information System (TRAINS) database. TRAINS is a comprehensive database at the most disaggregated level under the harmonised system (HS), covering tariff and non-tariff measures as well as import flows by origin for more than 150 countries. Tariff information was downloaded for all the HS codes used in the trade analysis and is presented in Table 2. The duty type is the "effectively applied rate", which uses preferential tariffs when they exist and is thus the best available measure of tariffs. Furthermore, we use the "weighted average" tariff, which is the average of tariffs weighted by their corresponding trade value.

Foreign investment data

To measure foreign direct investment, the financial database ORBIS is used, provided by Bureau Van Dijk under a commercial licence.[13] The ORBIS database includes firm-level data on investment stocks in foreign countries (due to mergers and acquisitions, creation of subsidiaries, etc.). To identify FDI by firms involved in sectors related to climate change, the ORBIS database is matched with the PATSTAT database and companies that own at least one patent application in climate-related technology are identified. These companies are referred to as "CCMT companies". Because patent applications in the various categories presented in Table 1 are used in order to identify companies engaged in international investment activity, the FDI data covers exactly the same categories as those presented in the table.

The rationale for this restriction is twofold. First, it makes it possible to provide an indicator of FDI at the technology level. Economic sector classifications available at the company level are too aggregated to allow for meaningful analyses at the technology level. For example, in the "production of electricity" sector, companies can be identified in general, but not renewable energy producers. Second, the restriction makes it possible to identify foreign investment that potentially involves the transfer of climate-friendly technologies. This explains why patent and FDI statistics have the same technology scope.

13 The ORBIS dataset, provided by Bureau van Dijk, is one of the sources most commonly used by researchers and contains financial information on millions of listed and unlisted companies worldwide. For this study, the April 2013 version of ORBIS was used.

Europe as a global centre of CCMT inventive activity

4
EUROPE AS A GLOBAL CENTRE OF CCMT INVENTIVE ACTIVITY

Geothermal power station, Iceland

4.1
Global trends

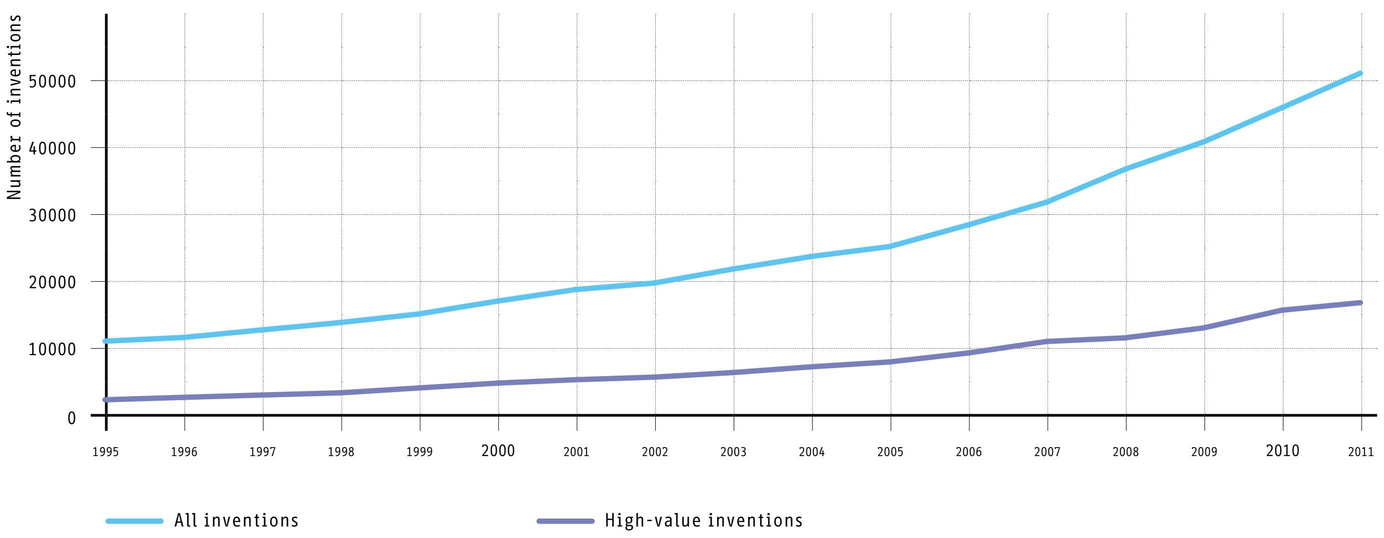
Before analysing Europe's performance, it is useful to look at overall trends in inventive activity in CCMT. Globally, there has been a continuous growth in the number of inventions in climate change mitigation technologies for which patent protection is sought. Between 1995 and 2011, the number of inventions developed annually rose almost fivefold, from 11 000 in 1995 to over 51 000 in 2011 (Figure 4). The number of "high-value" inventions, for which protection is sought at more than one patent office, increased still further, from around 2 500 in 1995 to just under 17 000 in 2011. The figures suggest that the growth of inventive activity has been accompanied by an increase in the average economic value of inventions. This is largely explained by the development in three major technology groups: clean energy technologies (Y02E), CCMTs related to transportation (Y02T) and CCMTs related to buildings (Y02B). In comparison, the technology areas of carbon capture and storage (Y02C), and smart grids (Y04S) remain marginal (Figure 5).

4.2
European inventive activities

4.2.1
Trends in European CCMT inventions

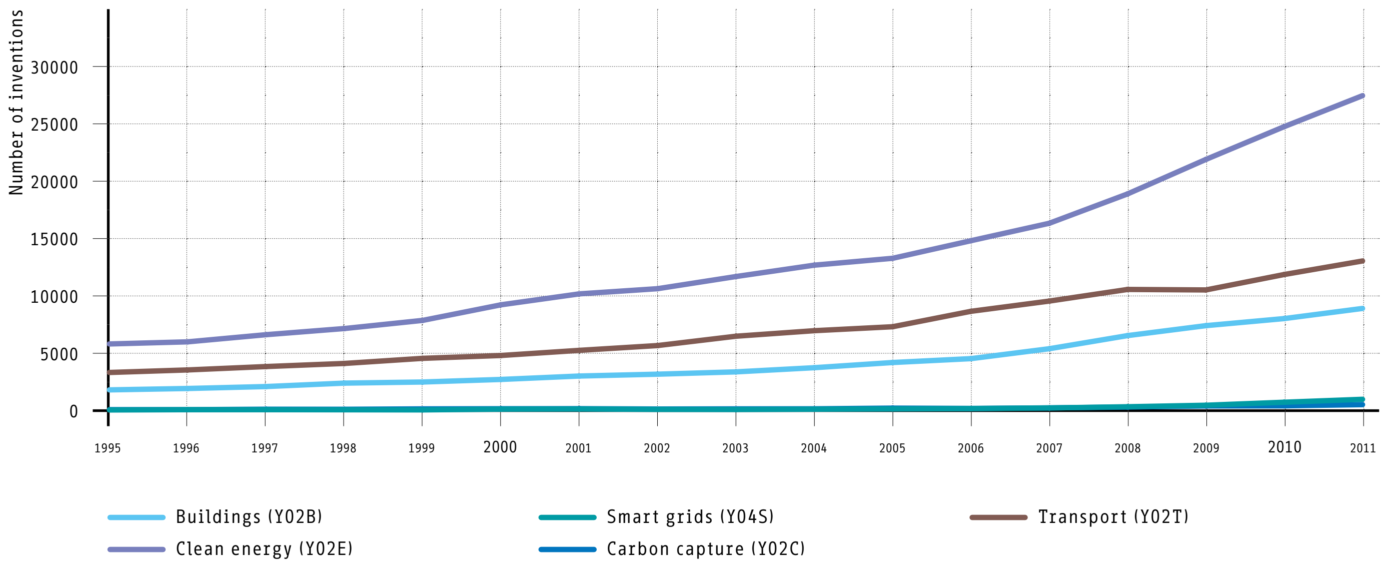
In line with what has been happening at the global level, the annual number of inventions developed by Europe-based inventors rose by a factor of more than five, from 1 765 in 1995 to over 9 000 in 2011. The number of "high-value" inventions, for which protection is sought at more than one patent office, increased sixfold, from less than 1 000 in 1995 to just under 6 000 in 2011 (Figure 6). This points also to an increase in the economic value of the average invention patented by European inventors. Interestingly, the growth rate of inventive activity seems to have accelerated since 2005. This roughly correlates with the adoption of the European Union's flagship climate change policy, the EU Emissions Trading System (EU ETS). Although it is not possible to establish any causal link by observing simple trends, it has been demonstrated elsewhere that the introduction of the EU ETS has led to a 30% increase in patenting activity in CCMTs by companies subject to carbon emissions reductions under the EU ETS (Calel & Dechezleprêtre, 2014).[14]

04 Worldwide trends in CCMT inventions 1995-2011

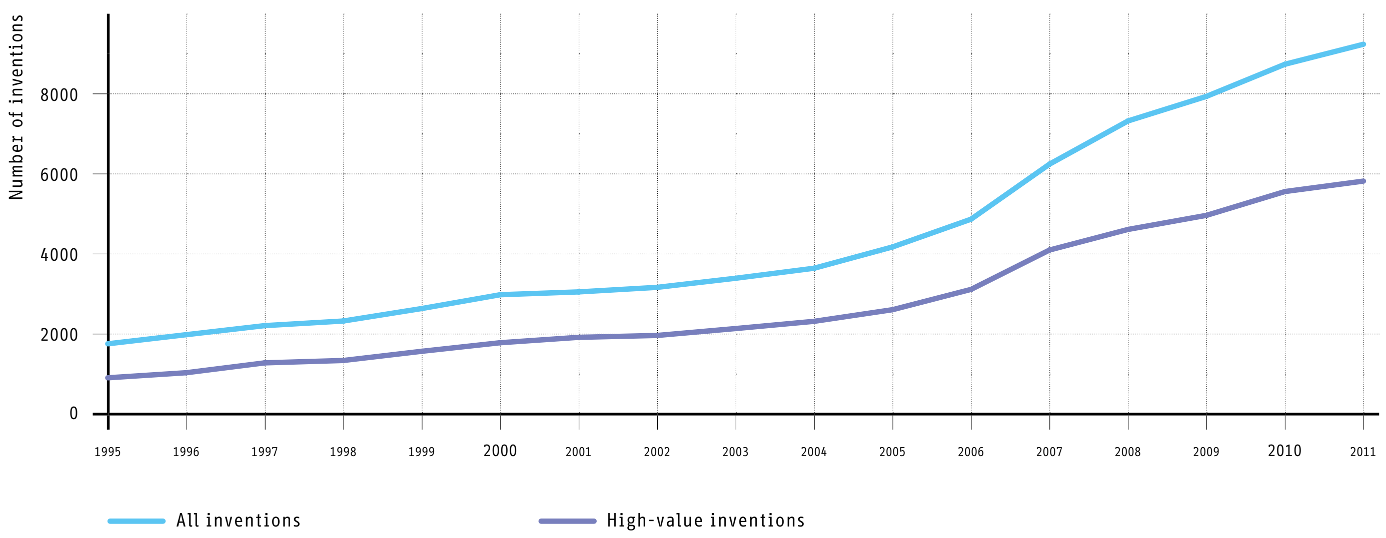


14 The relationship between inventive activity and public policies is examined in more detail in Chapter 6.

05 CCMT inventions worldwide by technology 1995-2011



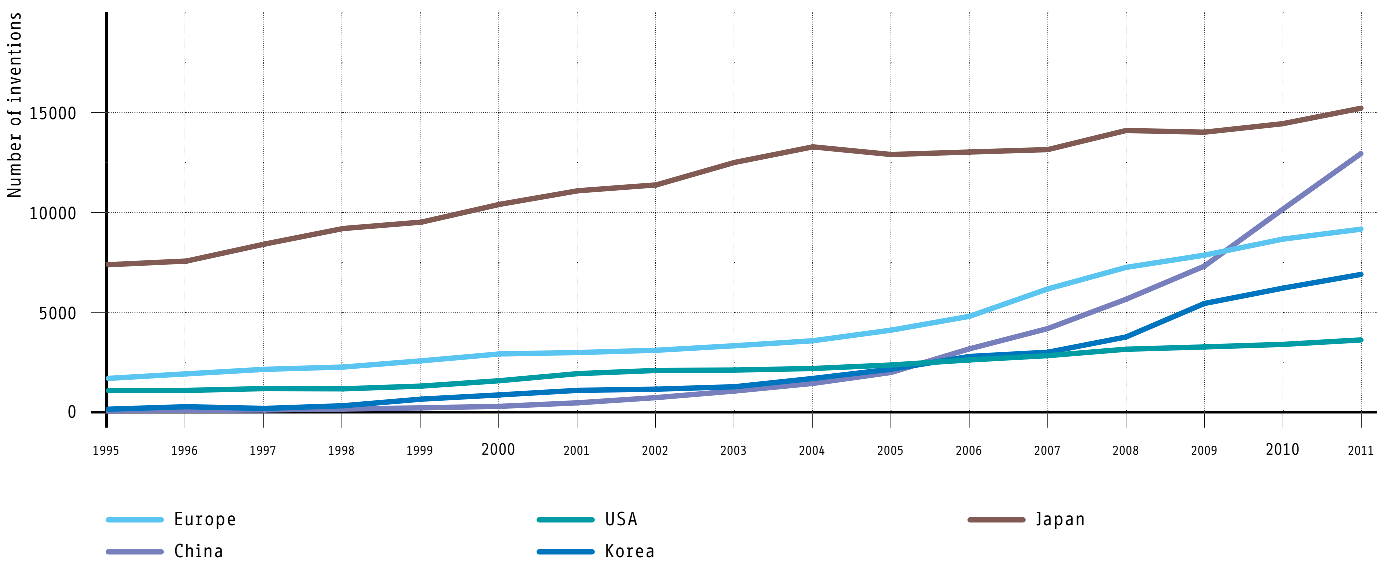
06 CCMT inventions from European inventors 1995-2011



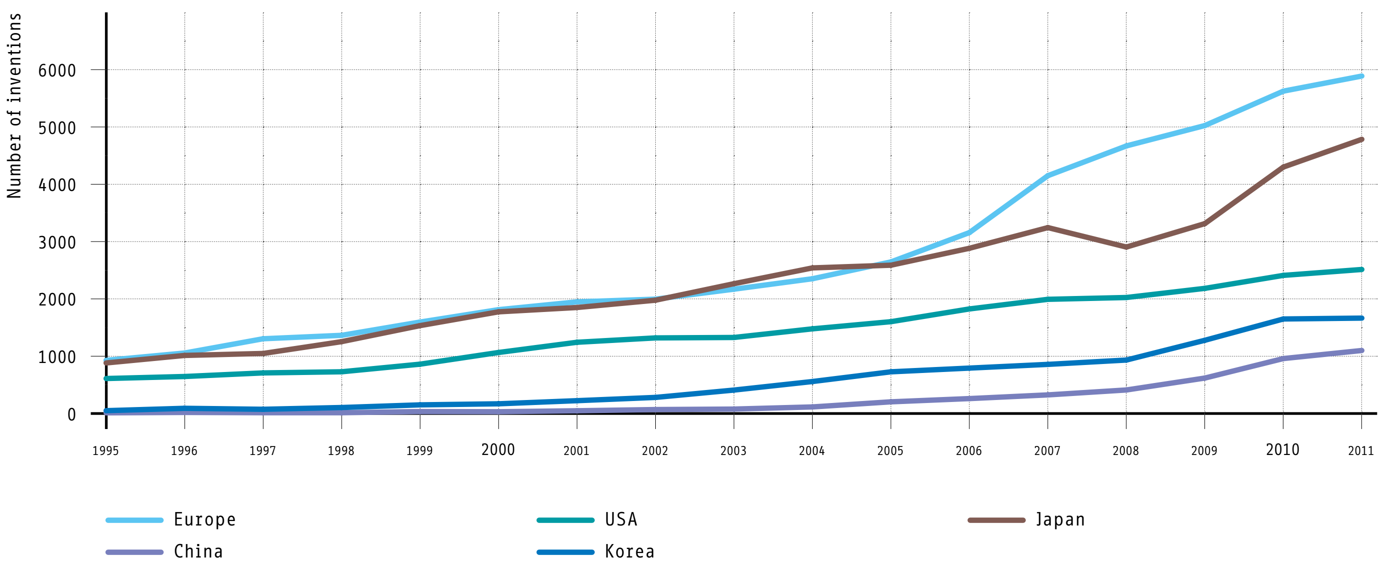
4.2.2
Europe compared to other major innovation centres

A sustained increase is apparent in the number of CCMT inventions developed in Japan, China and South Korea since 1995, with the US appearing to lag behind (Figure 7). The most recent performance of China and Korea (since 2005) is particularly remarkable. However, focusing on high-value inventions, Europe stands out as the world leader, far ahead of China, where the majority of recent inventions have been patented at the Chinese national IP office only (Figure 8). The number of high-value inventions with a global market perspective patented in China and Korea has increased substantially, but not as much as the number of inventions for which only local protection is sought. Looking at individual technologies, Europe appears as a clear world leader in clean energy technologies and in carbon capture and storage technologies. In transportation, buildings and smart grids, Europe's global leadership is less pronounced: its performance is in line with that of Japan. A detailed comparison of the performance of major innovation centres at the technology level is available in Annex 2.

07 CCMT inventions in the major innovation centres 1995-2011



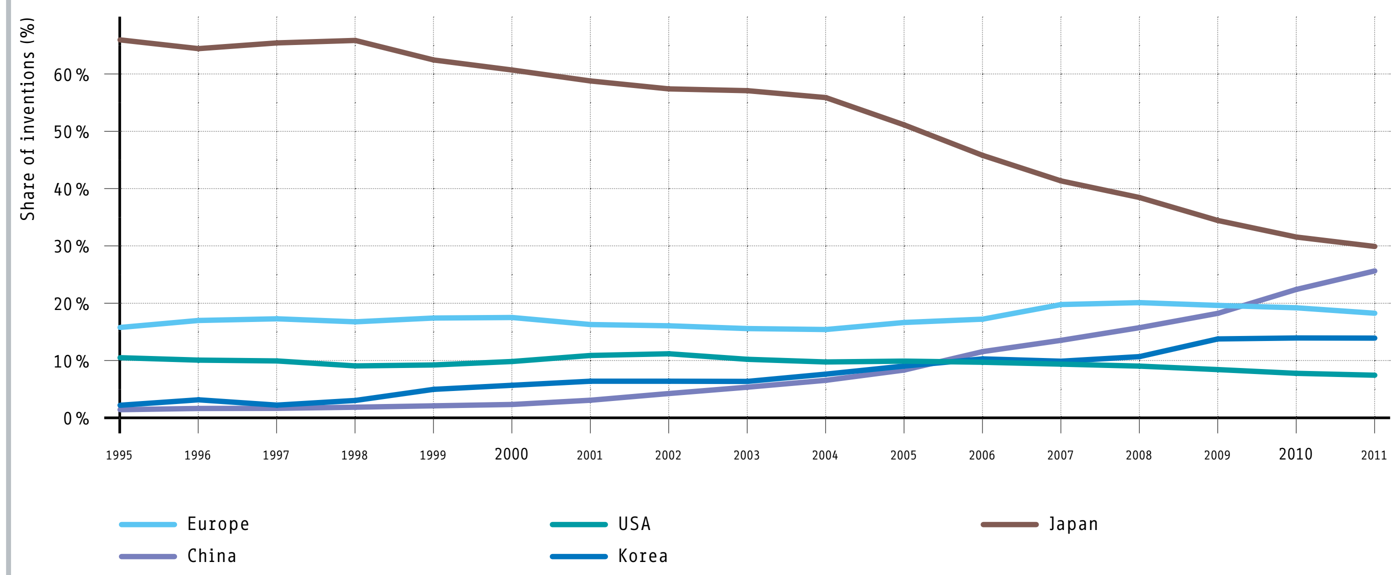
08 High-value CCMT inventions in the major innovation centres 1995-2011



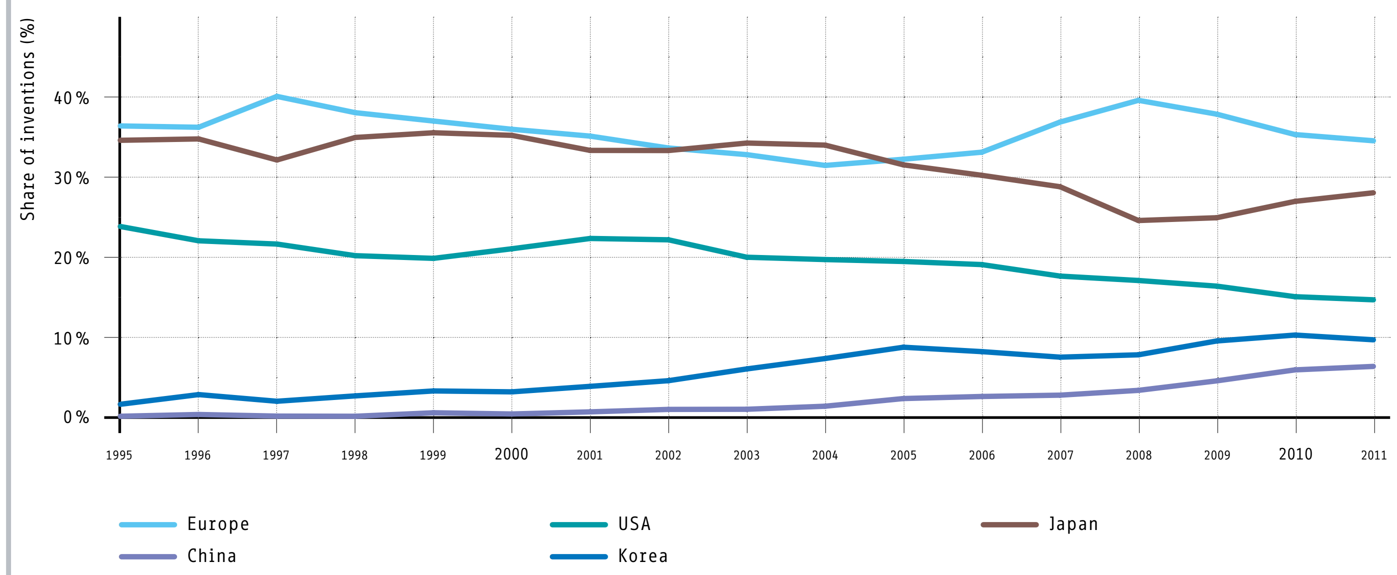
Europe as a global centre of CCMT inventive activity

Looking at the respective contributions of the five major innovation centres to global CCMT development (Figure 9), it appears that the proportion of inventions developed by inventors based in European countries has remained stable. Between 1995 and 2011, the proportion was around 18%, with a slight increase from 2007 onwards. In the high-value area, the contribution of European inventors has also remained fairly stable, but at a far higher level, with nearly 40% of the world's high-value inventions (Figure 10). This again suggests that European inventions have an above-average commercial value, as measured by the number of jurisdictions in which inventions are protected. The stability of Europe's contribution to global inventive efforts in CCMT, despite increasing competition, particularly from China and Korea, is a sign of strong innovative performance. In contrast, both the US and Japan have seen their global market shares decrease substantially, in CCMT inventions as a whole and in the high-value sector.

09 Share of major innovation centres in worldwide CCMT inventions 1995-2011



10 Share of major innovation centres in worldwide high-value CCMT inventions 1995-2011

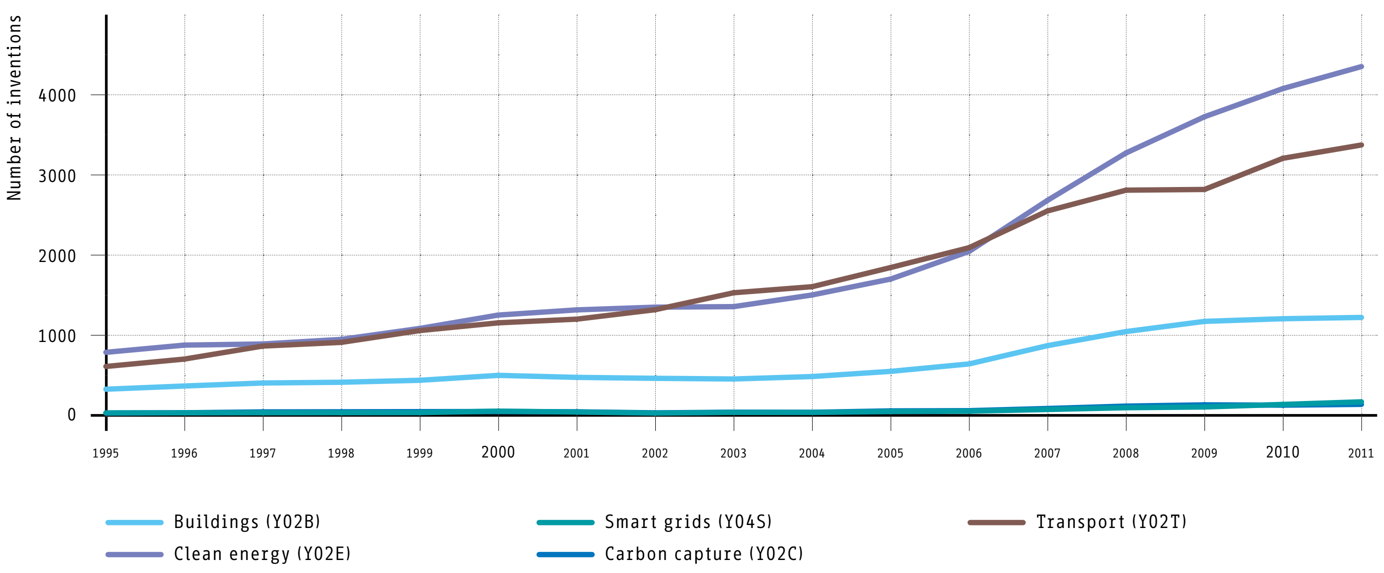


Europe as a global centre of CCMT inventive activity

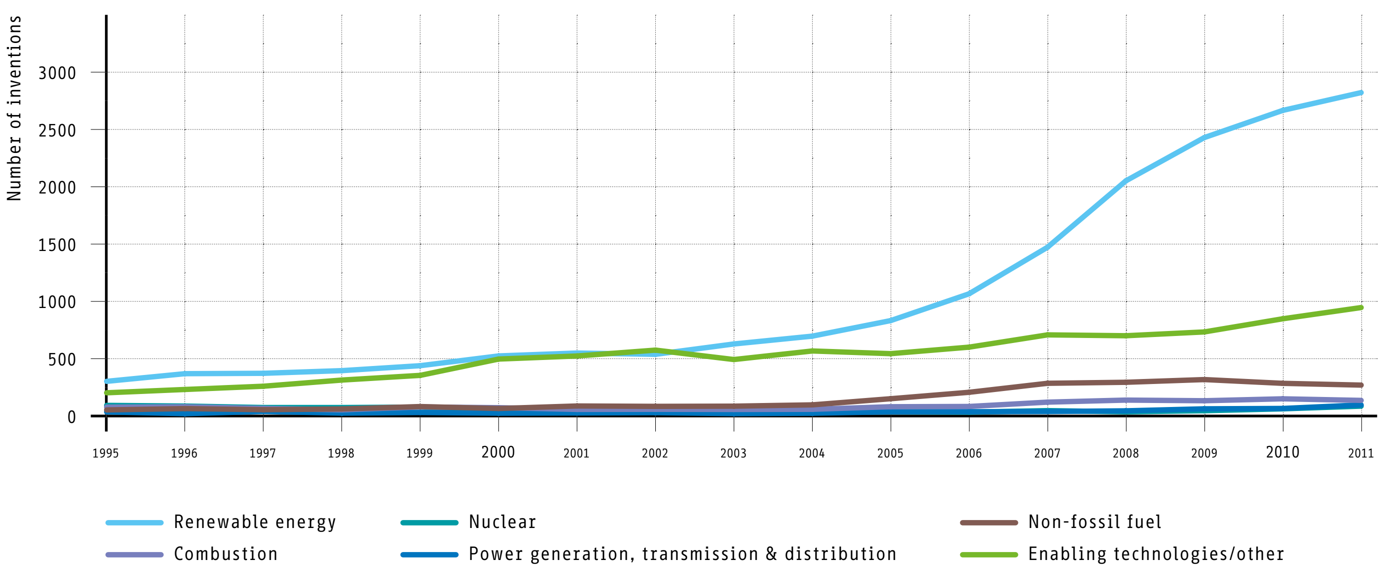
4.2.3
Inventive activity by technology

Corresponding to developments at the global level, the growth of inventive activity in CCMTs in Europe has occurred mostly in clean energy technologies (Y02E), CCMTs related to transportation (Y02T) and, to a lesser extent, in technologies for climate change mitigation in buildings (Y02B). In comparison, carbon capture and storage technologies (Y02C) and smart grids (Y04S) remain marginal (Figure 11). Among clean energy technologies (Figure 12), the majority of inventions are found in the fields of renewable energy (Y02E10) and enabling technologies, including energy storage, fuel cells and hydrogen (Y02E60-70). Road transportation technologies (Y02T10) account for the vast majority of inventions in CCMTs related to transportation (Figure 13).

11 European CCMT inventions by technology 1995–2011



12 European inventions in clean energy technology (Y02E) 1995–2011



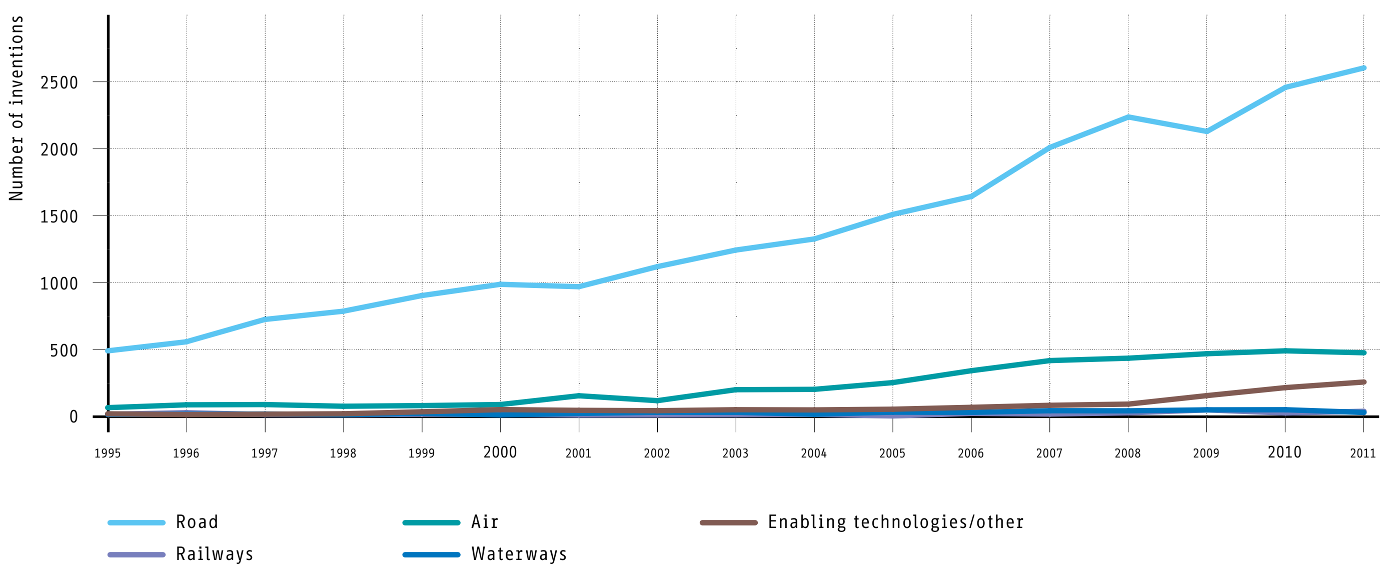
Jörg Horzel, Jozef Szlufcik, Mia Honore and Johan Nijs (Belgium, Germany)

Finalist of the European Inventor Award 2013 in the category of Research, in the area of energy generation through renewable energy sources (Y02E10)

Invention: Solar solution – making solar cell production easier and cheaper

Jörg Horzel and his team developed a process that streamlined the production of silicon-based solar cells, which had long been too expensive for commercially viable production. In order for solar cells to conduct electricity, their silicon base must be coated with phosphorous on one side, which involved applying a phosphorous paste to the entire front side of the cell. This caused some of the paste to end up on the rear side, and removing it was an expensive and time-consuming process. Horzel found a way to apply the paste to only certain sections of the cell surface, eliminating the step of removing it from the rear side. The result was a more efficient and cost-effective path to solar energy. As a source of renewable energy, solar power comes without the environmental costs of energy sources such as oil and coal. Thanks in part to Jörg Horzel's invention, solar-energy production has increased by an average of 40% per year worldwide since 2000.

13 European inventions in CCMTs related to transportation (Y02T) 1995–2011



The contribution of Europe to global inventive efforts varies across technologies. It is highest in CCMTs related to transportation and in carbon capture and storage (Figure 14), where Europe produces over 20% of the world's inventions and 40% of the high-value ones. The contribution of Europe to clean energy technologies, smart grids and CCMTs in buildings is slightly lower, but still significant, especially with regard to high-value inventions.

The evolution of Europe's contribution for individual climate change mitigation technologies has followed the overall trend described above: for most technologies, Europe's share decreased in the early 2000s before picking up again. Detailed trends by technology are presented in Annex 3.

4.2.4
Specialisation in CCMTs

To assess the specialisation of the major innovation centres in CCMTs, the relative technological advantage (RTA) of each country or region is calculated. RTA is measured as the proportion of CCMT inventions originating from the country or region, divided by the proportion of its inventions in all technologies. Hence the RTA controls for the overall invention performance of each country/region, as well as its propensity to use patents as a means of protection, and considers only its performance in CCMT inventions relative to overall performance. For example, if European inventors contribute to 20% of CCMT inventions worldwide and to 15% of inventions in all technologies across the world, Europe's RTA in CCMT will be equal to 1.3 (20% divided by 15%), indicating a high performance in CCMT relative to overall innovative performance.

Looking at the RTA index of the world's major innovation regions, Europe stands out as the most specialised area in terms of CCMT inventions. Its specialisation in CCMTs increased continually between 1995 and 2011, overtaking Japan in 2007 (Figure 15). In comparison, the US, and to a lesser extent China, do not appear to specialise in CCMTs, with RTA scores constantly below unity over the period of analysis. Korea has rapidly become strongly specialised in CCMTs and is now neck-and-neck with Japan. In high-value inventions, its performance is even stronger (see Annex 4).

4.2.5
International cooperation in R&D

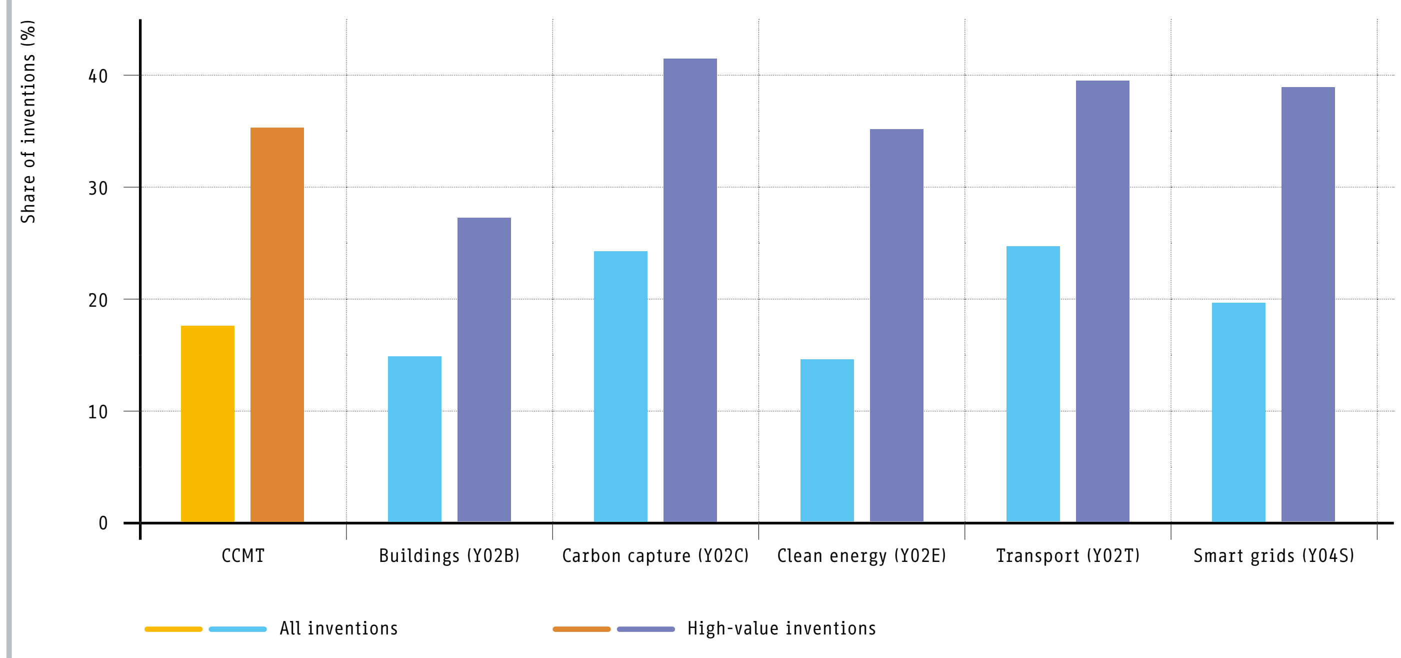
The designation of inventors from more than one country in a patent application is used as evidence of cooperation in R&D between these countries. Between 1995 and 2011, 3.5% of European CCMT inventions were developed in cooperation with non-European inventors. This proportion increased steadily over the period studied, from 2.2% in 1995 to 3.8% in 2011: an indication that international cooperation is becoming more important in CCMT development. The increased cooperation between European and non-European inventors in CCMTs mirrors a trend that can be observed for other technologies as well. For non-CCMT inventions, the proportion of European inventions developed together by European and non-European inventors increased from 2.0% in 1995 to 3.7% in 2011.

Figure 16 shows the countries/regions with which Europe has the main cooperation ties in R&D. Each arrow represents the number of co-inventions between pairs of countries or regions in CCMTs between 1995 and 2011.[15] The US appears to be Europe's key partner for CCMT inventions, with 55% of all inventions co-developed by a European and a non-European inventor involving an inventor based in the US. Japan and – interestingly – Russia are Europe's next main R&D partners, but the degree of cooperation appears far lower. In addition, European countries have also significant R&D cooperation ties with all regions of the world, including Africa, India, other Asian countries, and Latin America. This feature is entirely specific to Europe.

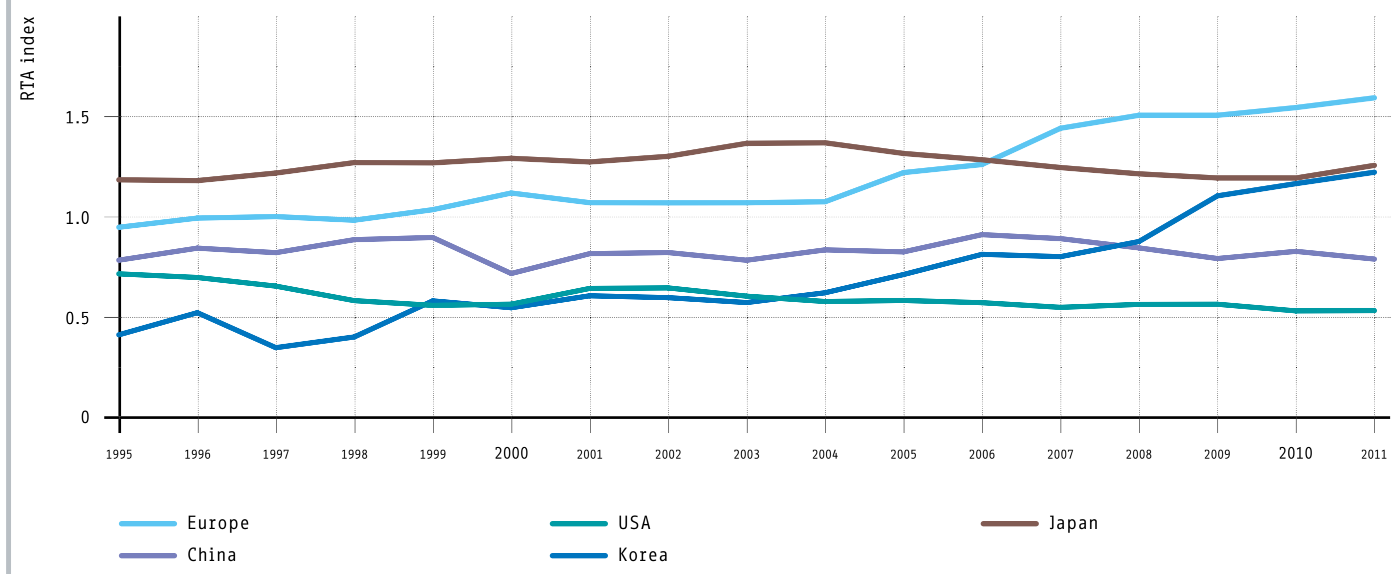
Looking at the evolution of co-invention activity between European and non-European countries, it appears that cooperation has increased with all partners, but especially with China (25 cooperative patents per year since 2006, up from only one per year on average between 1995 and 2005) and India (over 30 cooperations per year since 2010 against less than 5 in the pre-2007 period). Cooperation with US inventors has also quadrupled in the last 15 years.

15 A full table with all international co-invention pairs can be found in Annex 5.

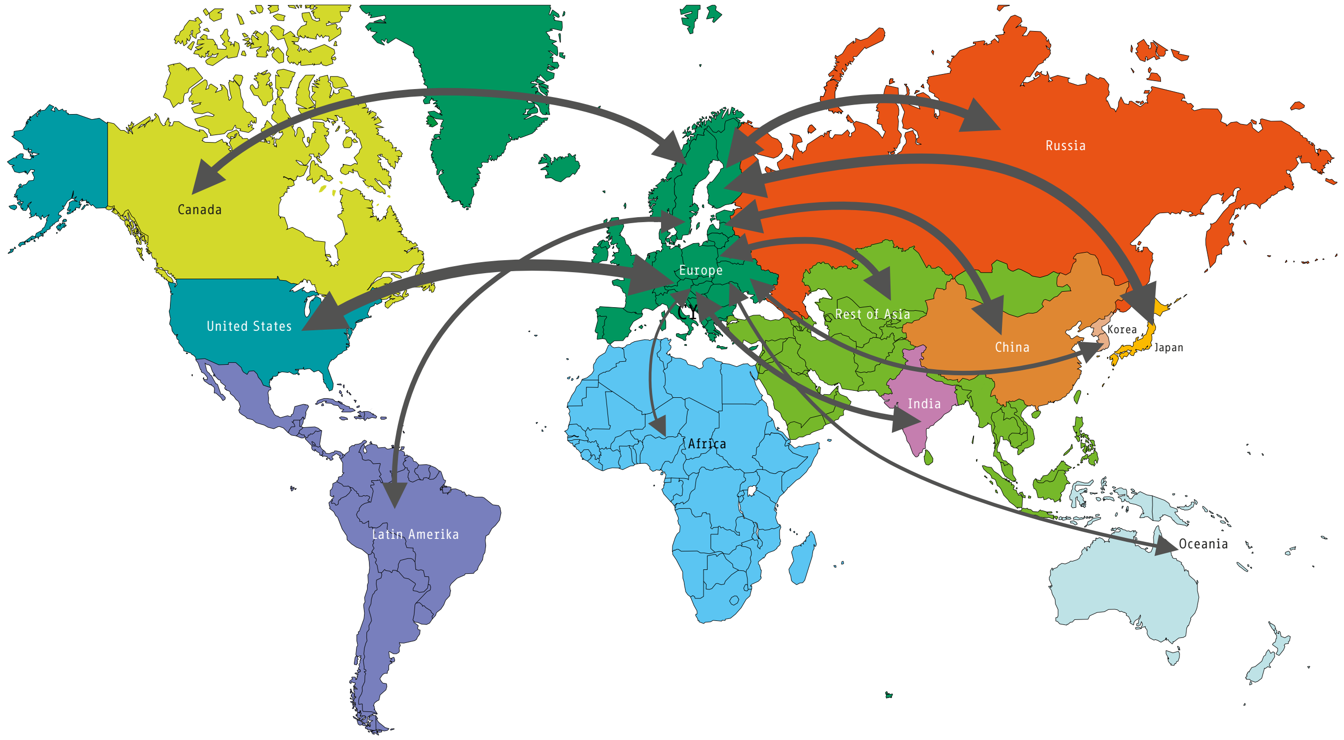
14 European share of global CCMT inventions 1995–2011



15 Relative technological advantage (RTA) of major innovation centres in CCMTs 1995–2011



16 CCMT inventions co-developed by European inventors and inventors from other countries 1995–2011



Co-operation			Co-inventions
Europe	↔	USA	1926
Europe	↔	Japan	301
Europe	↔	Russia	228
Europe	↔	China	187
Europe	↔	Canada	179
Europe	↔	Rest of Asia	170
Europe	↔	India	160
Europe	↔	Latin America	132
Europe	↔	Korea	115
Europe	↔	Oceania	54
Europe	↔	Africa	41

4.2.6
Top applicants for CCMT inventions

Table 3 and 4 show the top CCMT applicants at European and global level. They are found primarily in the transportation category (four applicants out of the top five), which could be a reflection of the high concentration as well as the high propensity to patent in this sector (Cohen et al., 2000). By comparison, only one of the five most prolific applicants specialises in clean energy technologies, although this is the largest CCMT category for European inventors.

The top applicants by technology are available in Annex 6.

03 Top 5 European applicants in CCMT patenting 1995–2011

Applicant	Country	Inventions	Main CCMT category
Robert Bosch	Germany	5824	Transportation (Y02T)
Siemens	Germany	4733	Clean energy (Y02E)
Renault	France	1698	Transportation (Y02T)
Peugeot Citroën Automobiles	France	1400	Transportation (Y02T)
Snecma (Société nationale d'études et de constructions de moteurs d'aviation)	France	1236	Transportation (Y02T)

04 Top 5 worldwide applicants in CCMT patenting 1995–2011

Applicant	Country	Inventions	Main CCMT category
Toyota Motor Corporation	Japan	10743	Transportation (Y02T)
Robert Bosch	Germany	6009	Transportation (Y02T)
Honda Motor Company	Japan	4951	Transportation (Y02T)
GE (General Electric Company)	USA	4932	Clean energy (Y02E)
Siemens	Germany	4818	Clean energy (Y02E)

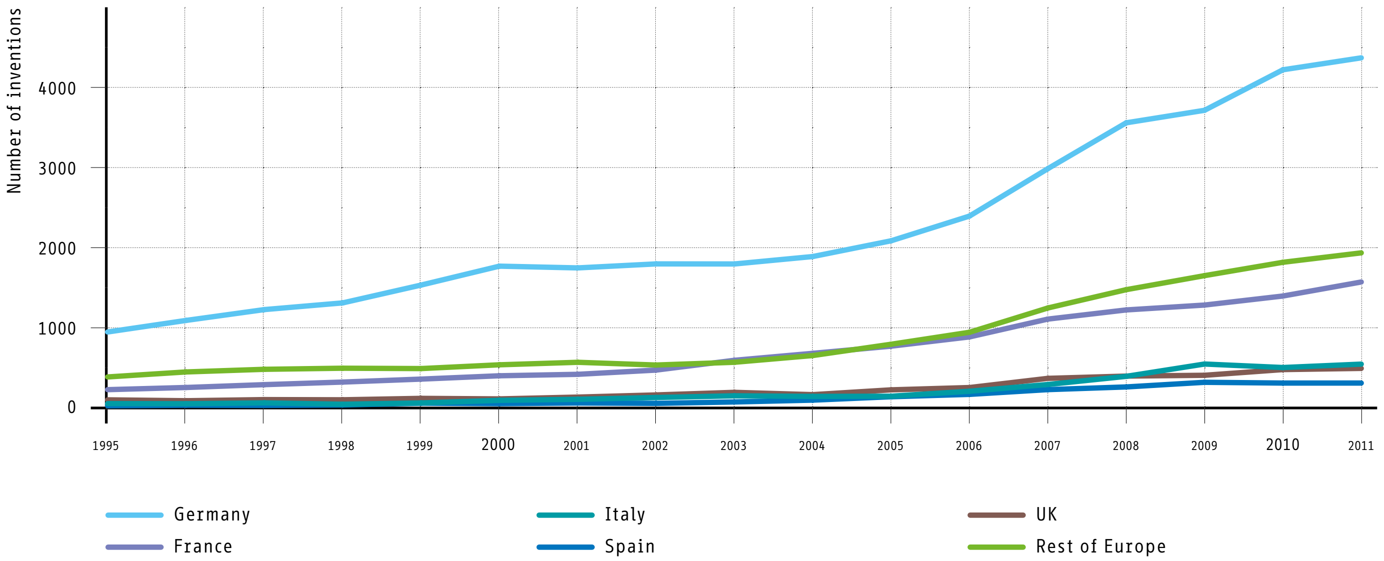
4.3
Inventive activity in individual European countries

4.3.1
Country comparison

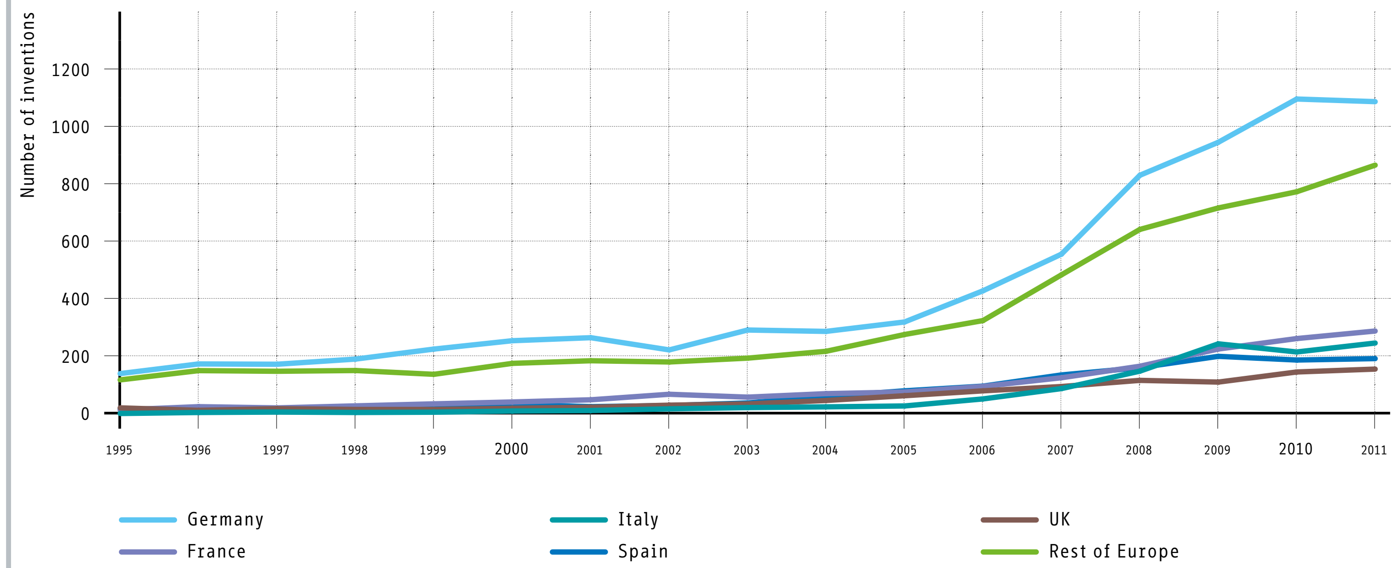
Inventiveness appears highly concentrated within Europe, five countries representing 80% of inventive activity. With almost half of Europe's CCMT inventions in the most recent period, Germany appears as the clear leader in CCMT, even if other countries are catching up, most notably France, Italy, UK and Spain. Germany's leadership is apparent in all technologies (Figure 17). Looking at the two technologies with the highest European inventive activity, it appears that in renewable energy Germany's invention performance is four times greater than that of the second largest inventor country, France (Figure 18). The share of German inventions in road transportation technologies is even higher (Figure 19).

CCMT inventions (1995-2011) for all EPC member and extension states can be found in Annex 7.

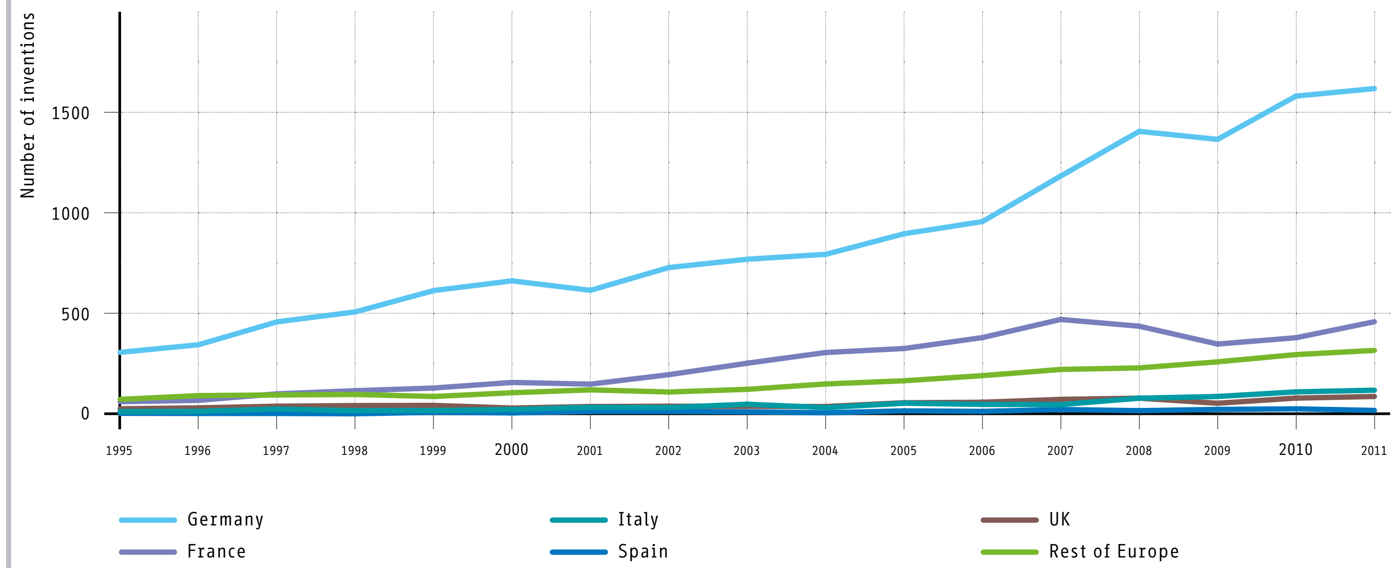
17 European CCMT inventions by country 1995–2011



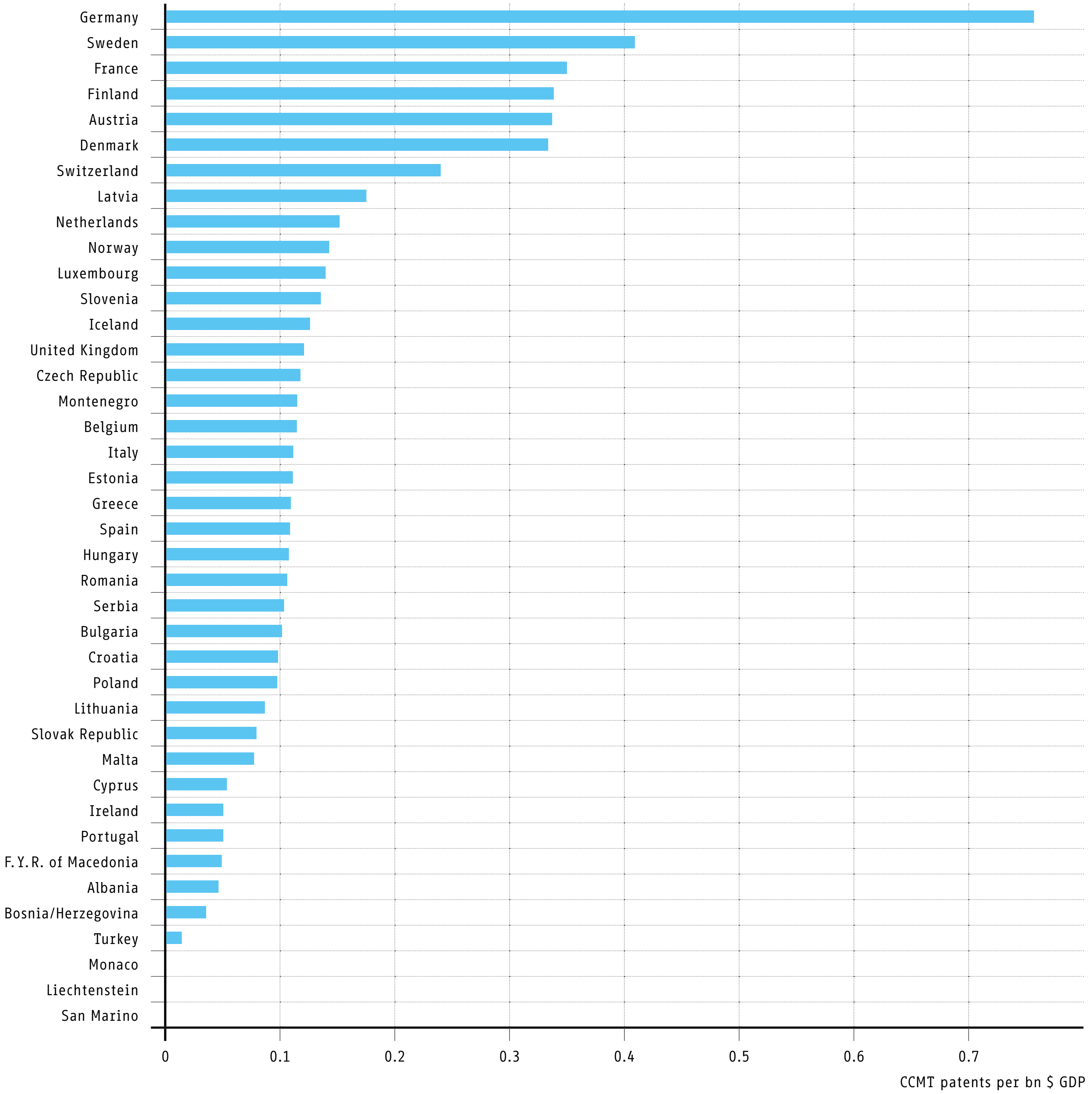
18 European inventions in renewable energy (Y02E10) by country 1995–2011



19 European inventions in road transportation (Y02T10) by country 1995–2011



20 European CCMT inventions per GDP by country 1995–2011

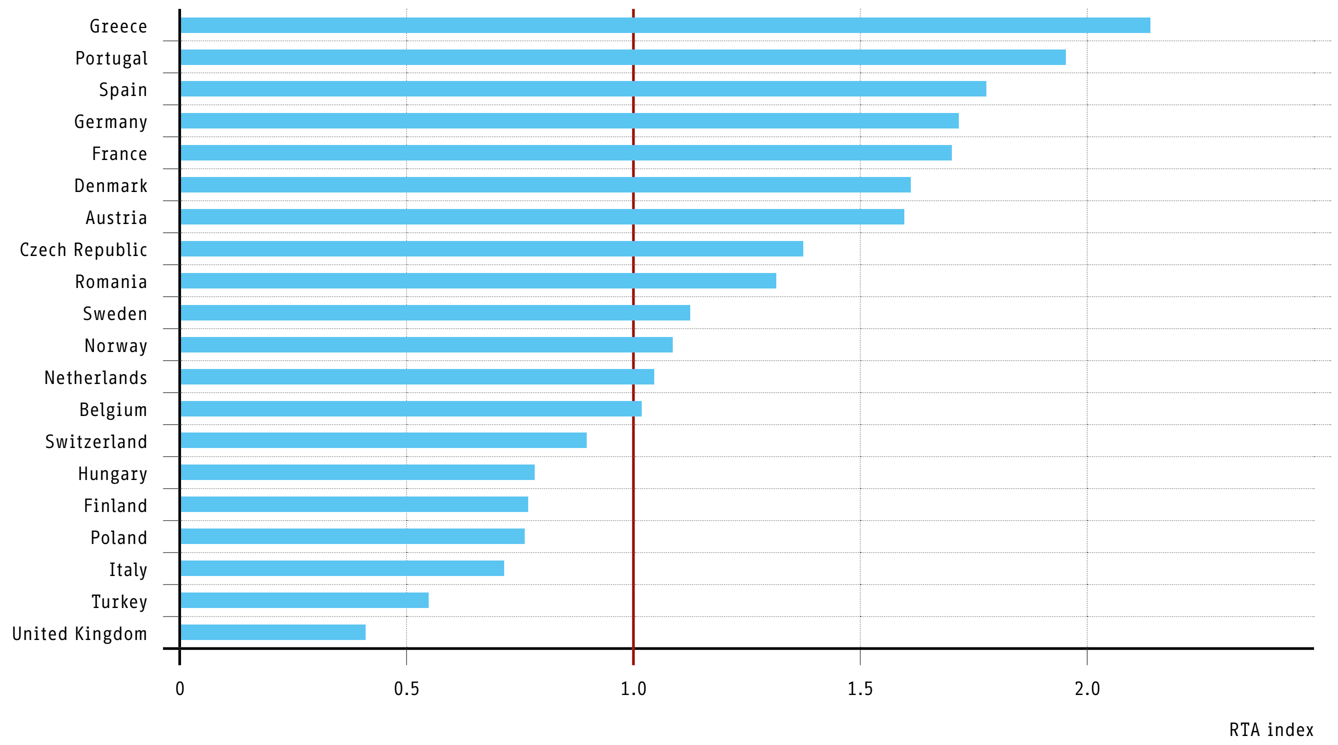


The concentration of inventive activity among a small number of large countries such as Germany and France might simply be a reflection of their economic size. To take this into account, the number of CCMT inventions developed by each European country is divided by their GDP. Using this metric, Germany still appears as the European leader, followed at a distance by Sweden and France (Figure 20). In contrast, UK's, Italy's and Spain's inventive performance seems to be related more to the size of their economy.

4.3.2 Specialisation in CCMT inventions

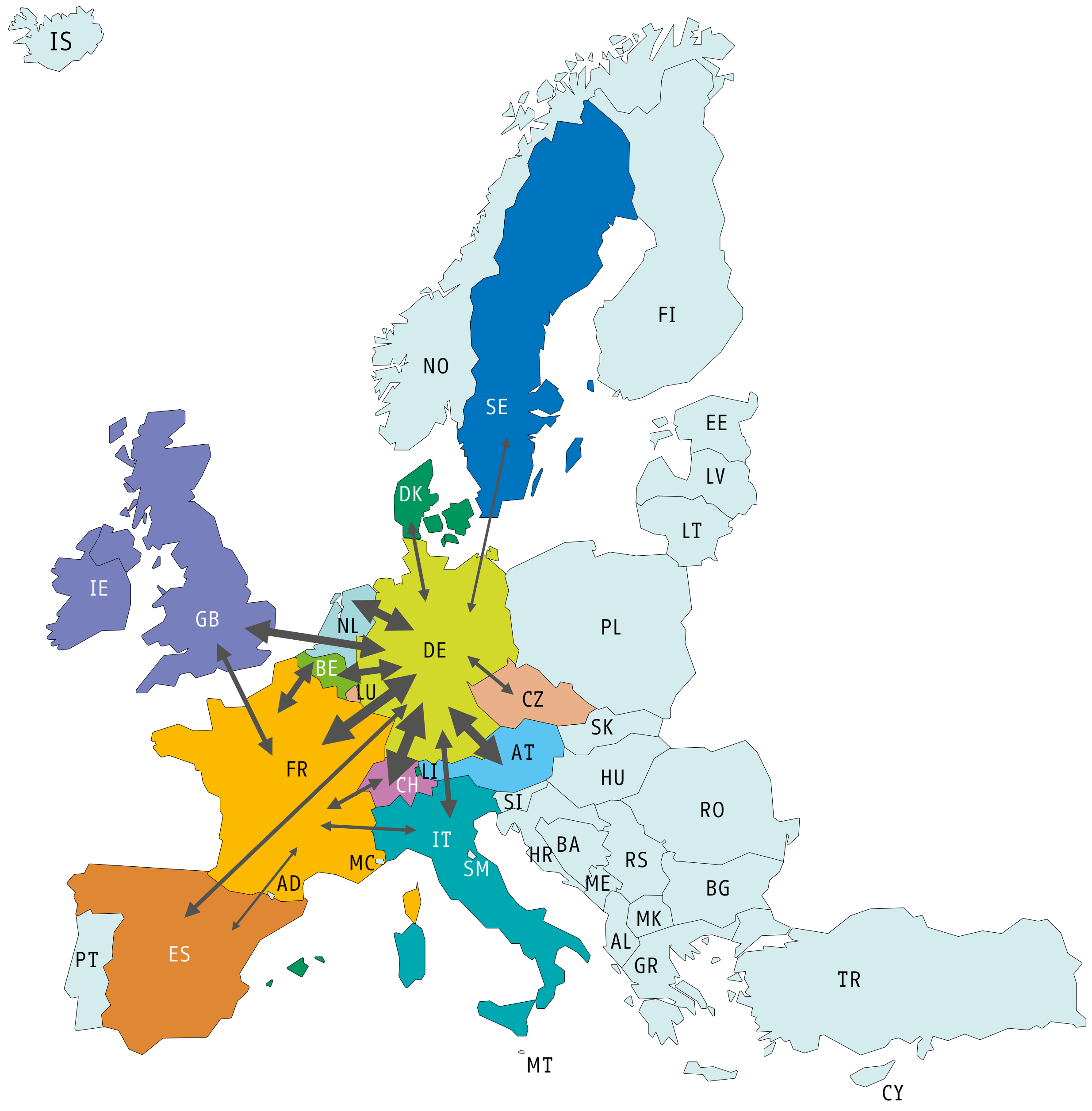
To analyse the specialisation in CCMTs across Europe the relative technological advantage of individual European countries, as defined in section 4.2.4, is calculated. Two of the main contributors to Europe's CCMT inventions, Germany and France, appear to be highly specialised in CCMTs (Figure 21).[16] However, this is not the case with other significant inventors, such as Italy and the UK. Interestingly, the European countries that are most specialised in CCMTs are (in descending order) Greece, Portugal and Spain. This remarkable performance seems to be driven by a strong specialisation in renewable energy technologies, in particular solar energy. Not surprisingly, Denmark is also strongly specialised in renewable energy technologies, primarily wind energy. France, Germany, Austria and Sweden have a strong specialisation in CCMTs related to transportation. Norway has a remarkable advantage in carbon capture and storage technologies, far ahead of the other leaders, France and the Netherlands. Austria and Finland appear to focus their efforts on CCMTs for buildings. Finally, Switzerland has clearly specialised in smart grids. Figures on RTA for individual Y02/Y04S technologies can be found in Annex 8.

21 Relative technological advantage (RTA) in CCMTs by European country 1995–2011



16 Countries that did not have a minimum number of patent filings in all technology areas in the periods covered are not presented. For example, a country with two patent filings of which one is in CCMT would show an RTA score several times higher than that of the current leaders.

22 CCMT inventions co-developed by European countries 1995-2011



Co-operation			Co-inventions
DE	↔	CH	335
FR	↔	DE	323
NL	↔	DE	285
DE	↔	AT	203
GB	↔	DE	168
DE	↔	BE	115
FR	↔	BE	99
IT	↔	DE	96

Co-operation			Co-inventions
GB	↔	FR	79
DE	↔	ES	71
FR	↔	CH	69
DE	↔	CZ	63
DE	↔	DK	63
IT	↔	FR	62
SE	↔	DE	52
FR	↔	ES	50

4.3.3
Intra-European cooperation in R&D

The number of patents where inventors from more than one European country are designated is used to assess the level of cooperation in R&D between European countries. Between 1995 and 2011, 3.2% of European inventions resulted from cooperation between inventors located in at least two different European countries. This number is comparable to the proportion of inventions developed between European countries and the rest of the world. However, the proportion increased substantially over the period of analysis, from 1.7% in 1995 to 4.1% in 2011. Hence, intra-European cooperation in R&D, measured by patent data, is developing at a faster rate than cooperation in R&D between European and non-European countries. Moreover, intra-European cooperation has become more prevalent for CCMTs than for other technologies. For non-CCMT inventions, the proportion of inventions developed by inventors from several European countries only increased from 1.6% in 1995 to 3.0% in 2011.

Figure 22 presents a map of the strongest R&D cooperation ties in CCMTs in Europe. The ties are measured by the number of inventions co-developed by inventors from different European countries between 1995 and 2011.[17] Germany appears to be the key partner of other countries for CCMT inventions. One third of all patents co-developed by inventors from two or more European countries involve an inventor based in Germany. Germany's main invention partners are Switzerland, France, the Netherlands and Austria. France, Switzerland and the Netherlands are Europe's other main cooperating countries.

17 The illustration is limited to pairs of countries with at least 50 co-developed inventions. A full table with all intra-European co-invention pairs can be found in Annex 5.

Markets for climate change mitigation technologies

5
MARKETS FOR CLIMATE CHANGE MITIGATION TECHNOLOGIES

Electric car charging, Nice, France

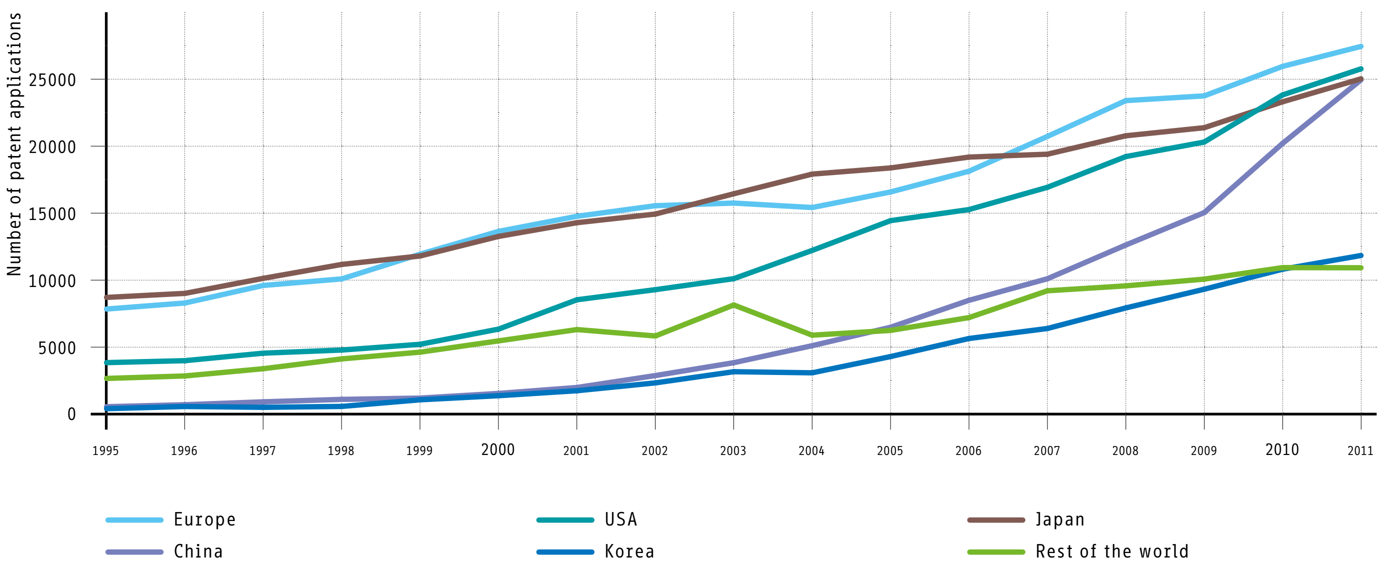
5.1 Evidence from patent data

5.1.1 Europe's position as a market for CCMT inventions

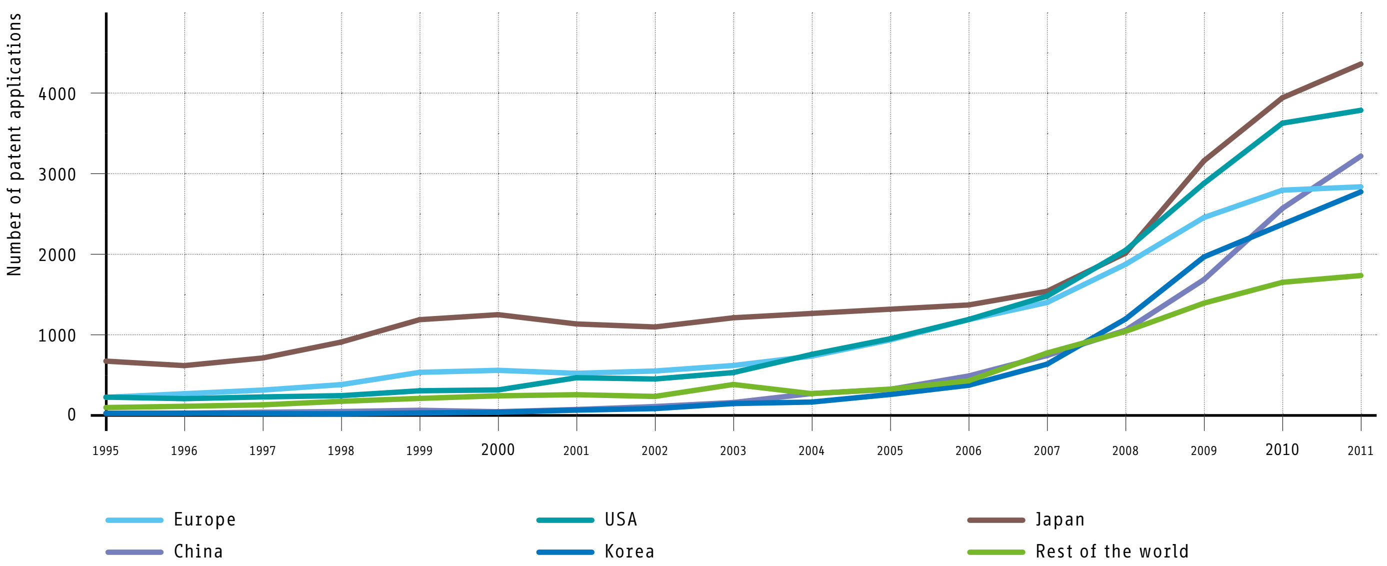
Figure 23 presents the countries/regions where applicants sought patent protection for CCMT inventions over the period 1995-2011. The number of patent applications in CCMTs increased considerably across all regions of the world. Europe appears as the main destination of CCMT patent filings worldwide, closely followed by Japan. The US is another major recipient of CCMT patent applications, as are China, where the growth rate from 2000 onwards was particularly impressive, and Korea. Other regions appear to be less attractive destinations.

Statistics for the top 25 target countries in patent applications can be found in Annex 9.

23 Patent filings in CCMTs by region 1995-2011



24 Patent filings in photovoltaic energy (Y02E10/50) by region 1995-2011

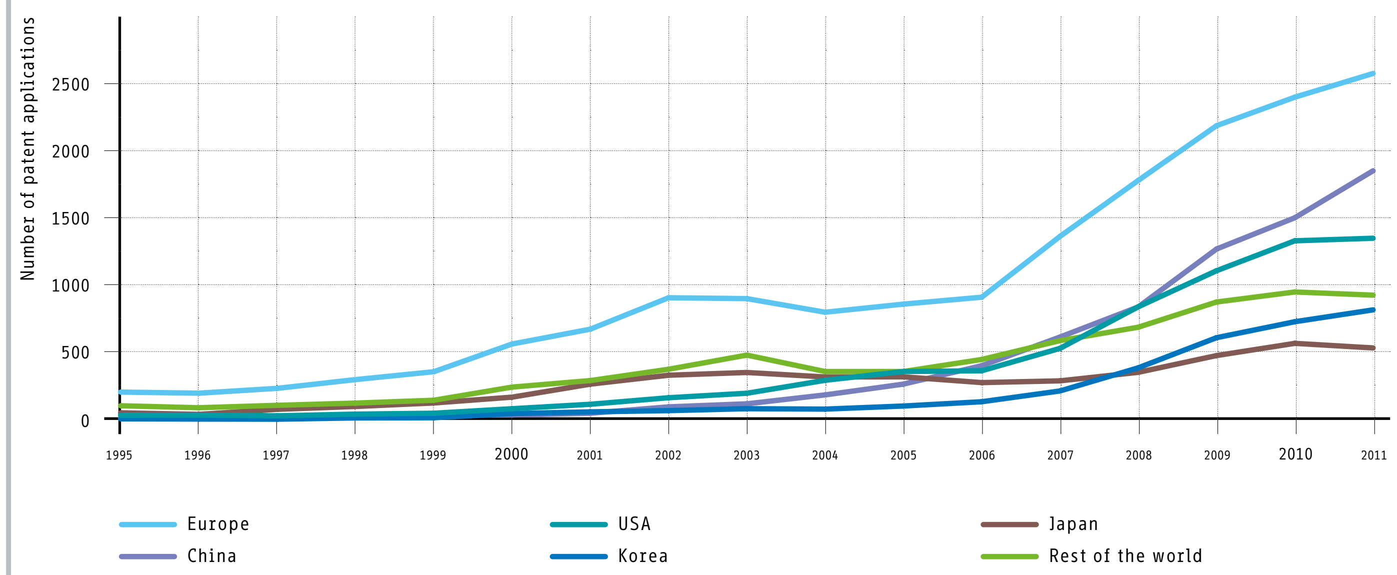


This ranking varies considerably across technologies, and specialists interested in a particular area of technology are recommended to perform their own more detailed analysis. As an example, the patent application analyses for photovoltaic energy and wind energy are presented in Figure 24 and Figure 25. Japan is the main destination for photovoltaic energy patent applications, followed by the US, while Europe is the main destination for wind patent applications, far ahead of China in second place. In general, the number of filings in all five regions accelerated immensely from 2006.

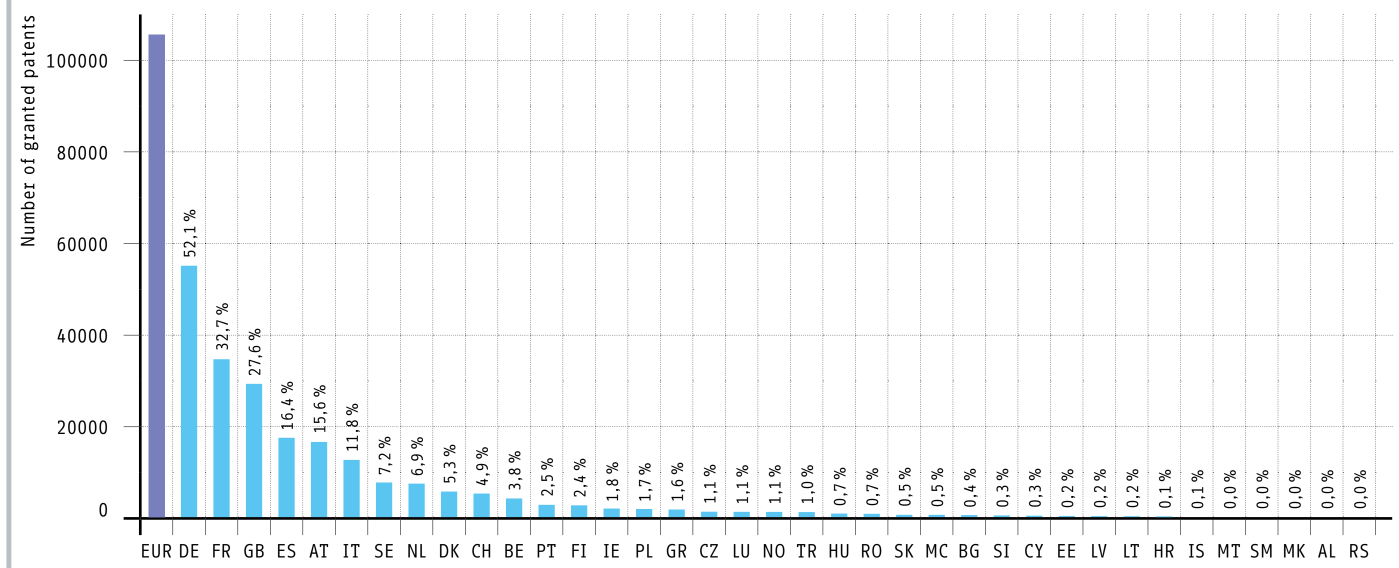
5.1.2 Key European markets for CCMT inventions

The next graph presents the distribution of granted CCMT patents across the 38 EPC contracting states and the two extension states between 1995 and 2011 (Figure 26). This includes patents granted directly by national IP offices and European patents granted by the EPO. To determine where European patents finally define exclusive rights, data on national validation after grant is used. The first column (EUR) includes all patents granted in Europe, by

25 Patent filings in wind energy (Y02E10/70) by region 1995-2011



26 Market coverage for granted CCMT patents in Europe 1995-2011



national offices or the EPO. Over 50% of these patents confer exclusive rights in Germany, which is by far the largest market in Europe for CCMTs. Around 30% confer rights in France; the proportion for the UK is slightly lower; and fewer than 20% confer rights in Spain, Austria or Italy.

The ranking is similar if one focuses only on patents granted by the EPO and analyses in which national offices they are validated (see Annex 10). In addition, comparing the market coverage of CCMTs with that of other technologies, no striking differences emerge, which suggests that patenting patterns in CCMTs and non-CCMTs are generally similar.

5.1.3
Origin of CCMT patent applications filed in Europe

European countries, in particular Germany, France and the UK, are the main sources of European patent filings (at the EPO and national patent offices). However, US, Japanese and Korean inventors are also among the top ten contributors to CCMT patent filings in Europe (Figure 27). Chinese inventors are still rarely named in patent applications in Europe.

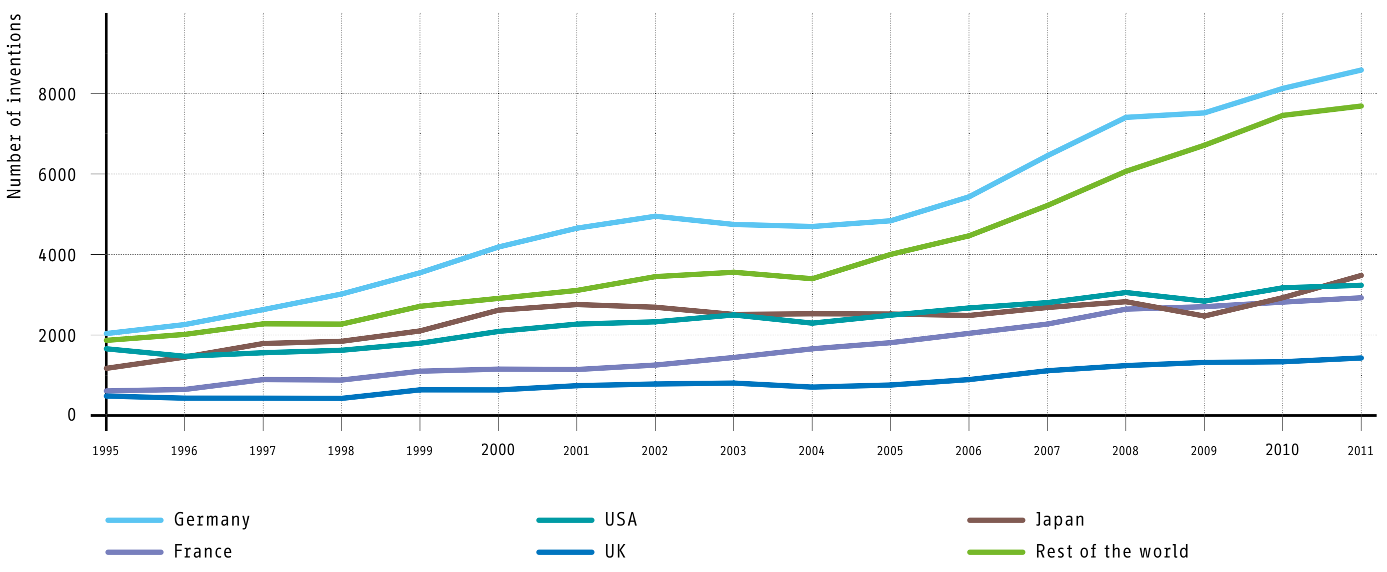
Statistics for the main origins of European patent applications by country (1995-2011) can be found in Annex 11.

5.1.4
Markets for European CCMT inventions

Nearly half of European CCMT inventions have a patent family size of one, and are therefore filed with only one patent office – typically the EPO[18] or the German national office. This means, however, that more than half are filed with at least two offices – an indication of the above-average commercial value of these inventions. As is typical with patents, the distribution of the family size of European CCMT inventions is heavily skewed: only 13% of inventions form the subject of applications filed with more than five patent offices and less than 2% lead to filings with more than ten offices (Figure 28). Interestingly, the distribution is similar to that for inventions not related to CCMTs.

Figure 29 shows the global patent filings for all inventions originating in Europe. The first column represents the total number of inventions with European inventors. Not surprisingly, patent protection was sought in Europe for 97% of all European inventions. The EPO is the primary patent office for these filings, closely followed by the German national office. However, European inventors also clearly target a global market. The third patent office for European inventions is the USPTO, followed by the Chinese, Japanese and, to a lesser extent, the Canadian, Australian and Korean IP offices. However, the aggregated numbers hide important recent trends. From 2009, over 2 000 patents in CCMTs were filed annually by European inventors in China, against only 300 in the early 2000s.

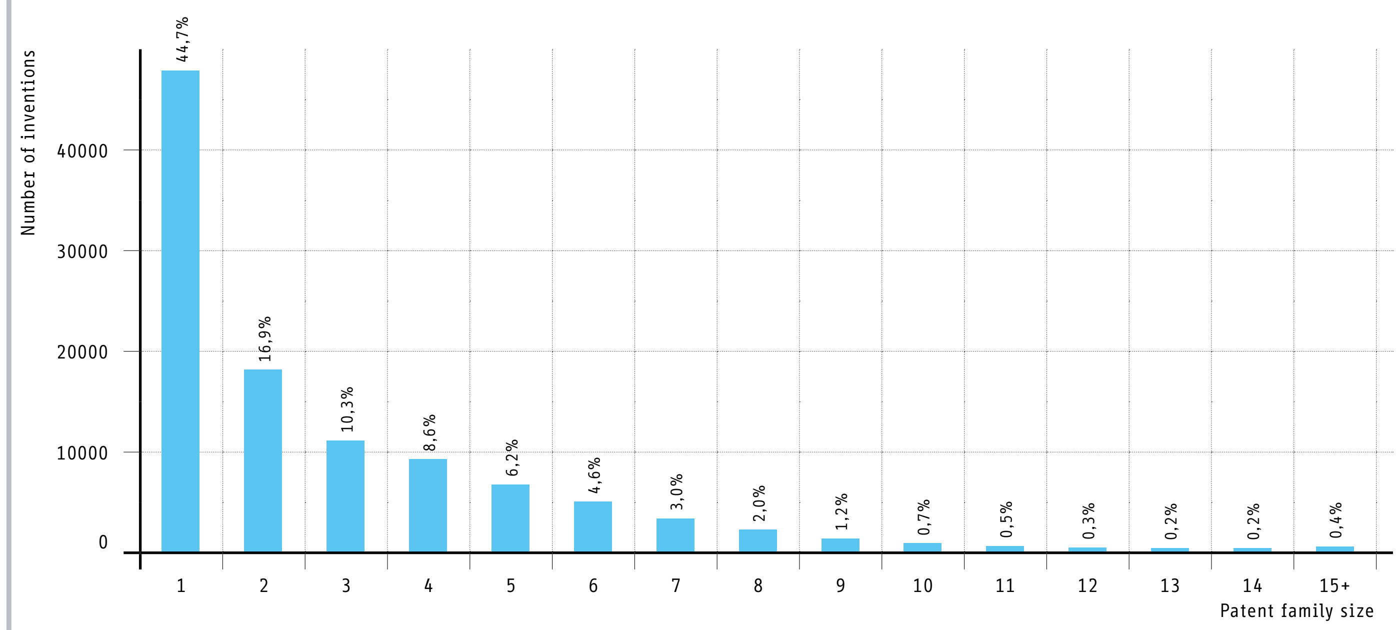
27 Origin of CCMT patent filings in Europe 1995–2011



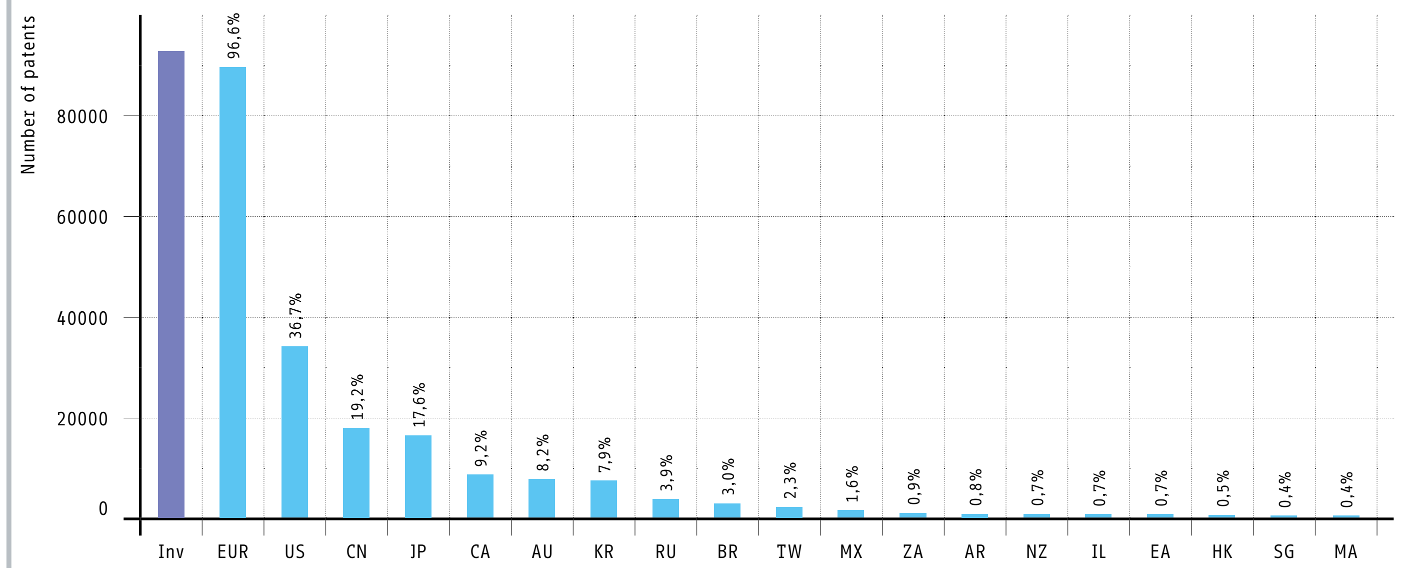
18 Only 7% of patent applications for CCMT inventions received by the EPO are filed with the EPO only. Using data on extension states, since an EPO patent may hide a number of extension patents in individual member states, almost the same distribution as in Figure 28 is obtained, although slightly shifted to the right (there are slightly more families with a size greater than five).

This represents around 25% of annual European CCMT inventions in 2011, compared with 10% ten years before. In Korea, over 1 000 CCMT patents are now filed every year by European inventors (over 10% of European CCMT inventions), up from only 160 in 2000 (4.5%). The number of CCMT patents filed in the US and Japan also increased, but less dramatically. In 2010, 38% of European CCMT inventions gave rise to filings in the US, against 14% in Japan.

28 Patent family size distribution of European CCMT inventions 1995–2011



29 Main patent filing destinations of European CCMT inventions 1995–2011



5.2 Evidence from economic data

5.2.1 Worldwide trade and FDI in CCMTs

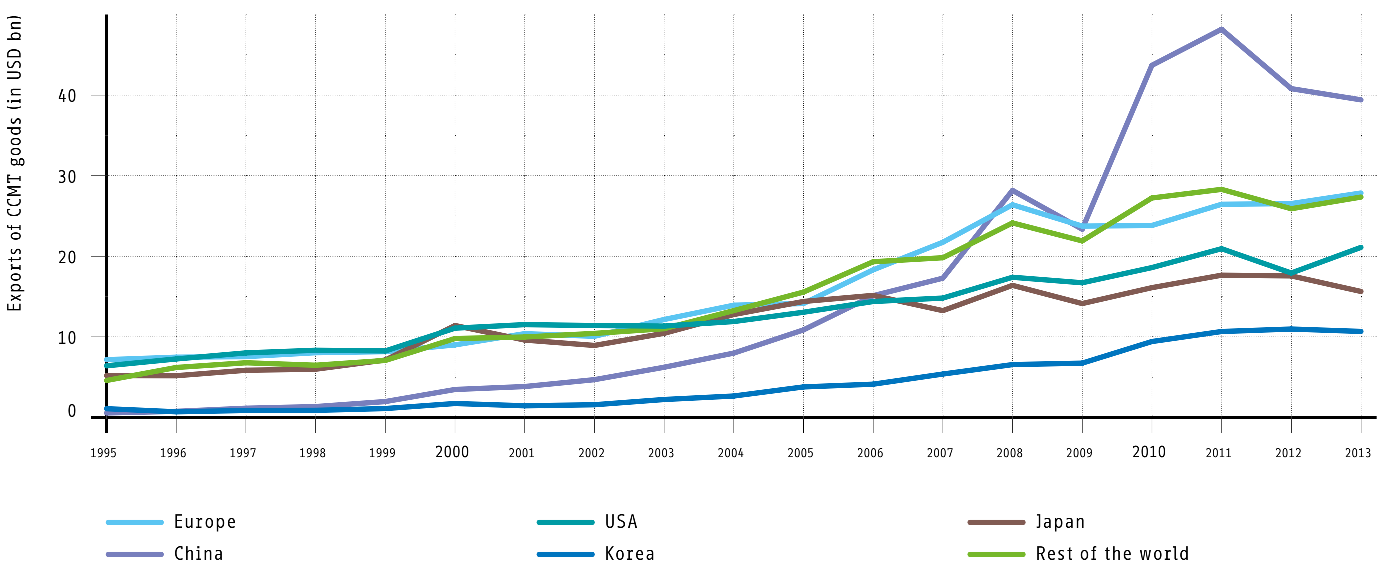
International trade is a major channel through which firms can earn returns on their inventions. The trade of capital goods, such as machines and equipment, is also a major channel for international technology transfer, since these goods embody technologies that can then induce knowledge "spillovers" in the recipient country (Rivera-Batiz and Romer, 1991). Local firms can reverse-engineer imported products, or acquire knowledge through business relationships (e.g. as customer or distributor) with the source company. As an illustration, China has acquired production technologies to develop a thriving solar photovoltaic industry by purchasing turnkey production lines from German, US and Japanese suppliers (de la Tour et al., 2011), and Chinese companies are now able to build production equipment on their own.

Between 1995 and 2013 there was sustained growth in the international trade of CCMT capital goods. This growth has accelerated recently, particularly in exports from China. However, Europe as a whole is still the second-largest exporter of CCMT capital goods, ahead of the US and Japan (Figure 30).

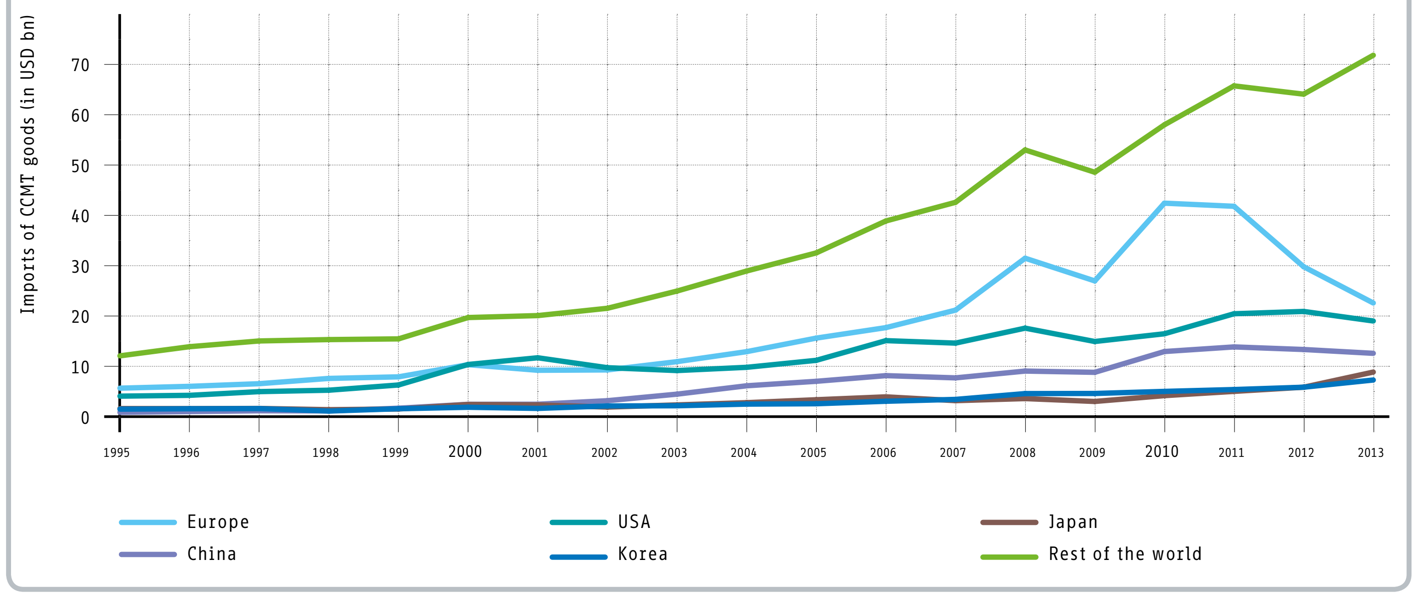
From the mid-1990s, Europe was also the largest importing region, followed by the US and China, for CCMT capital goods (Figure 31). What is remarkable, however, is the distribution of the value of exports compared to the value of imports across countries. While CCMT exports are concentrated on a few regions, which unsurprisingly also show strong patenting activity, the distribution of CCMT imports is much wider across the rest of the world.

Over the period analysed, Japan, China and Korea were clear net exporters of CCMT capital goods, whereas Europe, especially in the period 2008-2012, became a net importer (Figure 32). The "rest of the world" countries invariably had a negative balance of trade in CCMT capital goods.

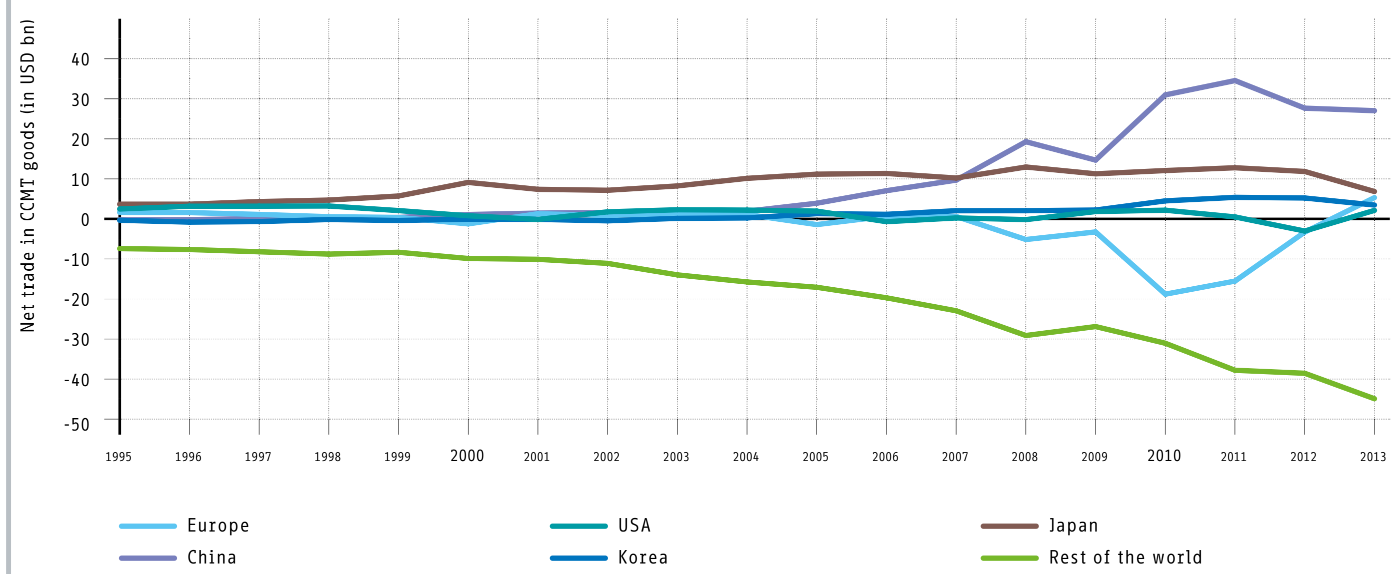
30 Main exporters of CCMT goods by region 1995-2013



31 Main importers of CCMT goods by region 1995-2013



32 Balance of trade in CCMT goods by region 1995-2013



The increasing volumes of CCMT capital goods imported into Europe in the recent period may have been partly encouraged by the falling tariffs applied by European countries. During the same period, tariffs applied to European exports also fell, but not as much (Figure 33). Since trade is a channel for technology diffusion, barriers to trade are likely to hinder the global diffusion of CCMTs. Saggi (2002) empirically shows that technology diffusion is facilitated by an open trade regime. Duke et al. (2002) show that the reduction of tariffs on solar modules in Kenya increased imports of PV systems. Looking at 13 climate change-related technologies, Dechezleprêtre et al. (2013) show that higher tariff rates decrease diffusion of CCMTs. The difference between tariffs applied by Europe on CCMT imports and tariffs levied by foreign countries on European exports may thus help to explain Europe's position as a net importer of CCMT goods in the recent period.

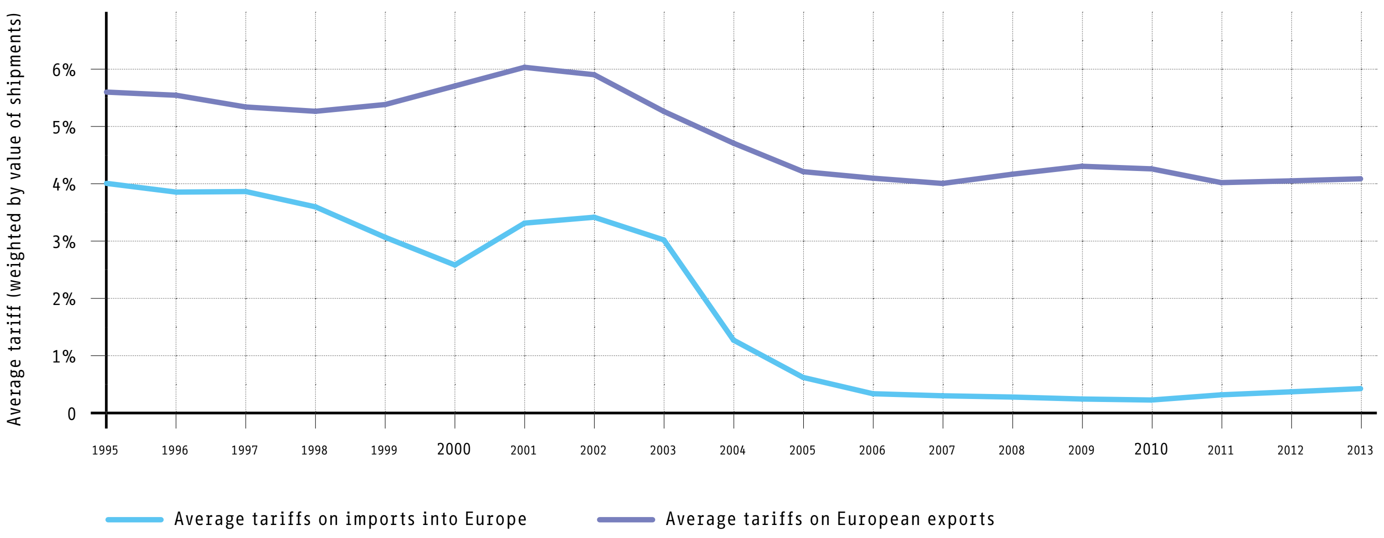
As explained in Chapter 3, foreign direct investment (FDI) in CCMTs is measured by the number of subsidiaries of companies that patent in climate change mitigation technologies (CCMT companies). Together with trade, FDI is a major channel for international technology diffusion. Several studies have found evidence that multinational enterprises transfer firm-specific technology to their foreign affiliates or partners in joint ventures (e.g. Lee and Mansfield, 1996; Branstetter et al., 2006). Foreign direct investments usually induce more knowledge transfer than trade in goods, since they aim at exploiting the technology directly in a local subsidiary of the source company or in a joint venture – and no longer in the source country. The transfer is particularly important with joint ventures, as the local partner has direct access to the technology. FDI may also generate local spillovers through labour turnover if local employees of the subsidiary move to domestic firms (Fosfuri, Motta and Ronde, 2001). Local firms may, additionally, increase their productivity by observing nearby foreign companies or becoming their suppliers or customers (see, for example, Ivarsson and Alvstam, 2005; Girma et al., 2009). Many studies have found empirical evidence that FDI has significant spillover effects in raising the level and growth rate of productivity of domestic manufacturing industries (see, for example, Liu, 2002 and 2008; Keller and Yeaple, 2003). Overall, the literature finds strong evidence that FDI is an important channel for climate change mitigation technology diffusion. For example, it is the key vector of technology transfer in the wind industry (Kirkegaard et al., 2009).

In 2012, Europe was both the main destination and the main source of foreign direct investment in CCMT, followed by the US (see Table 5). Unlike in trade activities, Europe is clearly a net supplier of FDI, whereas China is a net recipient. In contrast, the pattern of trade flows is mirrored in the concentration of outward FDI on a few regions: Europe, the US and Japan. Japan alone has more subsidiaries of CCMT companies than the countries making up the "rest of the world". Inward FDI, on the other hand, is much more widely distributed: the top three recipients – Europe, the US and China – are the destination of only every second subsidiary of CCMT companies.

05 Number of subsidiaries of CCMT companies by region in 2012

Source of FDI		Destination of FDI	
Europe	20558	Europe	13761
USA	19943	USA	9920
Japan	9343	China	5380
Korea	842	Japan	1530
China	563	Korea	1002
Rest of the world	6718	Rest of the world	26374

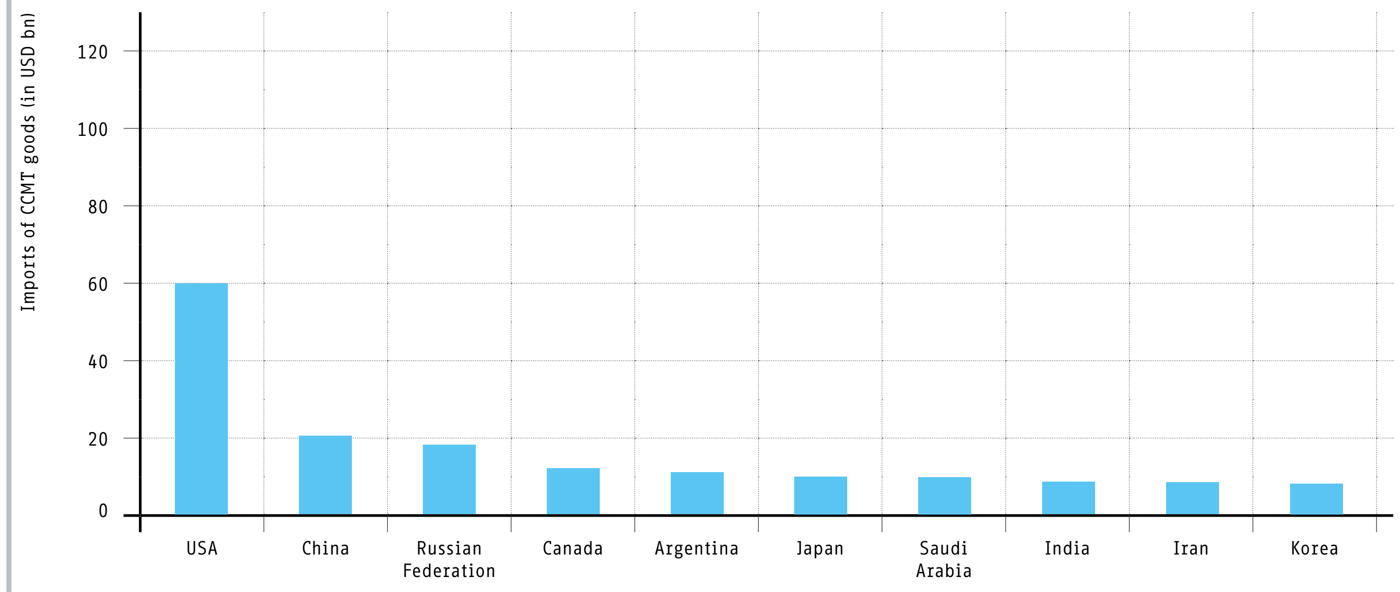
33 Average tariffs on European imports and exports of CCMT goods 1995-2013



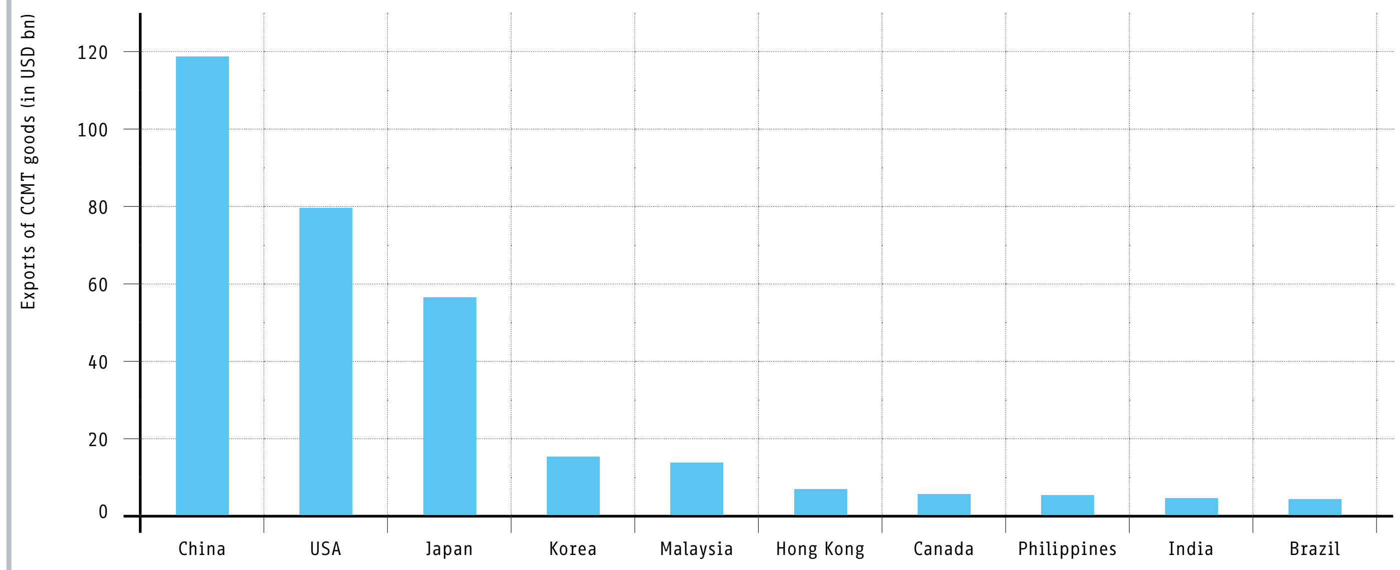
5.2.2 Europe's partners in trade and FDI

The main export destination of European CCMT capital goods is the US, with approximately three times as many imports as any other country; while the main source of European imports is China, followed by the US and Japan (Figure 34 and Figure 35).

34 Main destination countries of European exports of CCMT goods 1995-2013



35 Main sources of European imports of CCMT goods 1995-2013



The main destinations of European foreign direct investments are broadly similar to the export destinations for European capital goods: the main recipient is the US, with a figure approximately twice as high as China and Russia, which are among the top three destinations for FDI (Figure 36),[19] as well as capital goods. However, there are also some differences: Brazil and Mexico are among the top five destinations for European FDI, but are not among the top ten destinations for exports. This could point to a substitution effect between FDI and exports: in countries where technology imitation capacities are strong but patent protection is not perceived as strong enough, companies prefer setting up a subsidiary to exporting goods, as this makes it easier for them to protect their knowledge.

36 FDI in CCMTs between Europe and rest of the world in 2012

From	To	Number of subsidiaries
United States	Europe	9382
Europe	United States	5142
Europe	Latin America	3637
Latin America	Europe	137
Europe	Rest of Asia	3124
Rest of Asia	Europe	264
Japan	Europe	2472
Europe	Japan	771
Europe	China	2150
China	Europe	142
Europe	Africa	1853
Africa	Europe	30

From	To	Number of subsidiaries
Europe	Canada	778
Canada	Europe	542
Europe	Oceania	878
Oceania	Europe	342
Europe	Russia	1145
Russia	Europe	19
Europe	India	722
India	Europe	196
Europe	Korea	358
Korea	Europe	235

19 See Annex 13 for a table with FDI between all regions worldwide.

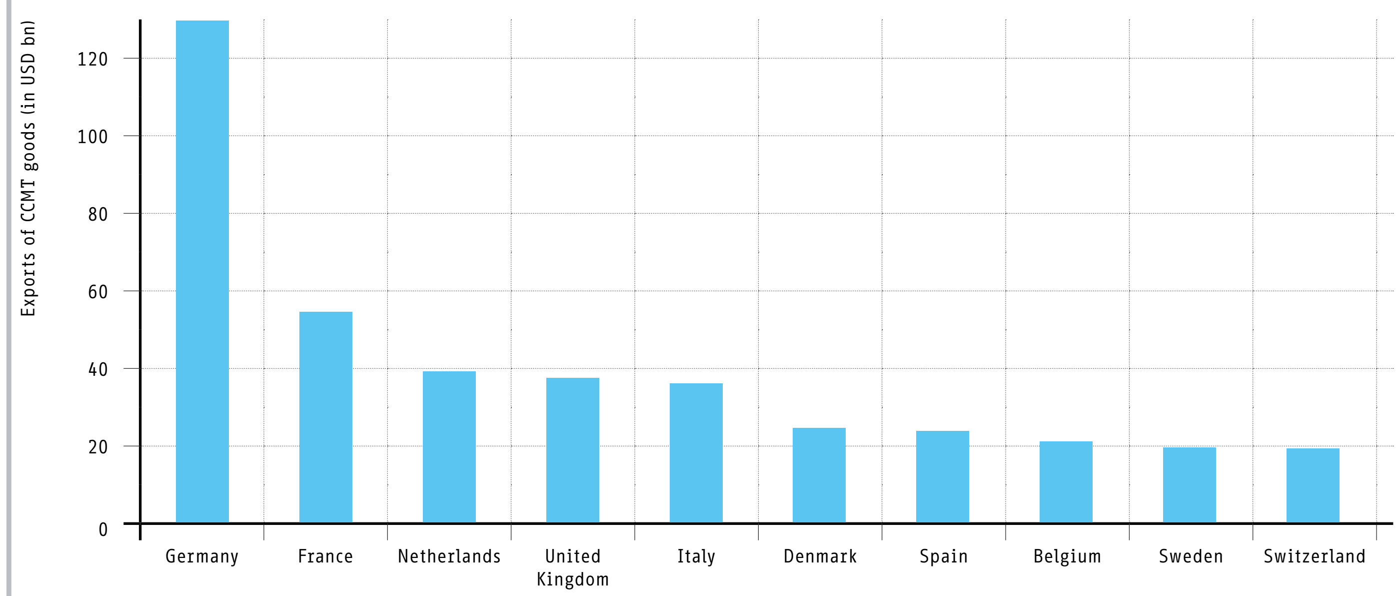
Looking at the global distribution of foreign direct investments of companies that patent in climate change mitigation technologies, Europe appears as a major source of investment. The presence of European CCMT companies is global, and is especially strong in Africa, Russia and China, in particular compared to the presence of their US counterparts.

Altogether, whereas patent protection is primarily sought in Europe, some other OECD countries and China, exports and FDI are distributed over a wider range of states, including many more in Asia and Latin America. This provides evidence that Europe is not only a centre of inventive activity but also a supplier of innovative CCMTs on a global scale.

5.2.3 Intra-European trade and FDI

Germany is both the main exporter to other European countries and the main importer from other European countries in climate change-related goods (Figure 37–Figure 39). It exports and imports at least twice as much as any other European country. In the next eight countries, exports are roughly balanced against imports, the exception being Denmark, a leading innovator in wind energy, ranking second to Germany as a net exporter. Italy, Turkey and the UK are clear net importers of CCMT goods from other European countries.[20]

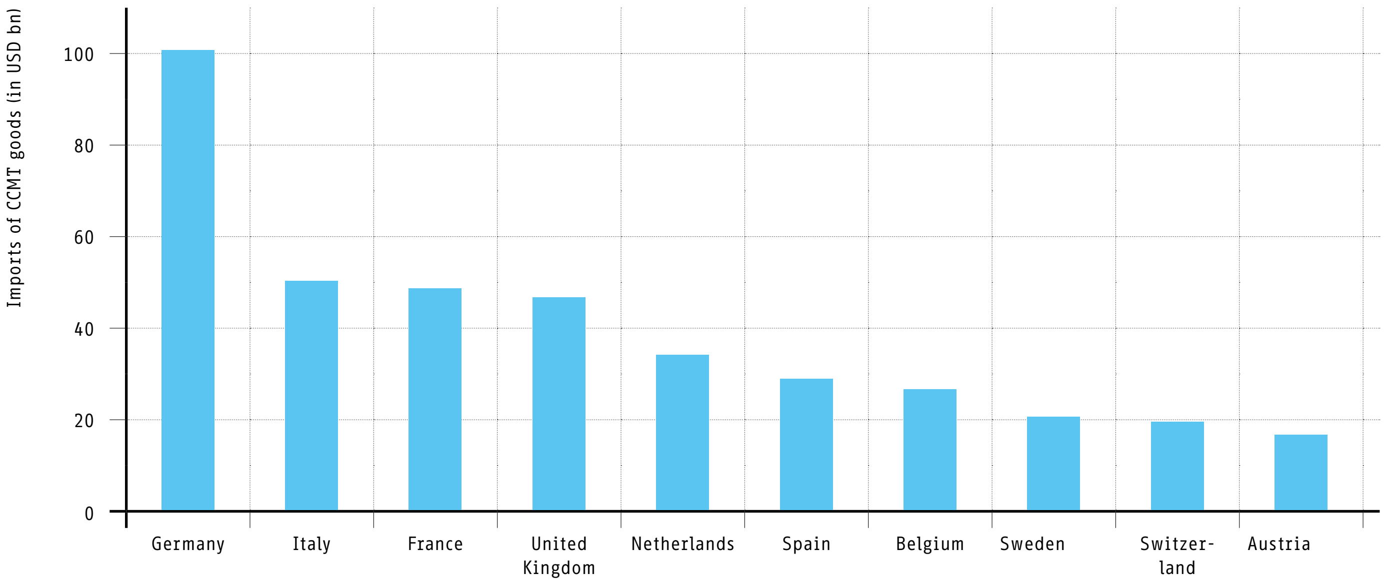
37 Main European exporters of CCMT goods to other European countries 1995–2013



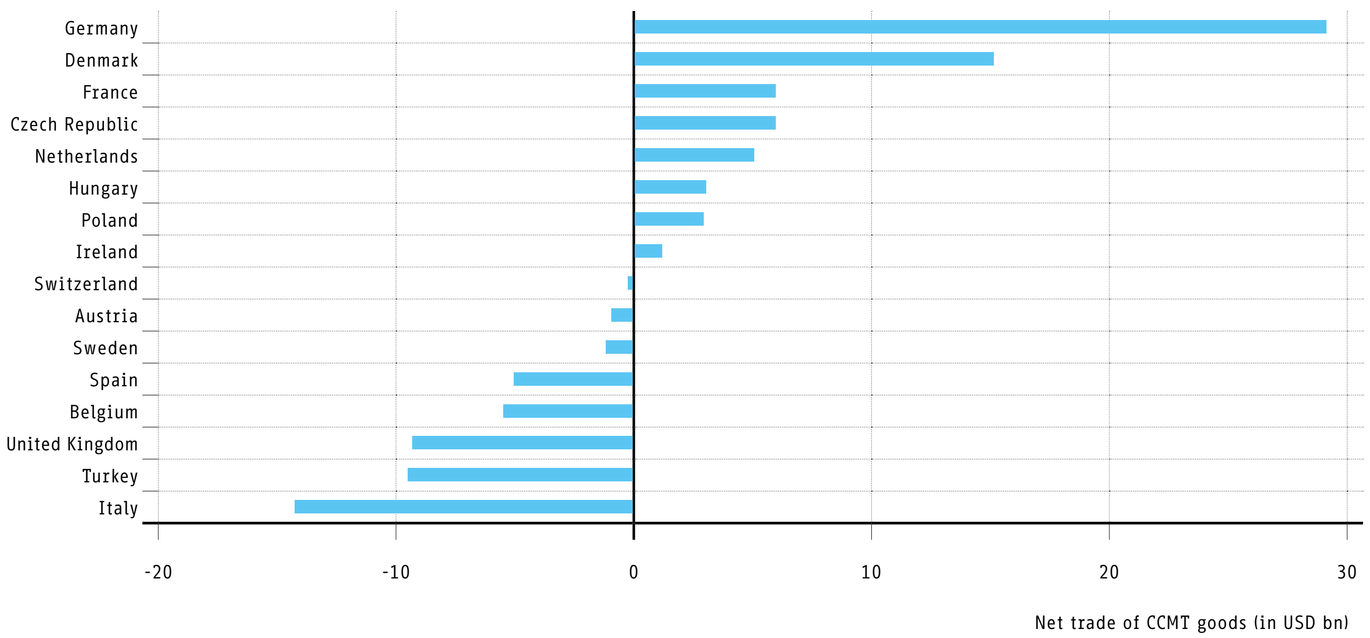
20 Statistics on the main European exporters to other European countries and main European importers from other European countries between 1995 and 2013 can be found in Annex 12.

The main destinations of intra-European FDI are the UK and Germany. France is the leading investor in CCMT companies in the UK, followed by Germany (Figure 40). Germany is also the largest source country for CCMT foreign investments within Europe, closely followed by France.[21]

38 Main European importers of CCMT goods from other European countries 1995–2013

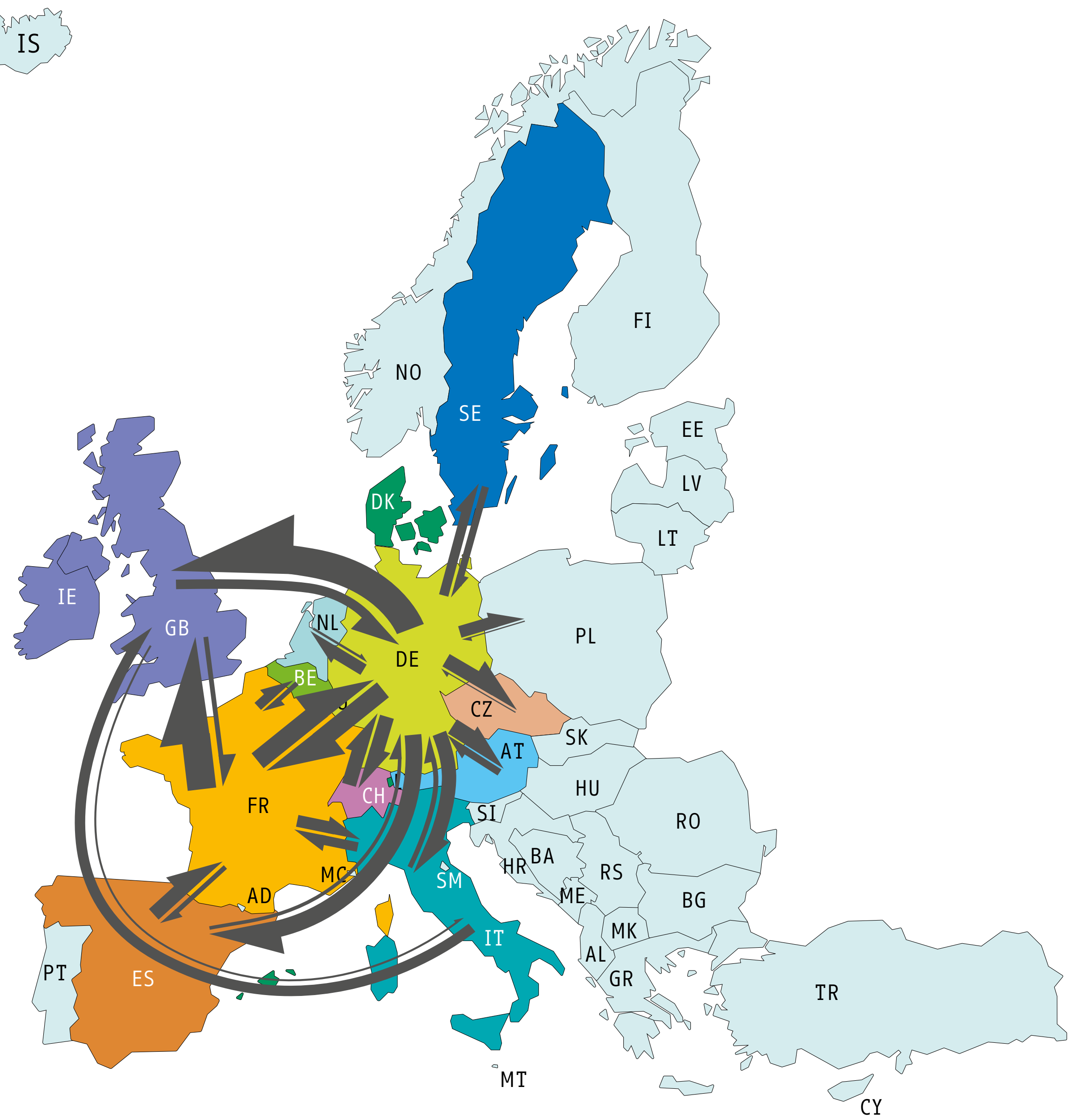


39 Balance of trade in CCMT goods between European countries 1995–2013



21 The illustration is limited to pairs of countries with at least 300 subsidiaries (inward plus outward) in 2012. A full table with all intra-European subsidiaries of CCMT companies can be found in Annex 13.

40 FDI in CCMTs between European countries in 2012



From	To	Nr of subsidiaries
FR	GB	1249
GB	FR	138
DE	GB	1122
GB	DE	252
FR	DE	653
DE	FR	602
CH	DE	410
DE	CH	385
DE	AT	469
AT	DE	170

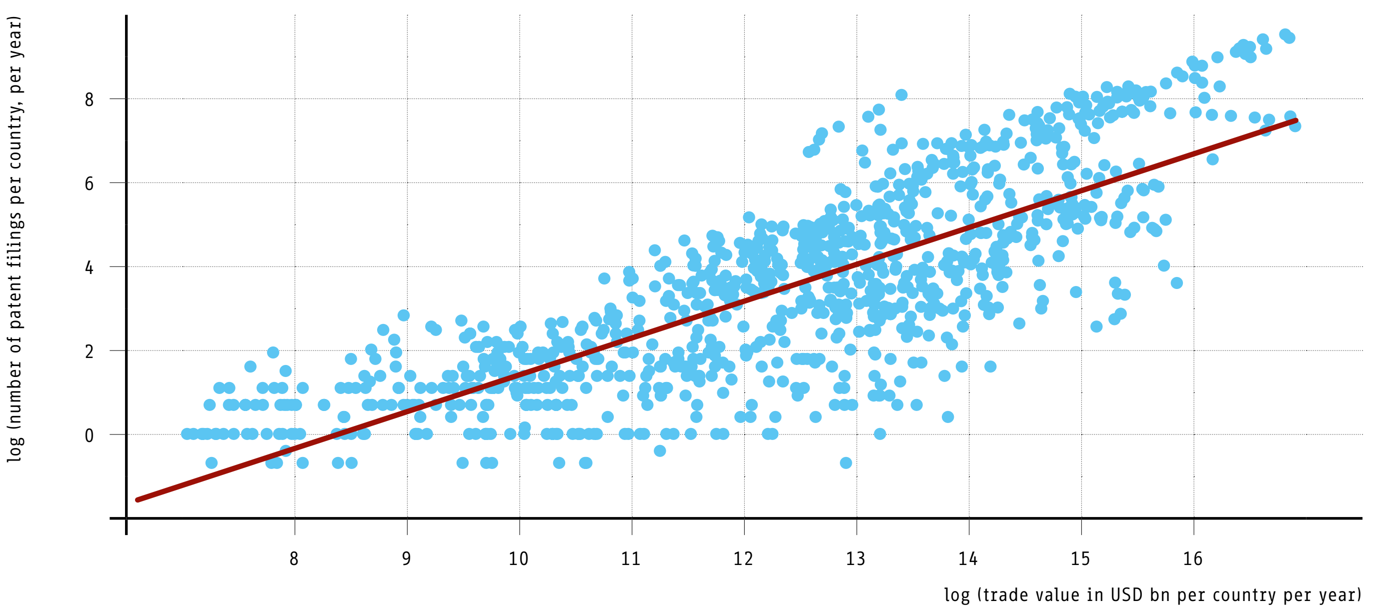
From	To	Nr of subsidiaries
DE	IT	422
IT	DE	211
FR	IT	360
IT	FR	234
DE	ES	466
ES	DE	110
FR	ES	396
ES	FR	152
FR	BE	281
BE	FR	142

From	To	Nr of subsidiaries
DE	NL	357
NL	DE	48
SE	DE	214
DE	SE	191
DE	CZ	386
CZ	DE	6
IT	GB	324
GB	IT	51
DE	PL	346
PL	DE	5

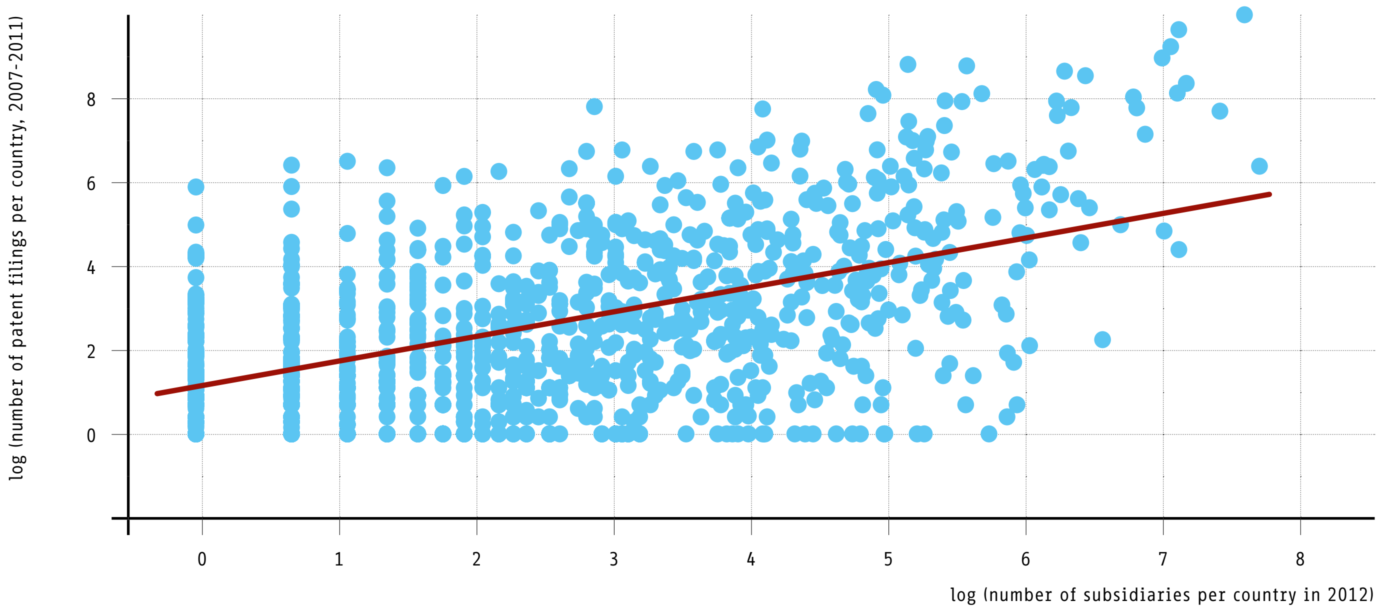
5.3 Relationship between patenting activities, trade and FDI

The following section (Figure 41 and Figure 42) compares patent filings in CCMT with imports and with FDI for all countries worldwide.[22] In Figure 41 the number of patents filed by country and year is presented on the y-axis, together with the volume of imports in CCMT in the same country and year on the x-axis. For example, one data point represents the volume of Brazil's imports of CCMT capital goods from all countries in 1999 and the number of patents filed in Brazil but by foreign inventors in the same year. In Figure 42 the number of patents filed in CCMTs over the preceding five years is presented on the y-axis, together with the stock of inward FDI in 2012 in the same country on the x-axis. Here, one data point represents the number of subsidiaries of German CCMT companies in Brazil in 2012 and the number of patent filings in Brazil in the period 2007-2011 by German inventors. One can see that there is a clear and strong positive correlation between the number of patents filed by foreign inventors and the value of imports, as well as between patent filings and the volume of FDI.[23] Trade and foreign investment in CCMTs, both major channels of international technology diffusion, are likely to involve patent protection in the recipient country. Higher incoming trade and investment volumes are, on average, associated with higher numbers of patent filings from the originating countries. These results are consistent with the evidence that patent protection is relied upon to protect goods that are either exported or produced locally from imitation in the destination country (Maskus, 2000; Smith, 2001).

41 Relationship between patent filings and imports of CCMT goods



42 Relationship between patent filings and FDI in CCMTs



22 Europe is represented as individual countries.
23 All values are logarithmically transformed. Therefore, the precise meaning of the positive correlation between patent filings and imports as well as patent filings and FDI is that a 1% increase in one variable is associated with a positive percentage increase in the other variable.

6 CLIMATE CHANGE POLICY IN THE EUROPEAN UNION

Public building made of solar panels, wood and mirror glass, Barcelona, Spain

6.1
Literature review on the impact of climate change policies

Since greenhouse gas emissions that damage the climate are a negative externality, public policies are needed to force economic agents to "internalise" the benefits of protecting the environment. Environmental policy tools are usually grouped in two categories: market instruments, which establish a price on the externality (for example, a tax on carbon emissions or a cap-and-trade system), and command-and-control instruments, which impose limits on emissions of pollutants or require adoption of particular technical standards. By making polluting emissions costly, both types of environmental policies change the relative costs and benefits of competing technologies. For example, carbon taxes make coal relatively more expensive than natural gas. Renewable energy portfolio standards make alternative energy sources more attractive relative to carbon-based energy. Thus, policies that force agents to internalise environmental externalities encourage the diffusion of environmentally friendly technologies. In fact, studies addressing the adoption of environmental technologies show that regulations dominate all other firm-specific factors in explaining the gradual diffusion of new technologies. Examples include Kerr and Newell (2003) on the removal of lead from gasoline in the US, Kemp (1998) on the effect of effluent charges on biological treatment of wastewater, Snyder et al. (2003) on the diffusion of membrane-cell technology in the chlorine manufacturing industry, and Popp (2009) on NO_x pollution control technologies at power plants.

Environmental regulation also encourages innovation. Because R&D is a profit-motivated investment activity, innovation responds to environmental regulations by developing cleaner technologies. This notion of induced innovation (Acemoglu, 2002; Acemoglu et al., 2012; Hicks, 1932) provides the theoretical background for the vast empirical literature on the effect of policy and prices on environmental innovation. The literature in question – recently surveyed in Popp et al. (2010), Popp (2010), and Ambec et al. (2013) – supports the induced innovation hypothesis and provides evidence on the magnitude of the effects. These studies show that both stricter environmental policies and higher energy prices encourage additional innovation in clean technologies, and that the innovative response to policy happens quickly.

Early studies of induced innovation from environmental policy made use of pollution abatement control expenditures (PACE) to proxy for environmental regulatory stringency. Examples include Lanjouw and Mody (1996), Jaffe and Palmer (1997), and Brunnermeier and Cohen (2003). Each finds a significant correlation within industries over time between PACE and innovative activity. Renewable energy policies, which require the adoption of renewable energy technologies to generate electricity, have also been shown to incentivise innovation. Johnstone et al. (2010) find that patenting activity for renewable energy technologies, measured by applications for renewable energy patents filed with the EPO, has increased dramatically in recent years, as both national policies and international efforts to combat climate change begin to provide incentives for innovation. Dechezleprêtre and Glachant (2013) show that every 100 MW of new wind power capacity installed in OECD countries induces three new patented innovations globally.

Other studies examine the effect of changing energy prices on innovation, providing evidence on how innovation will react to higher energy prices resulting from regulation. Newell et al. (1999) show that the energy efficiency of home appliances available for sale changed in response to energy prices between 1958 and 1993. Suggesting the role that policy-induced technological change may play as climate policy moves forward, they find that energy efficiency in 1993 would have been about one-quarter to one-half lower in air conditioners and gas water heaters if energy prices had stayed at their 1973 levels, rather than following their historical path. Both Popp (2002) and Verdolini and Galeotti (2011) find similar estimates of the elasticity of energy patenting activity with respect to energy prices for alternative energy and energy efficiency technologies, with a 10% rise in energy prices leading to a 3.5-4% long-term increase in energy patenting activity. Aghion et al. (2012) examine innovation activity among some 3 000 firms in the car industry and show that companies tend to innovate more in clean technologies (i.e. electric, hybrid and hydrogen cars) and less in dirty technologies (i.e. internal combustion engines) when they face higher fuel prices. A 10% higher fuel price is associated with about 10% more patent filings in clean and 7% fewer patent filings in "dirty" technologies.

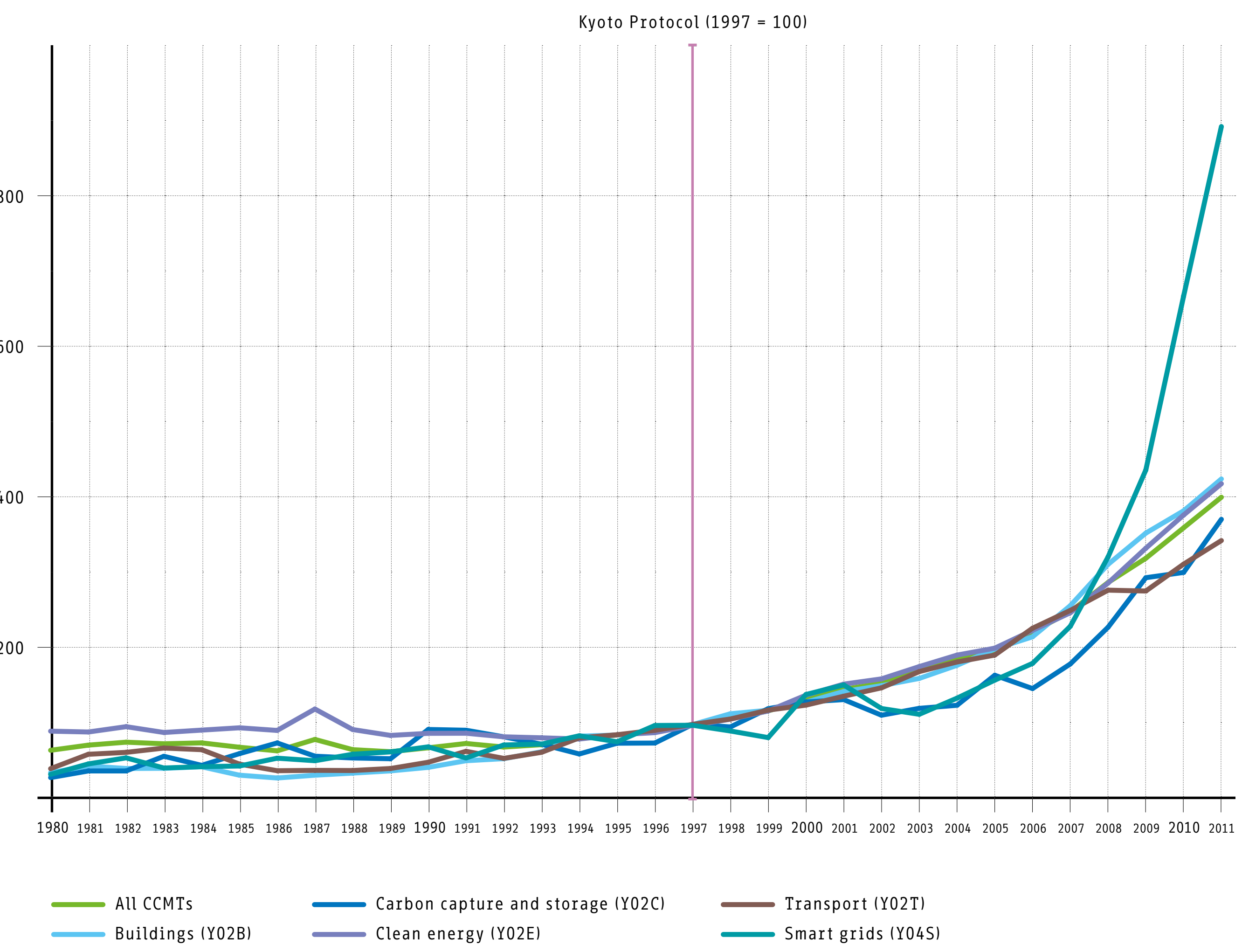
There is also evidence that environmental policy encourages the international diffusion of environment-friendly technologies. Lanjouw and Mody (1996) find evidence that strict vehicle emissions regulations in the US led to the inward transfer of up-to-date technology from Japan and Germany. Popp et al. (2007) examine the case of chlorine-free technology in the pulp and paper industry and find an increase in the number of patents filed by US inventors in Finland and Sweden after the introduction of tighter regulations in these countries. Similarly, they observe an increase in Swedish patents in the US following the adoption of new regulation there. Dechezleprêtre et al. (2008) and Haščič and Johnstone (2011) find that the Kyoto Protocol's Clean Development Mechanism encourages the transfer of climate change mitigation technologies from developed Annex I countries to developing non-Annex I countries. Dechezleprêtre et al. (2013) find that the strictness of climate change policies encourages international flows of CCMTs. Importantly, according to the latter study, the only difference between the drivers of technology diffusion in general and the drivers specific to climate change technologies is the impact of climate change policies, which obviously matter only for CCMTs.

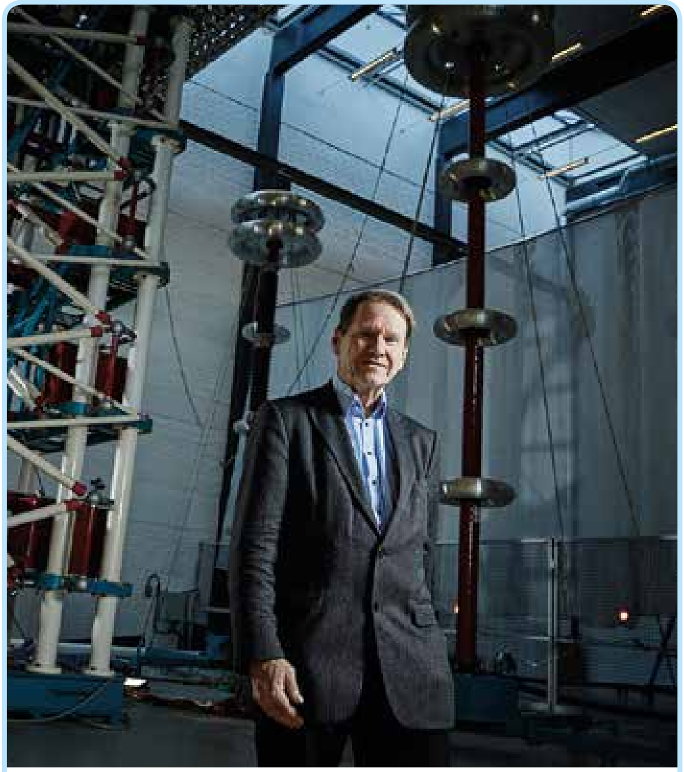
6.2
Policy measures in the European Union and other key regions

The first global treaty with the objective of fighting global warming was signed in 1997, when nearly 200 countries adopted the Kyoto Protocol, committing the parties to reduce their carbon emissions by 2012. Back then, however, only industrialised countries set legally binding targets for reduction of emissions. In the past two decades, the Kyoto Protocol has been followed by a wide range of policies across the globe, aiming to reduce carbon emissions associated with human activities. Figure 43, illustrating the evolution of patenting rates since 1980, shows that worldwide inventive activity in CCMTs accelerated sharply after 1997, presumably as a consequence of post-Kyoto developments in climate change policies.

The European Union's efforts to combat climate change have since accelerated and it now has significant experience in the formulation of proactive policy measures in this area. Since the mid-1990s, EU countries have adopted a number of increasingly stringent policies to reduce carbon emissions. Perhaps the best known of these policies is the European Union Emissions Trading System (ETS), the flagship policy to address climate change throughout the EU member states.

43 Post-Kyoto growth in worldwide CCMT inventions 1980–2011 (normalised to 1997 = 100)





Gunnar Asplund (Sweden)

Finalist of the European Inventor Award 2015 in the category of Industry, in the area of enabling technologies or technologies with a potential or indirect contribution to GHG emissions mitigation (Y02E60)

Invention: High-voltage power grid connection

Ugly pylons and power lines, long strands of cables and large, unsightly power conversion stations: Although modern civilisation would be unthinkable without it, electrical distribution is often obtrusive. Dealing with this problem, Swedish engineer Gunnar Asplund has helped hide away much of a power grid's infrastructure. At the same time, he's boosted the efficiency of transmitting electricity from remote power stations, making renewable energy sources, such as solar and wind, a more viable option.

Beginning with an overall cap on carbon emissions in Europe, the EU sets a national CO_2 emissions limit for each country. For specified economic activities (such as energy generation or the production of cement), carbon allowances are then set which can be traded by the operators of installations under the scheme.[24] As a result, the ETS covers around 45% of the EU's greenhouse gas emissions. In the transportation sector, EU standards have been adopted to limit emissions from new vehicles. The "Euro" emission standards were first implemented across EU member states in 1992 (Euro 1) and have subsequently been tightened in a series of incremental steps (Euro 2, 3, etc.). In 2009 the EU established an ambitious target of 20% share[25] of energy from renewable sources in the overall energy mix by 2020[26], and a target of saving 20% of the Union's primary energy consumption by 2020[27]. Furthermore, on 23 October 2014 EU leaders adopted a commitment to reduce domestic greenhouse gas (GHG) emissions by 40% in 2030 relative to 1990 and an even more ambitious objective to reduce greenhouse gas emissions by at least 80% below 1990 levels by 2050. The targets are supposed to be met by a combination of renewable energy, gas and nuclear energy sources.[28]

Alongside EU-wide policies, the individual member states have adopted a large array of further policies aiming at reducing GHG emissions. In particular, all EU countries have implemented at least one of the major support instruments towards renewable energy deployment (feed-in tariffs, feed-in premiums, tender schemes or quota obligations). Among these instruments, feed-in tariff schemes are clearly dominant, with implementation in 85% of countries. Almost all countries have also implemented at least one supplementary support scheme: investment grants, fiscal measures (tax incentives, etc.) or financing support (loans, etc.).

An indicator developed by the OECD to measure the overall stringency of these various policies is available for all OECD countries since 1990 (Botta and Kozluk, 2014). Looking at the EU as a whole,[29] it is evident that climate policy stringency has increased substantially since 1995. However, comparing the stringency of climate policy across the world, the EU is not a clear leader and appears less ambitious than Korea and Japan, albeit only by a small margin (Figure 44).[30] It is also interesting to find that climate policy in the US, which is generally seen as unambitious, is in fact almost as stringent as in Europe when all policies related to carbon emissions are taken into account.

In terms of carbon emissions per unit of GDP, however, the EU appears as the clear leader, with the lowest level of CO_2 intensity (Figure 45). In the period studied, the carbon intensity of the EU economy fell remarkably, from over 320g CO_2 per euro of GDP in 1995 to less than 220g in 2010.

24 Activity-specific size criteria then determine which installations are included in the EU ETS. In energy production, for example, only combustion installations with a yearly thermal input exceeding 20 MWh are covered. In the absence of data on non-regulated installations, it is not possible to determine the fraction of emissions produced by installations with an input of less than 20 MWh.

25 Each EU member state has its own Europe 2020 target. The national targets take into account the member countries' different starting points, renewable energy potential and economic performance. For more information on the targets that each country has adopted, together with the respective action plans, see: https://ec.europa.eu/energy/node/71 (Last accessed: 3 September 2015).

26 Directive 2009/28/EC of the European Parliament and of the Council on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77EC and 2003/30/EC, of 23 April 2009. Available at: http://ec.europa.eu/agriculture/bioenergy/potential/index_en.htm

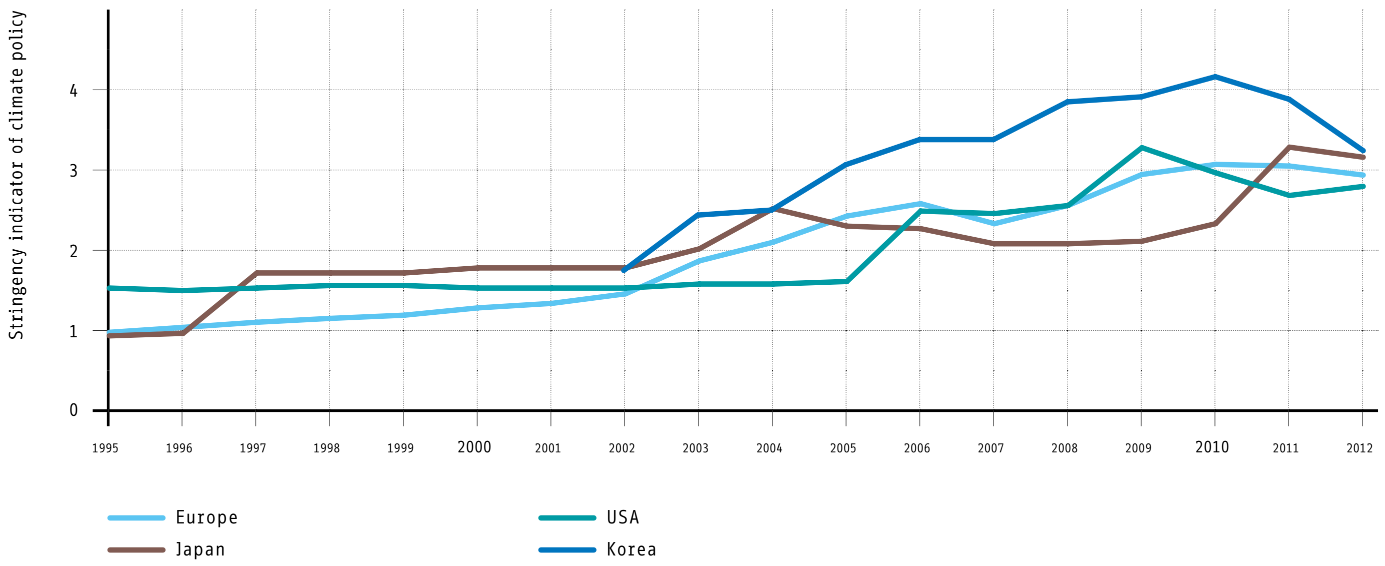
27 In 2012, with a view to achieving this target, the EU adopted Directive 2012/27/EU of the European Parliament and of the Council on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC. Available at: http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32012L0027&from=EN (Last accessed: 3 September 2015).

28 The 2050 Energy Strategy, including the Roadmap 2050 for a competitive low-carbon economy. For more information see: European Commission. Energy. 2050 Energy Strategy. Available at: http://ec.europa.eu/energy/en/topics/energy-strategy/2050-energy-strategy. (Last accessed: 4 September 2015).

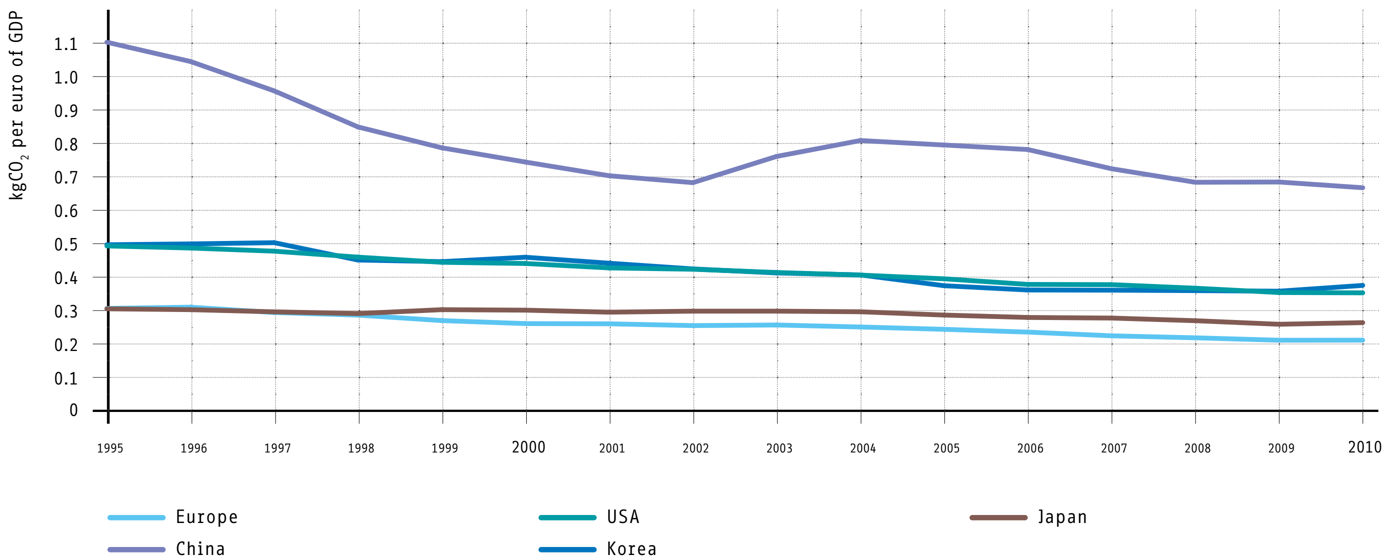
29 Individual countries are weighted by GDP in order to calculate the average European policy stringency.

30 The indicator was not available for Chinese climate policy stringency, since China is not an OECD member country.

44 Stringency of climate policy in the EU, Japan, Korea and the US 1995-2012



45 CO_2 intensity of GDP in major innovation centres 1995-2012



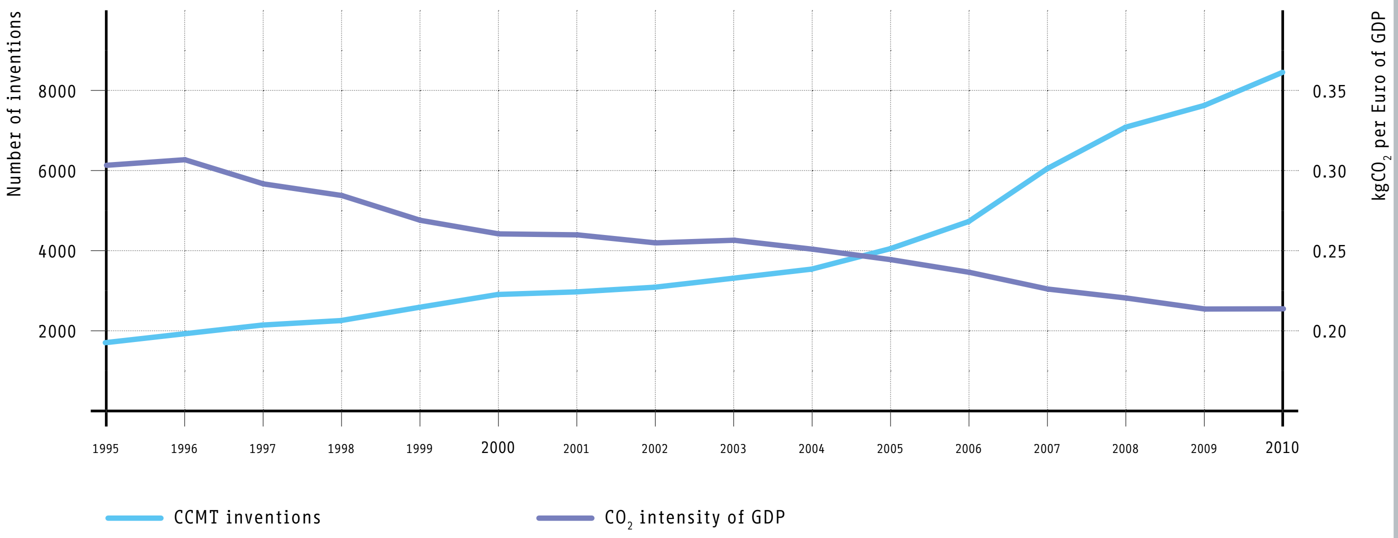
Looking at CO_2 intensity in conjunction with climate change policy and invention activity, it is clear that invention efforts and policy stringency have gone hand in hand, and that the proliferation of inventions in CCMTs has been accompanied by a decrease in CO_2 intensity. Despite the difficulty of establishing a causal relationship, it is reasonable to assume that the increasing stringency of climate change policy has been a major driver behind the growth in CCMT inventions in Europe (Figure 46 and Figure 47). As explained in section 6.1, a large literature has shown that environmental policies increase innovation in environment-friendly technologies (see Lanjouw and Mody, 1996; Jaffe and Palmer, 1997; Brunnermeier and Cohen, 2003); Johnstone et al., 2010; Dechezleprêtre and Glachant, 2013; Newell et al., 1999; Popp, 2002; Verdolini and Galeotti, 2011; Aghion et al., 2012).

6.3 Public R&D investment in CCMTs

In Europe, the development of CCMT inventions has been largely supported by public spending on R&D. The International Energy Agency collects data on public R&D expenditures in CCMT among its members. Public R&D includes R&D funded by public bodies at central or federal level, or at a country's first administrative subdivision level (i.e. provincial or state government units).[31] Government establishments include ministries or cabinet-level departments, regional councils, independent public agencies, state-owned enterprises, government-funded research organisations and public higher-education establishments.

After a long decline, the amount of public R&D spending devoted to climate change technologies by European governments has doubled since 2000, from EUR 2.2bn annually to EUR 4.5bn, which represents around 0.05% of Europe's GDP.[32] However, public R&D expenditures on CCMTs are still 20% below what they were in 1985 after the second oil shock, when they peaked at EUR 5.5bn (Figure 48).

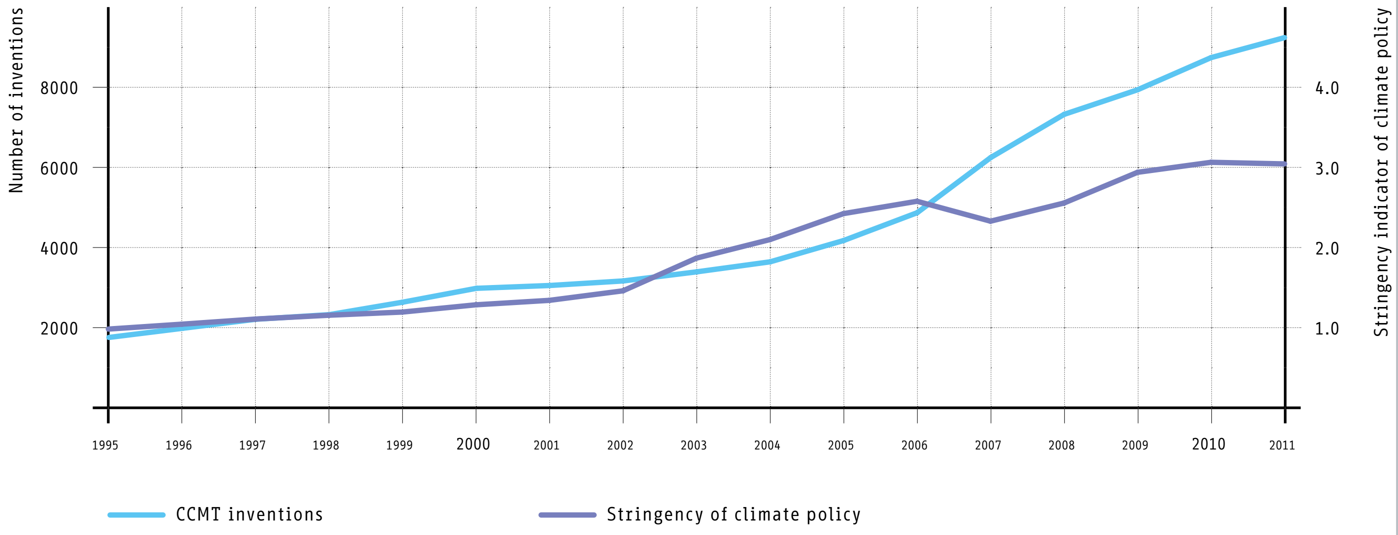
46 CCMT inventions in Europe and CO_2 intensity of GDP in the EU 1995–2010



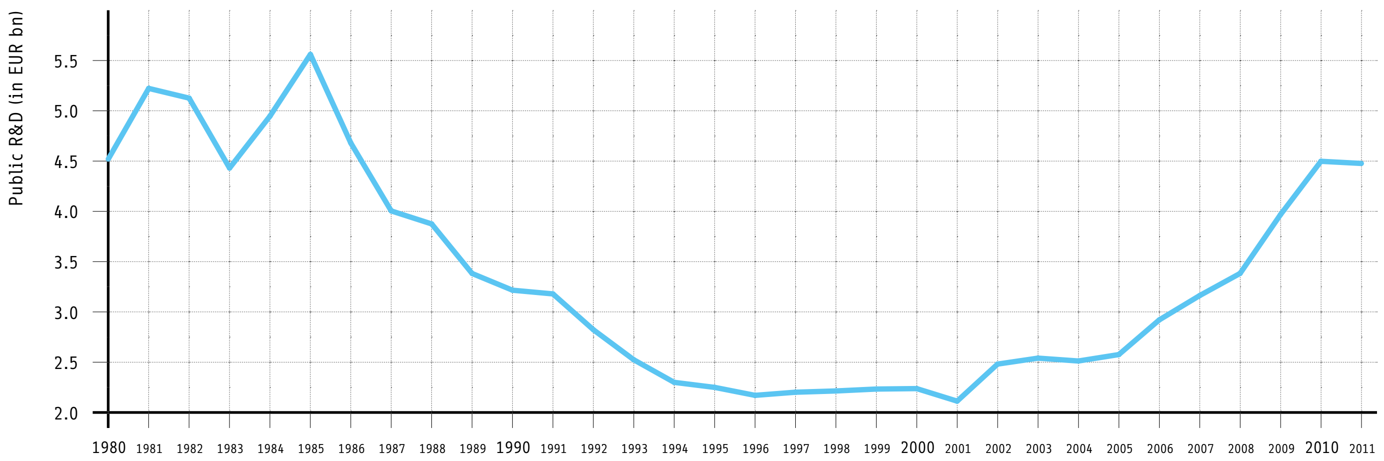
31 The public R&D data is taken from the International Energy Agency database, so only the European countries that are members of the OECD are included, namely: Austria, Belgium, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Poland, Portugal, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey and the UK.

32 The central EU funding for R&D in the CCMT area is not included in the comparison of Europe with other IP5 regions because there is no comprehensive data on EU funding for CCMTs. However, this does not significantly distort the picture, since the vast bulk of public funding for clean energy technologies in Europe comes from national governments, with European institutions playing only a marginal role. For example, the estimated public (EU and national) RD&D investments dedicated to six CCMTs covered by the EU Strategic Energy Technology Plan in 2010 amounted to EUR 2.26bn, made up of EUR 2.02 bn from national sources and EUR 0.24bn (11%) from the EU (see Dechezleprêtre and Popp, 2015).

47 CCMT inventions in Europe and stringency of climate policy in the EU 1995–2011



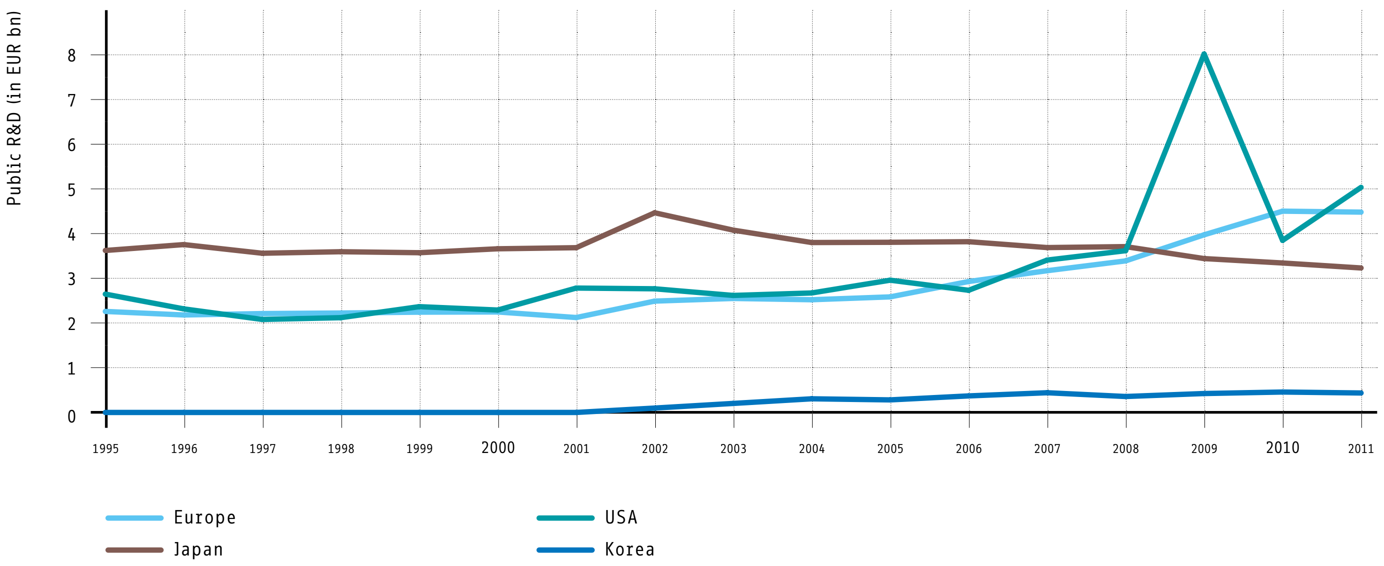
48 European public R&D spending on CCMTs 1980–2011



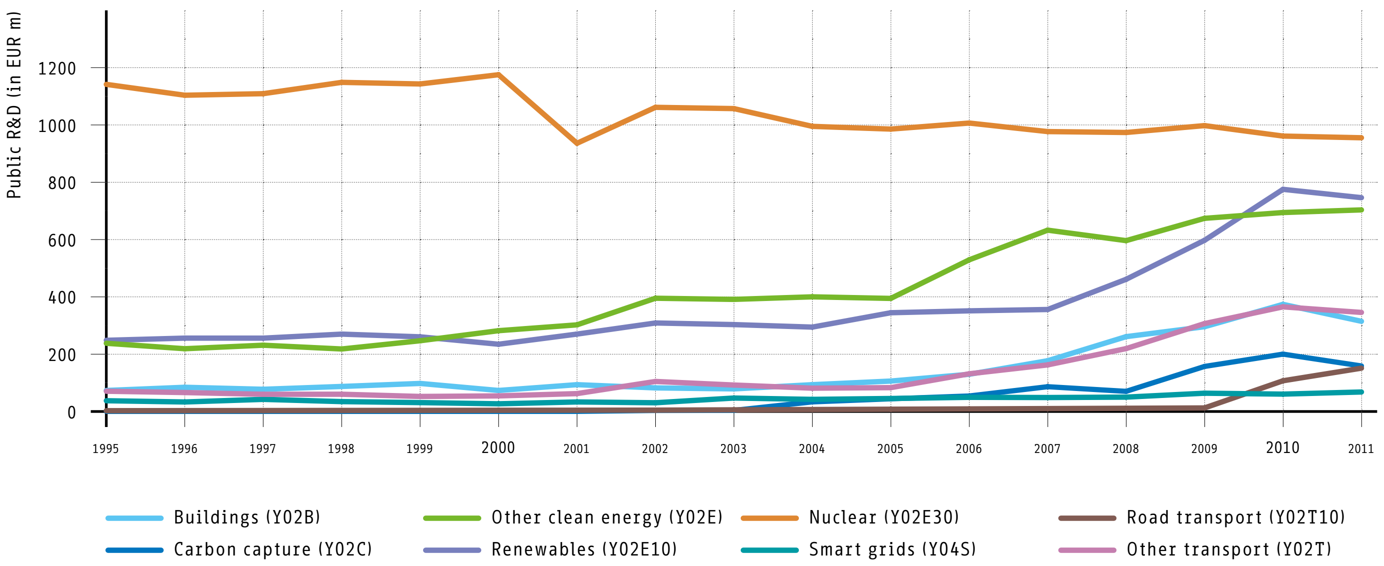
Looking at other major OECD innovation centres, Europe's public support for R&D in CCMT appears comparable in volume to the US and Japan (Figure 49). Europe has recently overtaken Japan in absolute terms, but still lags behind in relation to GDP: public R&D expenditures on CCMT represent 0.074% of GDP in Japan against 0.05% in Europe. In comparison, the US spent 0.032% of its GDP on CCMT R&D and Korea 0.027%.[33]

The technology that receives the largest amount of public money in Europe is nuclear energy. However, support for nuclear energy has stagnated since 1995, and the growth of public expenditure is explained by increased support for clean energy technologies, in particular renewable energy, and, to a lesser extent, for CCMTs related to transportation, buildings and carbon capture and storage (Figure 50).

49 Public R&D spending on CCMTs in Europe, Japan, Korea and the US 1995-2011



50 European public R&D spending on CCMTs by technology 1995-2011

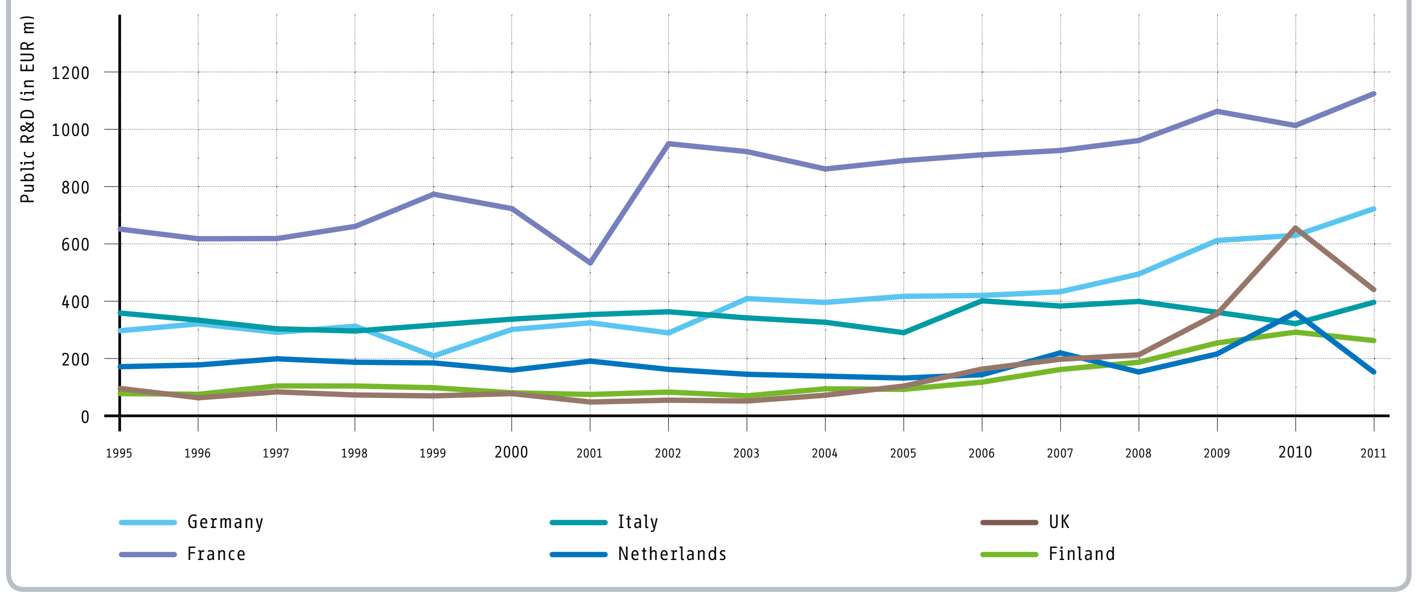


33 The spike in public R&D expenditures in the US in 2009 was due to the American Recovery and Reinvestment Act of 2009, which included EUR 27.2bn for research and investment in energy efficiency and renewable energy.

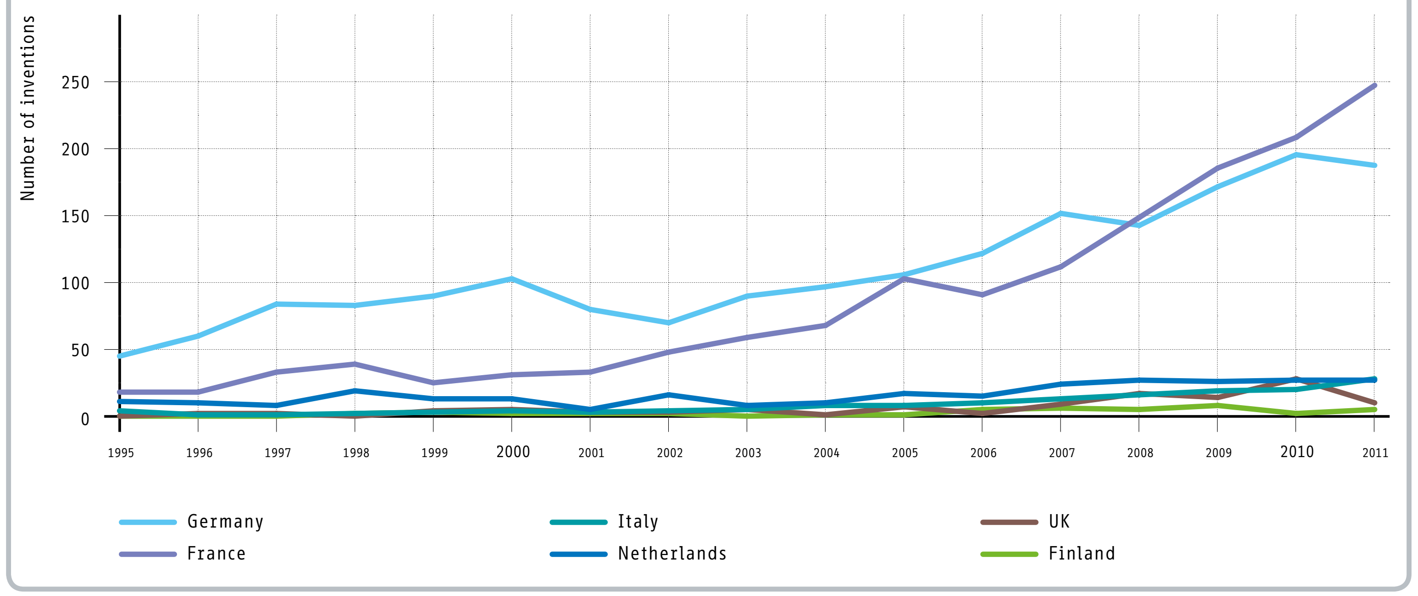
Within Europe, France is the largest provider of public money for CCMT R&D, with over EUR 1bn in 2011. It is followed by Germany, with EUR 700m in 2011. This represents 0.05% of GDP in France against only 0.02% in Germany (Figure 51). However, almost half of France's public expenditure on CCMT R&D was devoted to nuclear energy.

As a consequence of large public R&D expenditures, France and Germany are also the top two countries in terms of the number of patents filed by public bodies (universities, government-funded research centres, etc.) in Europe, as shown in Figure 52.

51 European public R&D spending on CCMTs by country 1995-2011



52 European CCMT inventions from public institutions by country 1995-2011



7
EUROPE'S CLEAN ENERGY POTENTIAL AND EXPLOITATION

Germany's first self-sufficient bioenergy village, Juehnde, Germany

7.1
An overview of Europe's clean energy landscape

Although CCMTs are also essential in the transport and building sectors, clean energy is the area with the most inventive activity as measured by the number of patent filings, both in Europe and worldwide (see Figure 5 and Figure 11). Clean energy encompasses renewable energy (RE) and essential "enabling" technologies such as energy distribution, optimisation and storage; though RE is clearly the most active area. In Europe in particular, the number of inventions related to RE has increased rapidly since 2005 to almost 3 000 in 2011 alone (see Figure 12). Key RE technologies include not only wind power, solar thermal, and solar photovoltaic technologies, but also hydro, geothermal and ocean energy technologies. Europe is not only strong in generating inventions related to clean energy but is also an important potential market for inventions created outside Europe (see Figures 24 and Figure 25) as well as one of the world's largest importers of clean energy goods. The value of European imports of capital goods related to renewable energy alone has increased from USD 26.8 bn in 2005 to USD 4.76 bn in 2013.

Overall, Europe's performance in the implementation of "Clean Energy Technologies" is considerable and increasing rapidly. The share of energy from renewable sources in the in the EU's gross final consumption of energy grew from 8.3% in 2004 to 15.0% in 2013.[34] In fact, in June 2015 the European Commission published the mid-term review report of the 2020 goals, the Renewable Energy Progress Report, stating that Europe has three times more renewable power per capita than anywhere else in the world. The main renewable energy sources in the 28 current EU member states are biomass, with a contribution of 53.7% to the renewable energy mix in 2012, followed by hydropower with 17.9%, wind with 10.8%, biofuels with 7.5%, solar (thermal, photovoltaic and concentrated) with 5.1%, heat pumps with 4.3% and geothermal with 0.7%.[35]

In this context, the EU focuses its efforts on electricity, heating and cooling and on renewable energy for transport (including biofuels). Ultimately, it is argued, these efforts will help to reduce GHG emissions from energy generation and consumption, ensure European energy security by reducing dependence on imports of fossil fuels, and stimulate employment in the region through the creation of jobs in new "green" technologies.[36]

As shown in this section, the actual potential for clean energy in Europe is however much greater, and only a proportion of this potential is currently exploited. The EU currently faces several challenges that may slow the achievement of its clean energy and emissions targets. On the contrary: the shift towards renewables has contributed to the high price of energy in Europe. Renewable energies in the energy mix contribute to the high price of energy in Europe today. Hence, the current global financial crisis, coupled with the very low carbon price, could reduce incentives for investment in renewable energies, and energy-intensive companies in Europe could lose out to global competitors because of higher energy costs.[37]

This chapter presents an overview of the potential and exploitation of Clean Energy Technologies (CETs) in Europe, based on existing literature and studies, mainly using data provided by the EU, the OECD and the International Energy Agency.

7.1.1
Biomass

Biomass is defined as the biodegradable fraction of products, waste and residues of biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste.[38] In Europe, biomass for energy is mainly supplied by forestry (which provides half of the EU's renewable energy), agriculture and organic waste.[39]

In 2006, the EU's primary energy requirement was estimated at 1.8 billion tonnes oil equivalent (toe) in 2020, with a projected biomass contribution of 13% or 236 million toe.[40] According to current information, it is reasonable to assume that biomass could account for two-thirds of the renewable energy target in 2020.[41]

However, for this to become a reality, biomass use will have to roughly double. While the exploitation of the hitherto unused biomass potential from waste, forestry and residues will be relatively stable over time, there is major uncertainty as to how much biomass EU agriculture would

34 Eurostat news release, 10 March 2015. Renewable energy in the EU share of renewables in energy consumption up to 15% in the EU in 2013. Three member states have already achieved their 2020 targets. Available at: http://ec.europa.eu/eurostat/documents/2995521/6734513/8-10032015-AP-EN.pdf/3a8c018d-3d9f-4f1d-95ad-832ed3a20a6b (Last accessed: 18 July 2015).
35 European Commission. Snapshot of Renewable Energy Development in the EU-28. Volume 2. Current status and expected progress in comparison with national renewable energy action plans. Joint Research Centre Science and Policy Reports. 2015. Available at: http://publications.jrc.ec.europa.eu/repository/bitstream/JRC95262/ldna27182enn.pdf (Last accessed: 4 September 2015).
36 Eurostat. Statistics Explained. Renewable Energy Statistics. Last update: 3 September 2015. http://ec.europa.eu/eurostat/statistics-explained/index.php/Renewable_energy_statistics (Last accessed: 4 September 2015).

37 World Energy Council. What keeps energy leaders awake at night? World Energy Issues Monitor, 2014, p. 26. Available at: http://www.worldenergy.org/wp-content/uploads/2014/01/World-Energy-Issues-Monitor-2014.pdf (Last accessed: 3 September 2015).
38 Directive 2009/28/EC, op. cit. (note 3), Article 2(e).
39 European Commission. Agriculture and Rural Development. Bioenergy. Last update: 22 April 2015. Available at: http://ec.europa.eu/agriculture/bioenergy/index_en.htm (Last accessed: 3 September 2015).
40 Ibid. An almost identical projection is reproduced in the Commission's impact assessment of the Renewable Energy Roadmap, where the higher scenario results in a biomass potential of 230 million toe, the lower being 195 million toe. European Commission. Impact Assessment accompanying the Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions. Energy Roadmap 2050 Commission Staff Working Paper. 2011/ENER/002. Available at: https://ec.europa.eu/energy/sites/ener/files/documents/sec_2011_1565_part1.pdf (Last accessed: 4 September 2015).
41 European Commission. Agriculture and Rural Development. Bioenergy. Last update: 22 April 2015. Available at: http://ec.europa.eu/agriculture/bioenergy/index_en.htm (Last accessed: 3 September 2015).

be able to supply for energy. This is an important issue, since most of the real growth in biomass potential will have to come from agricultural products.[42]

Recent projections for 2030 quantify the sustainably realisable potential of wood for energy from EU forests at up to 675 million cubic metres per year, provided intensive wood mobilisation efforts are applied. It would be possible to intensify forest utilisation for energy: only 60-70% of the annual increment of EU forests is harvested. There is also expansion potential from forest residues and complementary fellings, as well as in smaller private forest holdings.[43]

In order to achieve development in the bioenergy sector over the coming years, there is a real need for a favourable policy environment to bring new technological and scientific advances to the market. For example, it will be necessary to increase research efforts on development of bioenergy feedstocks and land suitability mapping to identify the most promising feedstock types and locations for future scaling up; to support the installation of more pilot and demonstration projects, including innovative concepts for small-scale co-generation power plants; to set medium-term targets for bioenergy with a view to doubling current primary bioenergy supply by 2030; to introduce internationally aligned technical standards for biomass and biomass intermediates, in order to lower and eventually abolish trade barriers, enhance sustainable biomass trade and tap new feedstock sources; and to support international collaboration in capacity building and technology transfer to promote the adoption of best practices in sustainable agriculture, forestry and bioenergy production.[44]

There are a number of European initiatives in this area. One example is Biomass Energy Europe (BEE), a project that aims to harmonise methodologies for biomass resource assessments for energy purposes in Europe and its neighbouring countries. The relevant sectors that have been investigated are forestry, energy crops, and residues from traditional agriculture and waste.

In addition to economic and technological challenges, bioenergy faces pressing and controversial questions regarding its feedstock. The issues of competition with other uses of biomass (energy versus food), and of the requirements for sustainable bioenergy production, are at the forefront of discussion. It should, however, be pointed out that both the bioethanol and biodiesel production chains have protein-rich animal feed as a by-product, meaning that biofuel production does not compete with animal feed: in fact, it would help to reduce imports of often unsustainable animal feed from other parts of the world. Furthermore, the EU is introducing voluntary certification schemes to ensure that biomass feedstock complies with certain sustainability criteria.[45]

Co-firing of biomass and combustion of biomass by Combined Heat and Power (CHP), as well as biofuels as alcohol and oils, are the technologies that have the biggest market potential.[46]

Finally, it is estimated that in the future, more than two-thirds of the contribution of bioenergy to final energy consumption in Europe could be in the heating sector.

Biofuels in the transport sector

Biofuels are defined as "liquid or gaseous fuel for transport produced from biomass",[47] e.g. biodiesel and bioethanol. The utilisation of biofuels is a growing strategy to tackle climate change, enhance energy security and contribute to regional development.[48]

In view of the high levels of GHG emissions from the transport sector, the EU has designed a major policy and legal framework to boost and regulate this subcategory of renewable energy from biomass. It has set a target of supplying 10% of the transport fuel of every EU country from renewable sources by 2020.[49] Furthermore, in addition to the promotion of alternative fuel sources, conventional fuel suppliers are required to reduce the greenhouse emission intensity of the EU fuel mix by 2020 in comparison to 2010.[50]

After the initial enthusiasm for biofuels, this energy source soon proved to pose risks for environmental and social sustainability. The first impact associated with biofuels was the exacerbation of deforestation for biofuel crops.

Second, research on the impact of different biofuel feedstock and production methods raised questions about the validity of claims that biofuels reduced GHG emissions. A number of studies have shown that some biofuels have low net life-cycle benefits in terms of CO_2 compared to conventional fossil fuels; others have argued that the CO_2 impact of certain biofuels can be even higher than that of fossil fuels, if land use change is taken into account, although the result depends strongly on the specific biofuel chain and type of land use chain.

42 European Commission. Agriculture and Rural Development. Bioenergy. Biomass Potential. Last update: 22 April 2015. http://ec.europa.eu/agriculture/bioenergy/potential/index_en.htm (Last accessed: 4 September 2015).
43 Ibid.
44 International Energy Agency. Technology Roadmap. Bioenergy for Heat and Power. 2012. Available at: https://www.iea.org/publications/freepublications/publication/2012_Bioenergy_Roadmap_2nd_Edition_WEB.pdf (Last accessed: 4 September 2015).

45 European Commission. Report from the Commission to the Council and the European Parliament on sustainability requirements for the use of solid and gaseous biomass sources in electricity, heating and cooling. Brussels. 25 February 2010. Available at: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52010DC0011 (Last accessed: 4 September 2015).
46 http://www.erec.org/renewable-energy/bioenergy.html (Last accessed: 21 July 2015).
47 Directive 2009/28/EC, op. cit. (note 3) Article 2(i).
48 Bomb, Christian, McCormick, Kes, et al., Biofuels for transport in Europe: Lessons from Germany and the UK. Energy Policy, Vol. 34, Issue 5, 2007, p. 2256-2267.
49 Directive 2009/28/EC, op. cit. (note 3) .
50 European Commission. Energy. Biofuels. http://ec.europa.eu/energy/en/topics/renewable-energy/biofuels (Last accessed: 2 October 2015).

Third, biofuels and food production have entered into competition over land and other resources necessary for their production.[51] In 2011, for example, 13% of European agricultural land was already being used for bioenergy crops, causing land use conflicts related to the production of bioenergy.[52]

These concerns are more accentuated in first-generation biofuels[53] than in second-generation fuels.[54] Therefore, most first-generation biofuels, with the exception of sugar cane ethanol, will not be further promoted and are likely to have a limited role in the fuel mix for transport.[55] Second-generation biofuels are expected to play an increasing role in the coming decades.

While first-generation biofuels production is in an advanced state, with mature technologies and relatively well-understood processing and production pathways, second-generation biofuels are not yet well established and produced commercially.[56] In order to boost second-generation biofuels production, cooperation on R&D at a scientific level and access to technologies will be needed to build capacity in emerging and developing countries.[57]

Although second-generation biofuel crops and production are more efficient, their potential still depends on biomass potential, land availability and technology. About 70% of global second-generation biofuels production capacity is geographically distributed between the Asia-Pacific region and Europe. In Europe, 20% of the region's total potential second-generation biofuels production capacity relates to the production of synthetic diesel.[58]

The most advanced second-generation biofuels use lignocellulosic feedstocks, e.g. short rotation coppice, perennial grasses, forest residues and straws. According to the IEA, these second-generation biofuels should focus on currently available feedstock sources in the initial phase of the industry: for example, agricultural and forestry activities can provide feedstock from current activities without the need for additional land cultivation.[59] This cellulosic biomass requires advanced technologies, e.g. thermo-chemical[60] and biochemical conversion,[61] to break down biomass and convert it into liquid fuels.[62] In this connection, the first European unit – the Beta Renewables plant in Italy – was commissioned in 2013, which reflects the nascent maturity of these technologies.[63] However, despite the undisputable technological advances in recent years, the industry is still young and work is needed to improve the long-term profitability of its production through economic incentives such as tax breaks. There is also the major issue of developing the legislative framework required to enable market growth.

Regarding the legislative framework for second-generation biofuels, the EU has set rigorous sustainability criteria to ensure that the use of biofuels will guarantee real carbon savings and protect biodiversity. The criteria include the requirement that biofuels must achieve GHG savings of at least 35% in comparison to fossil fuels. This savings requirement rises to 50% in 2017. In 2018, it rises again to 60%, but only for new production plants. All life cycle emissions are taken into account when calculating GHG savings. This includes emissions from cultivation, processing and transport. Also, biofuels cannot be grown in areas converted from land with previously high carbon stock, and biofuels cannot be produced from raw materials obtained from land with high biodiversity, such as primary forests or highly biodiverse grasslands.[64]

To address indirect land use change concerns, the European Commission has proposed amending biofuels legislation, specifically the Renewable Energy Directive and the Fuel Quality Directive.[65]

To summarise, current biofuels, mainly from Europe, should maintain an important position, as they can save up to 88% of GHG emissions compared to fossil fuels and their production delivers almost double the amount of protein feed (defined in energy units) as liquid fuels. Advanced biofuels will continue to increase their market share. Biorefineries contribute sustainable processing of biomass into a spectrum of marketable bioenergy products; they will develop over the coming years and will have an important role in a 2050 strategy. Biofuels offer the possibility of deriving multiple energetic and non-energetic products from a mix of biomass feedstock (wood, energy crops, organic residues, aquatic biomass and waste).[66]

51 HLPE, 2013. Biofuels and food security. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, Rome 2013. Available at: http://www.fao.org/fileadmin/user_upload/hlpe/hlpe_documents/HLPE_Reports/HLPE-Report-5_Biofuels_and_food_security.pdf (Last accessed: 2 October 2015). FAO. Biofuels and the sustainability challenge: A global assessment of sustainability issues, trends and policies for biofuels and related feedstocks. Rome 2013. Available at: http://www.fao.org/docrep/017/i3126e/i3126e.pdf (Last accessed: 2 October 2015).
52 Helmholtz Zentrum fur Umweltforschung. Land use conflicts related to the production of bioenergy. http://www.ufz.de/index.php?de=17615 (Last accessed: 2 October 2015). Last update: 12 December 2011.
53 First generation fuels are crops that can be grown for direct oil extraction or ethanol production from fermentation, e.g. grains, sugar cane and vegetable oils.
54 Second-generation fuels are other organic materials that can be used for ethanol production from enzymatic processing of plant biomass, e.g. trees, gases and agricultural wastes.
55 European Commission. Energy. Biofuels, op. cit. (note 22).
56 International Energy Agency. Sustainable Production of Second Generation Biofuels. Potential and perspectives in major economies and developing countries. Information paper. February 2011. Available at: https://www.iea.org/publications/freepublications/publication/second_generation_biofuels.pdf (Last accessed: 2 October 2015)
57 Ibid.
58 Chabrelie, Marie-Françoise, Gruson, Jean-François, et al. Panorama 2014. Overview of second-generation biofuel projects. Available at: http://www.unece.lsu.edu/biofuels/documents/2015Mar/bf15-20.pdf (Last accessed: 2 October 2015), p. 3.
59 International Energy Agency. Sustainable Production of Second Generation Biofuels, op. cit. (note 28), p. 9.

60 Thermo-chemical conversion: biomass is gasified to syngas at 600-1 100 °C and then converted to biodiesel using Fischer Tropsch synthesis. This "biomass to liquid" process can be applied to woody or grass-derived biomass and cellulosic or lignocellulosic dry residues and wastes. Currently, there are no commercial biomass to liquid plants, but several pre-commercial plants exist in Germany, Japan and the United States. See European Environment Agency. EU Bioenergy Potential from a Resource Efficiency Perspective. Luxemburg: Publications Office of the European Union, 2013. Available at: http://www.eea.europa.eu/publications/eu-bioenergy-potential (Last accessed: 2 October 2015).
61 Biochemical conversion involves pre-treatment of cellulosic biomass and enzymatically enhanced hydrolysis and subsequent fermentation to convert hemicellulose and sugar into ethanol. There are demonstration plants in the EU (Denmark, Spain and Sweden) and Canada. Other countries such as Brazil, China, Germany, Japan and the US are also developing such second-generation ethanol technologies. Ibid.
62 Ibid.
63 Chabrelie, Marie-Françoise, Gruson, Jean-François, et al. Panorama 2014, op. cit. (note 30).
64 European Commission. Energy. Sustainability Criteria. http://ec.europa.eu/energy/node/73 (Last accessed: 2 October 2015). For the related legislation, see: Decision on Information about biofuels and bioliquids to be submitted by economic operators to Member States (2011/13/EU); Decision on guidelines for the calculation of land carbon stocks (2010/335/EU); Renewable Energy Directive (2009/28/EC); Commission Regulation (EU) No. 1307/2014 on defending the criteria and geographic ranges of highly biodiverse grasslands.
65 European Commission. Energy. Biofuels, op. cit. (note 22).
66 http://www.erec.org/renewable-energy/bioenergy.html. (Last accessed: 21 July 2015). For further information, see also: European Commission: Energy Roadmap 2050; European Technology Platform on Renewable Heating & Cooling: Biomass for Heating and Cooling.

06 Regional hydropower technical potential 2009

Region	Technical potential, annual generation TWh/yr (EJ/yr)	Technical potential, installed capacity (GW)	2009 Total generation TWh/yr (EJ/yr)	2009 Installed capacity (GW)	Undeveloped potential (%)	Average regional capacity factor (%)
North America	1,659 (5.971)	388	628 (2.261)	153	61	47
Latin America	2,856 (10.283)	608	732 (2.635)	156	74	54
Europe	1,021 (3.675)	338	542 (1.951)	179	47	35
Africa	1,174 (4.226)	283	98 (0.351)	23	92	47
Asia	7,681 (27.651)	2,037	1,514 (5.451)	402	80	43
Australasia/ Oceania	185 (0.666)	67	37 (0.134)	13	80	32
World	14,576 (52.470)	3,721	3,551 (12.783)	926	75	44

Source: IPCC. Renewable Energy Sources and Climate Change Mitigation. Special Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. 2012. P. 80

7.1.2 Hydropower

Hydropower is a renewable energy source where power is derived from the energy of water moving from higher to lower elevations. The mechanical power is used to turn turbines and generate electricity. It is a proven, mature, predictable and cost-competitive technology.[67] Hydropower has the best conversion efficiency of all known energy sources (about 90% efficiency, water to wire) and a very high energy payback ratio.

Currently, hydropower supplies around 380 TWh to the 28 EU member states, and 600 TWh to Europe as a whole, equivalent to 13% and 18% respectively of total electricity generation. The 2012 Special Report of the Intergovernmental Panel on Climate Change predicts that European hydropower will be able to generate 700 TWh by 2030 and 750 TWh by 2050, an increase of approximately 16%, or 100 TWh by 2030.[68]

Undeveloped capacity in Europe amounted to about 47% in 2008. The resource potential for hydropower could be modified by climate change. Annual power production capacity in 2050 could decrease by 0.8 TWh (2.88 PJ) in Europe.[69]

There are two types of hydropower plants: large-scale and small hydropower plants (SHP).[70] Most of the plants in Europe are smaller than 1 MW. In 15 countries, plants < 1 MW make up for more than 50% of the total. In Latvia, Germany, Poland and Lithuania, these small plants account for more than 90%. In absolute numbers, Germany has by far the most small plants (7 325), which is 44% of small plants in all the countries surveyed.[71] However, the relatively small number of hydropower plants > 10 MW accounts for the largest share of installed capacity. For example, France has a relatively small number of plants > 10 MW (281 plants > 10 MW against 515 plants between 1 MW and 10 MW and 1 355 plants < 1 MW), accounting for 90% of installed capacity. The large number of plants < 1 MW in Germany accounts for only 12% of total installed capacity.[72]

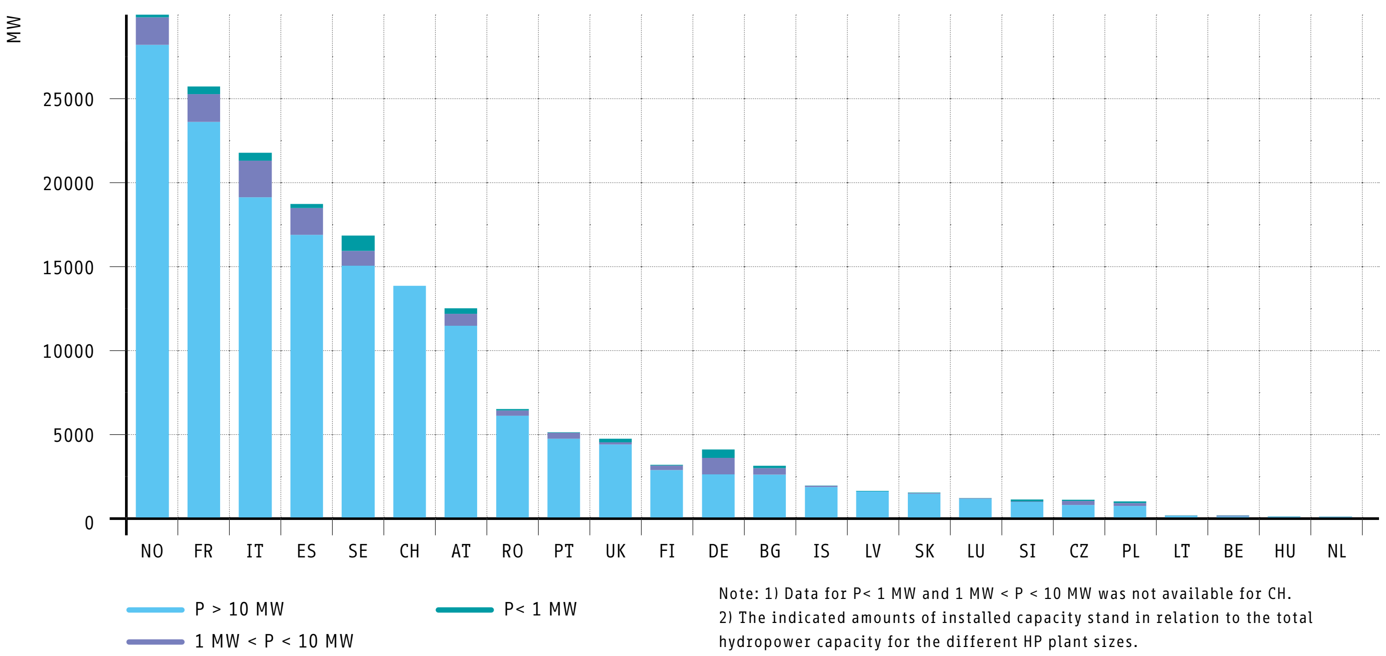
Since large-scale hydropower plants can be controversial with regard to socio-environmental impacts,[73] the current focus in Europe is on developing SHP and upgrading old large-scale hydropower plants, especially in terms of increasing efficiency and electricity production as well as environmental performance.[74] In Europe, small hydropower has a huge untapped potential that could allow it to make a more significant contribution to future energy needs. The remaining economically feasible potential amounts to some 23 TWh/year in EU-15 and 31 TWh/year in the new member states and candidate countries.[75]

SHPs are not simply a reduced version of a large hydro plant. They use a different technology, do not require reservoirs and are more environmentally friendly. Small hydro plants generate electricity or mechanical power by converting the power available in flowing water in rivers, canals and streams with a certain fall (termed the "head") into electric energy at the lower end of the scheme, where the powerhouse is located. The power of the scheme is proportional to the flow and the head.

67 IPCC. Renewable Energy Sources and Climate Change Mitigation. Special Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. 2012, p. 80. Available at: http://www.ipcc.ch/pdf/special-reports/srren/SRREN_Full_Report.pdf (Last accessed: 3 September 2015)
68 Ibid.
69 Ibid.
70 There is no common definition of a Small Hydropower Plant. However, a total capacity of 10 MW is generally becoming accepted in Europe and is supported by the European Commission and the European Small Hydropower Association.

71 Water Management, Water Framework Directive and Hydropower. Common Implementation Strategy Workshop. Brussels, 13-14 September 2011. Issue Paper, p. 14. Available at: http://www.ecologic-events.eu/hydropower2/documents/IssuePaper_final.pdf (Last accessed: 4 September 2015)
72 Ibid.
73 For example, large-scale plants affect water availability downstream, inundate valuable ecosystems, put migratory fish species at risk and may require the relocation of populations. European Commission. Research and Innovation. Energy. Hydropower. Last update: 11 August 2015. Available at: http://ec.europa.eu/research/energy/eu/index_en.cfm?pg=research-hydropower (Last accessed: 4 September 2015).
74 Ibid.
75 European Commission. Research and Innovation. Energy. Technical Background. Technology. Last update: 11 August 2015. http://ec.europa.eu/research/energy/eu/index_en.cfm?pg=research-hydropower-background (Last accessed: 4 September 2015).

53 Total installed hydropower capacity for different HP plant sizes

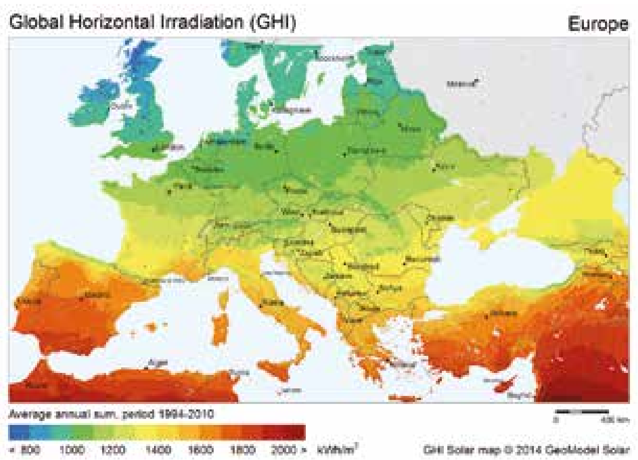


Source: http://www.ecologic-events.eu/hydropower2/documents/IssuePaper_final.pdf (Figure 7)

Small hydropower systems can be considered an environmentally friendly energy conversion option, since they do not interfere significantly with river flows and fit in well with their surroundings. Their numerous advantages include grid stability, reduced land requirements, local and regional development and good opportunities for technology exports.[76]

Hydropower projects encompass dam projects with reservoirs (storage hydropower), run-of-river and in-stream projects and cover a continuum in project scale.[77]

54 Global horizontal irradiation in Europe



Source: http://solargis.info/doc/_pics/freemaps/1000px/ghi/SolarGIS-Solar-map-Europe-en.png

7.1.3 Solar

Solar energy is the most abundant permanent energy resource on earth, available for use in direct (solar radiation) and indirect (heat pumps, wind, biomass, hydro, ocean, etc.) forms. The following section is limited to the direct use of solar radiation.[78]

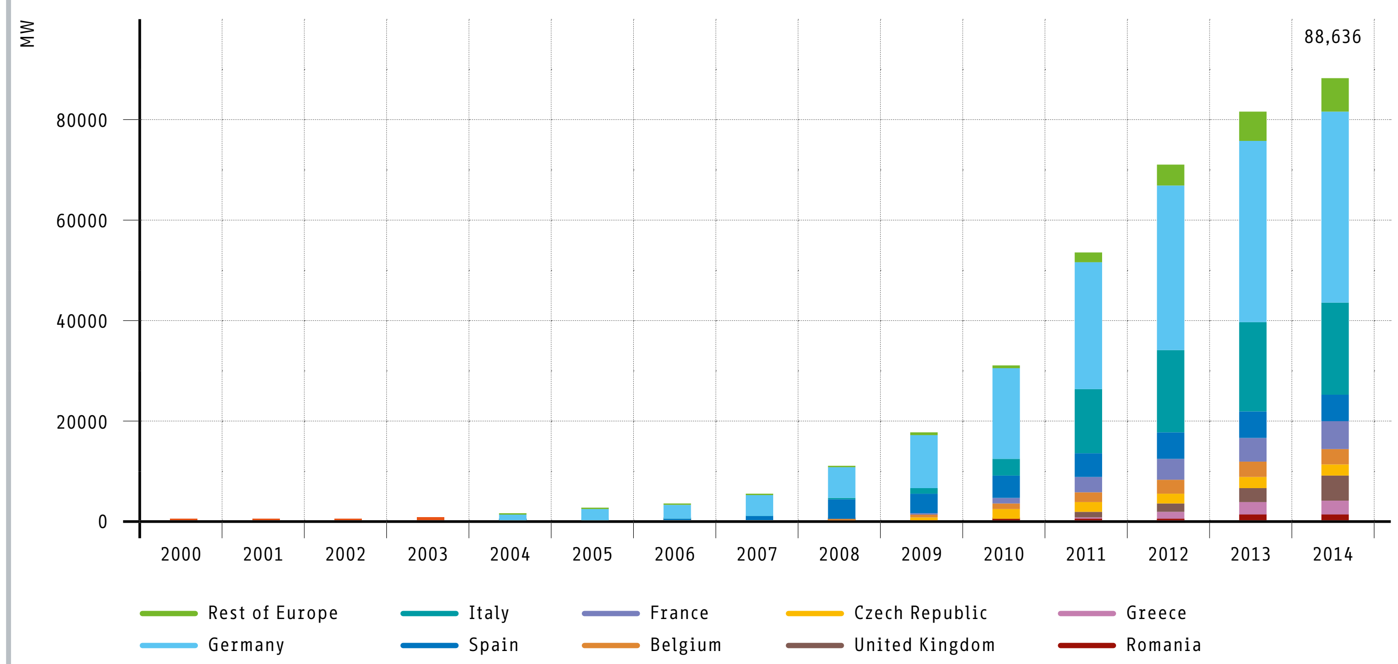
The annual average horizontal surface irradiance is approximately 170 W/m² globally. When 170 W/m² is integrated over one year, the resulting 5.4 GJ that is incident on 1 m² at ground level is approximately the energy that can be extracted from one barrel of oil, 200 kg of coal, or 140 m³ of natural gas. The flux changes from place to place: some parts of the earth receive much higher irradiance than this annual average, as shown in Figure 54.[79]

Notwithstanding this, it has been shown that economically attractive applications of solar energy are not limited to the sunniest regions. Northern European countries offer good examples of this.

There are two main technologies used for the production of electricity from solar energy: photovoltaic cells and solar thermal, including concentrated solar power.

76 European Commission. Research and Innovation. Energy. Hydropower. Last update: 11 August 2015. http://ec.europa.eu/research/energy/eu/index_en.cfm?pg=research-hydropower (Last accessed: 4 September 2015).
77 IPCC. Renewable Energy Sources and Climate Change Mitigation. Special Report of the Intergovernmental Panel on Climate Change, op. cit. (note 39), p. 8.
78 World Energy Council. World Energy Resources: Solar. 2013. Available at: https://www.worldenergy.org/wp-content/uploads/2013/10/WER_2013_8_Solar_revised.pdf (Last accessed: 4 September 2015).
79 SolarGis. Global Horizontal Irradition (GHI). Europe. Available at: http://solargis.info/doc/_pics/freemaps/1000px/ghi/SolarGIS-Solar-map-Europe-en.png (Last accessed: 4 September 2015).

55 Evolution of global solar PV annual installed capacity 2000–2014



Source: http://helapco.gr/pdf/Global_Market_Outlook_2015_-2019_lr_v23.pdf

Photovoltaic solar energy

Photovoltaic (PV) cells convert radiation into electricity by absorbing sunlight, which knocks electrons loose from their atoms, allowing the electrons to flow through the cells to produce electricity. PVs have an enormous potential to become a major source of clean electricity in the future.[80]

Back in 2007, European solar cells had reached 1 063 MW, which represented approximately 30% of the worldwide photovoltaic production. Germany was the leading market in solar energy in Europe, and Spain had introduced a feed-in tariff policy that led to it becoming the second biggest market (representing 11% of total EU installed capacity).

Ironically, these countries invested in solar energy when the electricity generation costs for PV systems were high and the efficiency of converting sunlight into electricity was low, and now that prices have declined massively and solar power has become broadly recognised as a cost-competitive, efficient and clean renewable energy source, installations in Europe have slowed down drastically.[81] In 2014 installations in Europe fell to the levels of 2009.[82] 7 GW of PV capacity were connected to the grid in Europe in 2014, compared to 10.5 GW in 2013 and 17.7 GW in 2012. In 2014, the UK led the development of solar power in Europe for the first time, with 2.4 GW, followed by Germany (1.9 GW) and France (927 MW).[83] Spain, which led the global PV market in 2008, has greatly reduced its rate of installations, after a shift of direction in political and economic policy.[84] Belgium, Bulgaria, the Czech Republic and Greece are also experiencing a reduction in the PV solar energy market.

Research has been identified as an important element in increasing renewable energy generation. The European Commission has mobilised industry, academia, regulators and financial institutions in order to create synergies to develop European leadership in PVs. The European Photovoltaic Platform is the forum where all these efforts come together. Current research focuses on the various technologies for harnessing solar energy, increasing efficiency, and storage and distribution to the grid.

Despite all the obstacles that PV solar energy has encountered in recent years in Europe, it is important to highlight that, with close to 90 GW of PV capacity in European countries, the 2020 targets defined in 2009 were already reached in 2014, six years ahead of the target date.[85]

80 European Commission. Research and Innovation. Energy. Photovoltaics. Last update: 28 August 2015. http://ec.europa.eu/research/energy/eu/index_en.cfm?pg=research-photovoltaics (Last accessed: 4 September 2015).
81 There are panels based on crystalline and polycrystalline silicon solar cells, and thin-film solar panels. At present, the former are the most common. However, the falling costs of thin-film solar panels, especially cadmium telluride (CdTe) and copper indium gallium diselenide (CIGS) are allowing them to gain market share. Their efficiencies have gradually increased, while costs have decreased. For example, the efficiencies of multijunction cells and concentrating PV have been reported to be as high as 44%, and most panels available in the market have efficiencies of the order of 15%. The price of PV panels came down from about USD 30/W about 30 years ago to less than USD 1/W in 2013. Although thin-film solar cells increased their global market share in the last decade because of lower cost, manufacturers have been able to reduce the cost of producing silicon-based solar panels to match the thin film panel costs. Therefore, silicon-based panels have kept their market share close to 80%. World Energy Council. World Energy Resources: Solar. 2013. Available at: https://www.worldenergy.org/wp-content/uploads/2013/10/WER_2013_8_Solar_revised.pdf (Last accessed: 4 September 2015).
82 http://helapco.gr/pdf/Global_Market_Outlook_2015_-2019_lr_v23.pdf (Last accessed: 20 July 2015).
83 Ibid.
84 Ibid.
85 Ibid.

Adolf Goetzberger (Germany)

Winner of the European Inventor Award 2009 in the category of Lifetime achievement, in the area of photovoltaic

When Goetzberger started to round up support for solar energy in the mid-1970s, the world's total solar cell production was at just 500 Kilowatts.

Goetzberger excelled in his early career working in semiconductor research. In the 1960s, he worked with a US Nobel Prize winner and at Bell Laboratories in the United States. During that stretch, Goetzberger published work that still plays a vital role in today's semiconductor technology. But he eventually returned to Germany to realise his dream - to help solar energy to a breakthrough.

In the late 1970s, he provided visionary research into fluorescent planar collector-concentrators for solar energy conversion, which could revolutionise efficiency levels of solar power generation. In 1981, he founded the Freiburg-based Fraunhofer-Institut for Solar Energy Systems (ISE).

Over the next few years he drove groundbreaking research in the young sector. To this day, his book "Photovoltaic Solar Energy Generation" is a standard cited by scientists all over the world.

Under Goetzberger's lead, the ISE developed the first highly efficient, fully electronic inverter for stand-alone photovoltaic systems, and it took first steps toward highly efficient silicon and III-V solar cells, thin-film solar cells and solar-grade silicon.

In the field of improving efficiency, it cooperated in the development of the first transparent insulation materials, which hit the market in 1988.

In 1989, the institute participated in the 1 000 Roofs Programme, at the time the world's largest, wide-scale testing project of small, grid-connected photovoltaic systems. In the early 1990s, the ISE also pioneered an energy self-sufficient, zero-emissions house that today is replicated all over the world.

Goetzberger has cooperated in researching Concentrating Solar Power (CSP), which could satisfy all of Europe's electricity needs by 2050, a study sponsored by the German government found.

Today, the European photovoltaic industry is worth EUR 14 bn a year, and Germany is home to the world's largest solar PV market. It's difficult to envision such a development without the work – and persistence - of Adolf Goetzberger.

Solar thermal

Given that 49% of the final energy demand in the EU is used for heating and cooling,[84] and that only biomass, geothermal and solar renewable sources generate heat, Europe has put its efforts into meeting the need for low-temperature heat with solar thermal energy.[85] Of this low-temperature heat demand, 61% is used in households, while 19% and 20% is used in services and industry respectively.[88]

In order to use the potential for solar energy to meet these needs, models of solar active houses, large-scale prefabricated solar renovation technologies and thermal energy storage were promoted. In 2010, the EU adopted the Energy Performance of Buildings Directive[89] concerning the residential and the tertiary sector. The Directive obliges member states to apply minimum requirements regarding the energy performance of new and existing buildings, such as the use of renewable energies for heating and cooling installations, including solar thermal for water heating.[90]

Recent progress in solar thermal energy in Europe is divided among small systems (mainly in the domestic sector), large systems and very large systems – such as solar district heating plants.

Looking at the year 2014, the market for small systems amounted to 2 GWth, which represents a decrease of 6.8% in comparison with the previous years. The total installed capacity in Europe reached 31.8 GWth. Solar thermal energy suffered, together with PV solar energy, a contraction in its largest markets in Europe. It reached the same market level as in 2007, before the peak year of 2008. The main factors influencing these developments include the falling price of gas, difficult access to finance for consumers, a slow-moving construction sector, fewer public support schemes for solar thermal, and competition from other energy sources with more attractive market incentives.[91] Nevertheless, there are still market development opportunities for solar thermal energies, provided that some barriers are removed and support policies put in place. For example, Greece and Spain managed to grow their markets by 18.9% and 9.8%.

A different scenario was observed for larger systems. Large systems – above 35 kWth – for commercial and industrial solar heating have not decreased as much as the small systems. Very large systems – above 350 kWth / 500 m^2 – are growing rapidly. Most of this growth is due to solar district heating plants[92] in Denmark, but significant developments are also apparent in other European countries, using different solutions led by other actors.[93] The EU sees potential for these very large systems to meet heating energy needs in Europe, but recognises that success does not depend only on the availability of ready-to-use technology and on physical conditions, but also on the combination of legislative and economic frameworks taking into account the specific interests of active local stakeholders and citizens.[94]

In the relatively new field of solar district heating, the SDHplus project, which has been running since 2012, brings together countries that have experience in this area with others which see the potential but have only recently started to explore the possibilities. The project has 18 pilot studies and 13 business models. The new countries involved in the project are France, Italy and Poland.[95]

Concentrated solar power

This technology concentrates solar energy at a single point, which is then used to heat up a fluid, produce steam and activate turbines that produce electricity. There are different techniques to concentrate the solar power, such as parabolic trough, parabolic dish or power tower systems. One of the advantages of the technology is that it can provide combined heat and power.[96]

In Europe, the Mediterranean region has the most potential for the development of concentrated solar power (CSP), since the exploitation of solar energy using this technology differs according to sunlight conditions. CSP power plants have been built in Spain, with the financial support of the EU.[97]

The severe financial and economic crisis of 2008 has affected the development of CSP in Europe, especially in Spain, which is the country with the highest potential for CSP in the region. Since 2010, Spain has installed only 2.3 GW.[98]

86 ESTIF. The Solar Thermal Potential in Europe. Available at: http://www.estif.org/fileadmin/estif/content/events/downloads/Potential%2520Solar%2520Thermal_Webinar.pdf (Last accessed: 4 September 2015).
87 http://www.estif.org/?id=661 (Last accessed: 20 July 2015).
88 ESTIF. The Solar Thermal Potential in Europe, op. cit. (note 59).
89 Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings. Available at: http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32010L0031&from=EN (Last accessed: 4 September 2015).
90 European Commission. Energy and Buildings. Renewable Energies and Energy Efficiency. Joint Research Centre. Available at: https://ec.europa.eu/jrc/sites/default/files/energy_and_buildings_en.pdf (Last accessed: 4 September 2015).
91 ESTIF. Solar Thermal Markets in Europe. Trends and Market Statistics 2014. June 2015. Available at: http://www.estif.org/fileadmin/estif/content/market_data/downloads/2014_solar_thermal_markets_LR.pdf (Last accessed: 4 September 2015).

92 Solar district heating systems collect the sun's energy over large areas, storing it and feeding it into the heating grid. This can generate enough power to supply heat and hot water to areas of towns or whole villages.
93 Ibid.
94 European Commission. Harnessing Solar Thermal Energy for District Heating. https://ec.europa.eu/easme/en/news/harnessing-solar-thermal-energy-district-heating (Last accessed: 4 September 2015).
95 Ibid.
96 European Commission. Research and Innovation. Energy. Concentrated Solar Power. Last update: 11 August 2015. http://ec.europa.eu/research/energy/eu/index_en.cfm?pg=research-csp (Last accessed: 4 September 2015).
97 Ibid.
98 Organisation for Economic Cooperation and Development/International Energy Agency. Technology Roadmap. Solar Thermal Electricity. 2014 Edition. Available at: https://www.iea.org/publications/freepublications/publication/TechnologyRoadmapSolarThermalElectricity_2014edition.pdf (Last accessed: 4 September 2015).

The challenge facing CSP at this stage is that the costs of these technologies need to decrease to facilitate their entry into the market.[99] Although the costs of CSP plants have fallen since 2010, the technology has not yet developed its potential, because of competition with cheap unconventional gas and PV. The future prospects for the technology are positive, however, as new CSP components and systems are reaching commercial maturity, promising increased efficiency, declining costs and higher value through increased dispatch ability.

7.1.4 Geothermal

Geothermal energy is described as "energy available as heat contained in or discharged from the earth's crust that can be used for generating electricity and providing direct heat for numerous applications such as: space and district heating; water heating; aquaculture; horticulture; and industrial processes. In addition, the use of energy extracted from the constant temperatures of the earth at shallow depth by means of ground source heat pumps (GSHP) is also generally referred to as geothermal energy".[100]

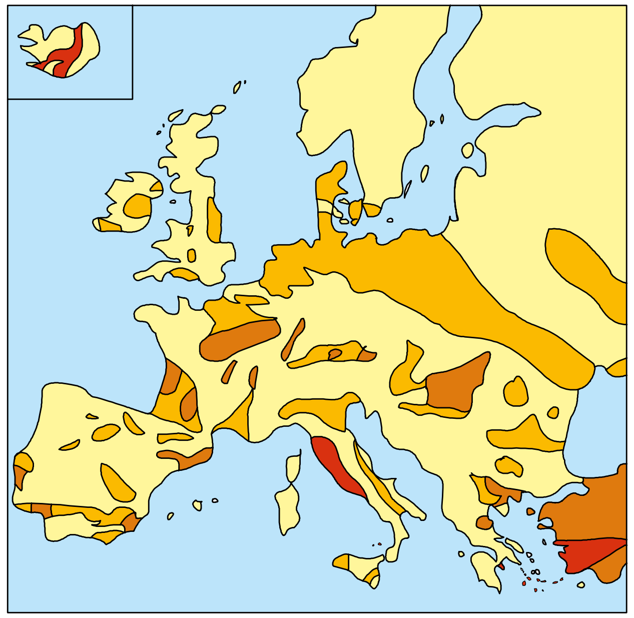
Among the many positive characteristics of geothermal energy is that the resource is available in all world regions. Other characteristics include: capability to provide base load power, no seasonal variation, immunity from weather effects and climate change impacts, and compatibility with both centralised and distributed energy generation.

Europe has significant geothermal resources in both volcanic and sedimentary basin environments, as can be seen in Figure 56.

Barriers to deployment include high capital cost, resource development risk, lack of awareness about geothermal energy and perceived environmental issues.

In 2007, in some regions of Europe, geothermal power plants already contributed substantially to a sustainable energy supply, using existing techniques of exploiting steam and hot water reservoirs. Geothermal energy was being exploited in Italy, Portugal (in the Azores), Iceland and other islands of volcanic origin. In Iceland, geothermal energy will be one of the two pillars upon which a fully renewable energy supply will be built. In south-eastern Europe, Turkey and the Caucasian region, further huge untapped reservoirs could contribute to a sustainable energy supply.[101]

56 Main basins and geothermal resources of Europe



- high enthalpy (el. power)
- high temperature basins (el. power, district heating)
- medium temperature basins (district heating)
- everywhere: EGS, shallow geothermal

Source: Antics, Miklos and Sanner, Burkhard. Status of Geothermal Energy Use and Resources in Europe. Proceedings European Geothermal Congress 2007. Unterhaching, Germany, 30 May-1 June 2007.

By 2012 the installed capacity of GSHP in the EU was about 16.5 GWth, while direct use capacity amounted to about 3.0 GWth. The total capacity of the 51 geothermal power plants in operation was about 0.95 GWe. Sweden, Germany, and Italy were the countries with the greatest installed capacity. Geothermal energy provided about 0.2% of the total EU final electricity demand and 0.9% of the electricity generated by renewable sources (about 660 TWh).[102]

The annual production of geothermal energy in the EU could reach about 49 TWh of heat from GSHP and 30 TWh from direct use in 2020. Projections for power generation assume an installed capacity of 1.6 GWe by 2020.[103]

99 European Commission. Research and Innovation. Energy. Concentrated Solar Power, op. cit. (note 69).
100 International Energy Agency. Renewable Energy Essentials: Geothermal. 2010. Available at: https://www.iea.org/publications/freepublications/publication/Geothermal_Essentials.pdf (Last accessed: 4 September 2015).
101 Antics, Miklos and Sanner, Burkhard. Status of Geothermal Energy Use and Resources in Europe. Proceedings European Geothermal Congress 2007. Unterhaching, Germany, 2007. Available at: http://www.geothermie.de/fileadmin/useruploads/wissenswelt/Materialien/Tagungen/EGC07/082-Antics_Sanner_EGC2007_BSA.pdf (Last accessed: 4 September 2015).
102 European Commission. 2014 JRC Geothermal Energy Status Report. Technology, Market and Economic Aspects of Geothermal Energy in Europe. Joint Research Centre Science and Policy Reports. 2015, p. 10. Available at: http://publications.jrc.ec.europa.eu/repository/bitstream/JRC93338/jrc%20geothermal%20report_final.pdf (Last accessed: 4 September 2015).
103 Ibid. p. 11

Europe's clean energy potential and exploitation

7.1.5 Wind energy

The extent of wind energy resources is very considerable, and they have a leading role in achieving the European renewable energy targets. Europe's raw wind energy potential could be equivalent to almost 20 times the energy demand in 2020.[104]

Onshore wind energy potential is concentrated in agricultural and industrial areas of north-western Europe. The largest offshore potential is in low-depth areas in the North Sea, the Baltic Sea and the Atlantic Ocean. By 2009, the potential of deep offshore was still not being considered to contribute to the renewable energy mix because its costs were too high, making it economically unfeasible.[105]

Regarding environmental and social constraints in the calculation of wind energy potential in Europe, it should be noted that the assessments of onshore wind energy potential in Europe took into consideration the potential impacts of wind power plants on nature and biodiversity, showing that the exclusion of Nature Protection Areas (NPAs) that are part of Natura 2000 from wind power exploitation plans would not significantly decrease the wind energy potential in Europe. Natura 2000 is a network of NPAs with the purpose, inter alia, of protecting bird migration corridors. Offshore, however, the environmental and social constraints reduce wind energy potential by more than 90%.

Considering that the production costs of wind energy are very competitive and the potential is about 20 times the energy demand by 2020, the focus for policymakers should be on facilitating the integration of wind power into the energy system via research and development.[106]

According to statistics published in February 2015, there is now 128.8 GW of installed wind energy capacity in the EU: approximately 120.6 GW onshore and just over 8 GW offshore. During 2014, 11 791 MW of wind power capacity was installed in the EU-28, an increase of 3.8% compared to the previous year. The wind power capacity installed by the end of 2014 would, in a normal wind year, produce 284 TWh of electricity, enough to cover 10.2% of the EU's electricity consumption. This has contributed to the efforts of the EU to move away from fuel oil, coal and gas.[107]

Since the potential assessment conducted in 2009, significant progress has been made in the exploitation of wind energy in Europe. During 2014, 12 819 MW of wind power was installed across Europe, of which 11 791 MW was in the EU, with 10 308 MW onshore and 1 483 MW offshore. The onshore market increased in the EU by 5.3%, and offshore installations decreased by 5.3% compared to 2013. Overall, EU wind energy annual installations increased by 3.8% compared to 2013. Investment in EU wind farms was between EUR 13.1bn and EUR 18.7bn. Onshore wind farms attracted around EUR 8.9bn to EUR 12.8bn, while offshore wind farms accounted for EUR 4.2bn to EUR 5.9bn.[108]

7.2 Sub-regional distribution of clean energy resources

7.2.1 Northern Europe

This sub-region has abundant wind, biomass, ocean and hydro resources for renewable energy. The sub-region is poor in solar energy; however, PVs are also being installed in some northern countries.

Denmark, Lithuania, Latvia, Estonia, the UK, Ireland and Finland have high wind energy potential. By 2011, Denmark already relied on renewable energies for 22.4% of its total primary energy supply, and 40.3% of its electricity was generated with renewables. Its targets under the EU renewable energy framework include providing 50% of electricity consumption from wind (only) by 2020 and covering 100% of total energy consumption from renewables by 2050. With a view to this goal, Denmark has six wind power projects, amounting to 836 MW of capacity. Finland is also stepping up the exploitation of its high wind-energy capacity, with 28 projects that will add more than 4 550 MW of capacity. In Sweden, there are 42 projects to add around 4 500 MW of wind capacity. Ireland has 15 projects for adding 542 MW of wind capacity for electricity generation. Within the sub-region there is underexploited wind energy potential.

Other abundant renewable energy resources in the sub-region are biomass and ocean. Biomass is used mainly for heat and transportation in the form of biofuels. Sweden will add 429 MW and 107 MWth of biomass-fired capacity and 126 million litres of bioethanol per year, and has projected 2 230 MW and 700 MWth of biomass-fired capacity, 341 million litres of biodiesel per year and around 40 000 MW.

Iceland is the world leader in the use of geothermal energy for space heating and generation of electricity. By 2014, Iceland was able to supply 85% of its primary energy from renewables, with 66% from geothermal sources.

104 European Environment Agency. Europe's onshore and offshore wind power potential. Technical Report No. 6/2009. Available at: http://www.eea.europa.eu/publications/europes-onshore-and-offshore-wind-energy-potential (Last accessed: 4 September 2015).
105 Ibid.
106 Ibid.
107 The European Wind Energy Association. Wind in Power. 2014 European Statistics. 2015. Available at: http://www.ewea.org/fileadmin/files/library/publications/statistics/EWEA-Annual-Statistics-2014.pdf (Last accessed: 4 September 2015).
108 Ibid.

7.2.2 Eastern Europe

In this European sub-region, the renewable energy resources provide a mosaic of clean energy potential that is awaiting exploitation. In general, though with some exceptions, energy consumption per capita is lower than the European average, with heavy reliance on fossil fuels to meet energy demands.

Bulgaria is a country with vast wind, solar, hydro, biomass and geothermal potential. Currently, 7.1% of its primary energy supply is from renewables. By 2020, Bulgaria aims to provide 16% of its final energy from renewables; it has one small hydropower project that will add 80 MW of capacity, and has announced 12 PV projects that together would add a further 185 MW of installed capacity, as well as 23 wind power projects to install a capacity of 2 300 MW.

The Czech Republic is one of the countries in the sub-region with more diversity of renewable energy resources, second only to Romania. The Czech Republic is rich in wind, hydro, biomass and geothermal. By 2013 its share of renewables in the total primary energy supply was 12.4%,[109] which is to increase to 13.5% by 2020. It aims to achieve this objective by exploiting its solar, biomass and wind energy resources. Its main source of renewable energy is biomass, accounting for 87.2% of total renewable energy production. There is also potential to develop hydro and geothermal.

Romania is going in the same direction as the Czech Republic, developing solar, wind and biomass energy resources. Romania had set a goal of 24% of renewable energy in total energy generation by 2020, which has already been achieved, far in advance of the target date.[110] There is further potential for exploiting geothermal and hydro power. In the latter field, Romania is one of the sub-region's leaders, with hydropower taking a 23.1% share in total renewable energy generation; the only country where this proportion is higher, at 28.4%, is Slovakia.[111]

Poland, Slovakia and Hungary are generating energy from geothermal resources and biomass. By 2013, the share of renewables in primary energy supply was 11.3% in Poland, 9.8% in Slovakia and Hungary, which is already very close to the targets that they had set for 2020, i.e. 15%, 14% and 13% respectively.[112] The share of geothermal energy in total renewable energy generation is 5.4% in Hungary, 0.2% in Poland and 0.4% in Slovakia. Poland and Hungary produce more than 90% of their renewable energy from biomass.

7.2.3 Western Europe

Austria is rich in solar, hydro, geothermal and biomass resources, which it is successfully exploiting. By 2011, 26.3% of its total primary energy supply was from renewable energies.[113] Its target is to have 45% of final energy from renewables by 2020. Austria is the leader in hydropower generation in this sub-region, with 38.1% of its renewable energy production by 2013. The next source of energy is biomass, with 56.2% of Austria's renewable energy production, this being the country with the smallest share of biomass in the sub-region.[114]

Germany and Belgium are mainly rich in wind resources, although they also have some hydropower and biomass potential. Their prime current source of energy is biomass, with 70.8% and 79.7% respectively of total renewable energy production. After biomass, wind and solar are the most developed sources of renewable energy. Germany leads solar production in the sub-region, with a share of 9.6% in renewable energies; Belgium takes second place, with 8.4%. The situation in wind energy is similar: Germany leads the sub-region, with 13.2%; Belgium is in third place, with 10.7% of wind energy in total renewable energy generation in 2013. Both countries have several projects to increase the installed capacity in biomass and geothermal energy.

France is one of the countries with more diversity in renewable energy resources, including wind, solar, hydro, biomass, geothermal and ocean. By 2011, 7.2% of its total primary energy supply was from renewable energies. Its target is to achieve 23% of final energy from renewables by 2020. France produces renewable energy mostly from biomass and hydropower, with 70.8% and 26.3% of total renewable energy. On a smaller scale, it also produces wind, solar and geothermal energy.

The Netherlands is mainly rich in biomass and wind energy. The country's share of renewable energies in total primary energy supply amounted to 4.2% by 2011. Its target is to increase this to 14% by 2020. In 2013, its chief resources for renewable energies were biomass and wind, with 86.3% and 11.3% respectively of total renewable energy production. It also produces energy from solar, hydropower and geothermal, but to a lesser extent. Its projects for increasing installed capacity are mainly in biomass and wind power.

109 Eurostat news release, 10 March 2015. Renewable energy in the EU, op. cit. (note 1).
110 Quartz. Three European countries have already hit their 2020 renewable energy goals. 10 March 2015. Available at: http://qz.com/359415/three-european-countries-have-already-hit-their-2020-renewable-energy-goals/ (Last accessed: 4 September 2015).
111 Eurostat. Statistics Explained. Primary Production of Renewable Energy between 2003 and 2013, op. cit. (note 82).
112 Eurostat news release, 10 March 2015. Renewable Energy in Europe, op. cit. (note 1).

113 IRENA. Renewable Energy Country Profiles European Union. EU-27. Available at: http://www.irena.org/DocumentDownloads/Publications/_EU27Complete.pdf (Last accessed: 4 September 2015).
114 Eurostat. Statistics Explained. Primary Production of Renewable Energy between 2003 and 2013, op. cit. (note 82).

7.2.4 Southern Europe

This sub-region is privileged in terms of renewable energy resources. Whereas the North is richer in wind, the South has clear skies and sunny days throughout the year, and therefore solar power has the most potential. There is also geothermal potential, as well as hydropower.

Malta covers 72.6% of its renewable energy from solar power; the remaining 27.4% is from biomass. This share is the highest in the region. Greece and Spain also have high shares of solar energy in their total renewable energy production, with 20.1% and 25.4% respectively in 2013.

Greece, Spain and Portugal have a more diversified renewable energy mix. Greece derives 21.9% of its renewable energy from hydropower, 14.3% from wind, 43% from biomass and 0.3% from geothermal. Spain has shares of 26.7% from wind power (the highest in the sub-region), 39.9% from biomass, 18.2% from hydropower and 0.1% from geothermal in total renewable energy production. Portugal produces 18.4% of its total renewable energy from wind, 55.4% from biomass, 21% from hydropower, 2% from solar, and, remarkably, 3.2% from geothermal. By 2011, Greece and Spain covered 11.7% of their total energy supply from renewables. Their target by 2020 is to increase this proportion to 20%, which appears entirely feasible, since by 2013 they had already reached 15% of renewable energies. In Portugal, 22.4% of the total energy supply was from renewable energies by 2011; the country's target for 2020 is to increase this share to 31%.

Cyprus has a small share of renewable energies (5.1%) in its total primary energy supply, and only 3.1% of its electricity generation is from renewables. Cyprus has high solar energy potential and medium wind potential, but hydro, biomass and ocean power are low. At present, 64.1% of its renewable energy comes from solar, 18.3% from wind, 16.3% from biomass and 1.4% from geothermal.[115] The country aims to double its share of renewables in final energy supply by 2020. To this end, it has announced a number of projects to increase its capacity in biomass, solar and wind installed capacity, to a total of 114.7 MW.

Albania and Montenegro are the countries of the sub-region with the highest shares of hydropower in the total of renewable energy production, with 73.7% and 55.3% respectively. Both countries complement hydropower with energy produced from biomass, with 24.8% and 44.7% respectively. However, they are not the only countries that exploit hydropower resources; Croatia and Macedonia also produce 45.9% and 44.8% of their total renewable energy mix from hydropower, combining this with biomass. Macedonia uses also geothermal power to produce energy, with a 3% share of the renewable energy mix.

Italy, Slovenia and Macedonia are the three countries with the highest proportion of renewable energy from geothermal power. Italy produces 21.3% from geothermal, and is the country in Europe with the highest share of this resource. Slovenia and Macedonia follow, with 3.6% and 3% respectively.

Units:

Terawatthours (TWh) = 109 kWh
GW of electrical output (GWe) = 106 MW
Petajoules (PJ) = 109 MJ
Exajoule (EJ) = 1 012 MJ
1 kWh = 3.6 MJ
The power in megawatts of an electricity generating plant may be expressed as MWe or MWt (or MWth)

115 Eurostat. Statistics Explained. Primary Production of Renewable Energy between 2003 and 2013. 2015. Available at: http://ec.europa.eu/eurostat/statistics-explained/images/8/8b/Primary_production_of_renewable_energy%2C_2003_and_2013_YB15.png (Last accessed: 4 September 2015).

Key findings and conclusions

8
KEY FINDINGS AND CONCLUSIONS

Wind power, Bouches du Rhône, France

This report has brought together data on patents, trade flows, foreign direct investments, climate change policies, CO_2 emissions, public R&D expenditures and renewable energy deployment and potential, in order to provide a comprehensive and up-to-date picture of invention and associated economic activities in climate change mitigation technologies, worldwide and specifically in Europe.

This chapter presents the key findings from the exploration of this large and unique dataset.

8.1 Key findings

Globally, there has been a continuous growth in inventive activity in climate change mitigation technologies since 1995, in particular in clean energy technologies, CCMTs related to transportation and CCMTs related to buildings. Between 1995 and 2011, the number of CCMT inventions developed annually in the world increased almost fivefold, from 11 000 to 51 000. This growth was even faster than in other technologies, with the share of CCMTs rising from 2% to nearly 6% of all global inventive activity. Furthermore, there is evidence that the average value of these inventions, as indicated by their international diffusion, has also increased: the number of “high-value” inventions, for which protection was sought in at least two countries, rose even more sharply, from around 2 500 in 1995 to just under 17 000 in 2011.

Europe appears to be a major global centre for CCMT invention activity. In line with developments across the world, invention in CCMTs in Europe increased by a factor of five, from 1 765 inventions in 1995 to over 9 000 in 2011, and with an acceleration of the growth rate since 2005. While it is difficult to compare patents filed in different jurisdictions, the metric used in this report indicates that Europe is the world’s leader in CCMT inventions, ahead of Japan, the US, Korea and China. European inventors are responsible for around 40% of high-value CCMT inventions developed in the world. This proportion has remained stable across the 16-year period of analysis, despite increasing competition from China and Korea. The number of high-value inventions from Europe has multiplied by roughly six, from less than 1 000 in 1995 to just under 6 000 in 2011.

This remarkable increase in Europe’s inventive activity is driven mainly by developments in renewable energy (such as wind and solar power), energy storage (including fuel cells and hydrogen) and road transportation technologies (efficient combustion engines, electric and hybrid vehicles). In other fields, in particular smart grid technologies, which are key to the large-scale deployment of renewable energy, the numbers of inventions have remained relatively small.

Compared to CCMT inventions worldwide, Europe’s relative performance is particularly strong in CCMTs related to transportation and smart grids, and carbon capture and storage. It is somewhat lower, but still significant, in clean energy technologies and in the buildings sector.

The degree of specialisation is increasing, as in Japan and Korea. Within Europe, inventiveness appears highly concentrated, with five countries accounting for 80% of inventive activity. It is clearly dominated by Germany, with almost half of Europe’s CCMT inventions in the most recent period for which data is available, followed by France, Spain, Italy and the UK. In renewable energy, Germany’s invention performance is fully four times greater than that of the second main inventor country, France.

Germany’s performance is partly a reflection of its economic size, but more importantly, it also has the highest number of CCMT inventions per unit of GDP. In terms of this indicator, it is followed by Sweden, France and Finland. Interestingly, the data reveals that some countries, such as Greece and Portugal, which are less active in innovation overall, are nevertheless highly specialised in CCMTs.

Between 1995 and 2011, only 3.2% of European CCMT inventions resulted from cooperation between inventors located in at least two different European countries. This number is comparable to the proportion of inventions developed between European countries and the rest of the world (3.5%). However, an interesting feature of European inventive activity in CCMT is that intra-European cooperation in these technologies is developing at a much faster rate than in others, from 1.7% in 1995 to 4.1% in 2011. It has even surpassed that between European and non-European inventors, which rose from 2.2% to 3.8% in the same period.

Not surprisingly, the intellectual property rights associated with European inventions are primarily protected in Europe, but they are also widely and increasingly protected around the world. For example, in 2010, 38% of European CCMT inventions gave rise to patent filings in the US, 25% in China, 14% in Japan and 10% in Korea. On average, CCMT patents are filed in two jurisdictions, while roughly 13% are filed in five or more jurisdictions. This distribution is similar to that for non-CCMT technologies.

Europe also appears as the world’s main market for CCMT, as measured by patent filings from both Europe and overseas. There is considerable variation across technologies; for example, Europe is the main destination for wind power patent applications, but comes after Japan, the US and China for solar PV. Although European inventors, in particular from Germany, France and the UK, are the main source of European CCMT patent filings, US, Japanese and Korean inventors are also among the top ten contributors. The number of European CCMT patent applications with Chinese inventors still remains relatively small.

A consequence of Europe’s strong inventive activity is that the region is one of the world’s main exporters of CCMT products. However, it is also a large importer of CCMT goods. Overall, Europe is a net importer of CCMT products, whereas Japan, China and the US are net exporters. Significantly, tariffs on European exports are on average around 4%, several times higher than the average European import tariffs on CCMT goods (less than 1%). Europe’s main trading partners in CCMT are China and the US. However, there are also important differences within Europe: for example, Germany is a net exporter of CCMT products to the rest of Europe. Europe also appears as a major source of foreign direct investment in CCMT, surpassing even that of the US, with investments spanning all continents. Germany and France are the largest source countries of intra-European FDI in CCMTs.

The analysis also reveals a strong statistical relationship between cross-border patent filings, trade flows and FDI. While this relationship has been observed for other technologies as well, it confirms that patent protection facilitates incoming trade and investment flows and may thus encourage the international transfer of CCMTs through these channels.

An analysis of Europe’s climate change policy stringency, combined with a review of the economic literature, suggests that policies which put a price on carbon emissions, such as fuel taxes and the European emissions trading system, and other regulatory measures, such as emission standards for new vehicles, have a key significance for Europe’s performance in CCMT invention. A likely consequence of these policies, and of the induced invention response, is that the carbon intensity of Europe’s GDP fell sharply between 1995 and 2010 by over 30%, from over 320g of CO_2 per euro of GDP to less than 220g, and has remained the world’s lowest since before 2000.

Evidence also suggests that Europe’s performance has been partly supported by direct public financing for research and development. Government funding in Europe for R&D activities in CCMT has doubled since 2000, from EUR 2.2bn annually to EUR 4.5bn, which represents around 0.05% of Europe’s GDP, and is of a similar order of magnitude to the US and Japan. However, European public R&D expenditures on CCMTs are still below the level of 1985. Moreover, some key enabling technologies, such as smart grids and carbon capture and storage, receive very small amounts of public money compared to nuclear and renewable energy.

Renewable energy (RE) already accounted for some 15% of energy in the European Union in 2013, and the EU can already claim three times more renewable power per capita than anywhere else in the world. It has further ambitious goals to reduce CO_2 emissions by 20% in 2020, and 80% by 2050. The current source of over 50% of the EU's renewable energy is biomass, together with 18% hydro, 10% wind, 5% solar, 4% heat pumps and nearly 1% geothermal, but all of these technologies still have huge untapped potential. For instance, biomass could account for two-thirds of the RE target in 2020, while wind energy is projected to supply half of Denmark's electricity by 2020, and the raw potential of wind power could meet the EU's energy needs 20 times over.

Policy has had a marked impact on European CCMT developments. Thermal and photovoltaic solar energy has had strong support in Germany and Spain in particular, and many regions have promoted the use of wind power. Biofuels have also had pan-European support. However, in many fields, the implementation of RE policies must also deal with environmental issues, such as land use and competition with food in the case of biomass production, and visual impact in the case of wind power.

8.2 Conclusions

The data suggests that policies have been successful in encouraging CCMT development in Europe, which today is the world's main centre for CCMT inventions. The strong and continuing growth in this field of inventive activity has helped Europe to achieve the lowest emissions per unit of GDP worldwide. However, the International Energy Agency estimates that public R&D spending would still need at least to double to achieve the intended carbon emissions reductions (IEA, 2010). Continued and intensified support for CCMT R&D, through carbon pricing mechanisms and policies that support innovation in general, therefore appears essential.

European inventors file a large number of patent applications abroad, in particular in the US, Japan, China and Korea. Climate change policies in these countries, which drive the local demand for CCMT, thus have a direct effect on European inventive activities by providing incentives to develop new technologies and export them to foreign markets. An ambitious global agreement on climate change at the COP21 in Paris could translate into strong climate change mitigation policies in signatory countries. This could have a tremendous positive impact in terms of avoided climate change, and it would also benefit European inventors, who are in a strong position to gain from global initiatives on CCMT inventions.

The analysis shows that European companies derive advantages from the international transfer of their CCMT inventions, which can generate benefits in Europe. They can also generate benefits overseas, in cases where European firms trade with or invest in recipient countries through foreign direct investments. In view of the strong statistical relationship between patent filings, trade flows and foreign direct investment, effective patent protection in destination countries could encourage trade in CCMTs and FDI. Policies that increase international technology diffusion could help both to reduce global emissions and to generate more business opportunities for European CCMT inventors.

ANNEXES

Solar panel installation, Italy

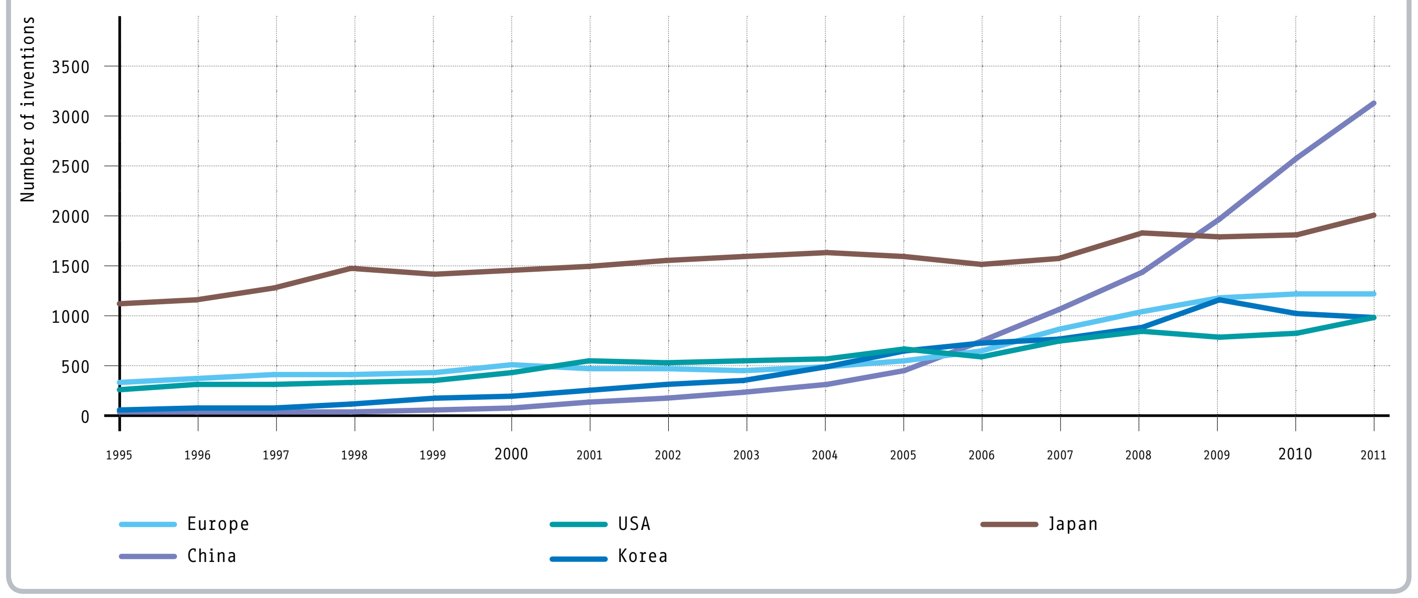
Annex 1

List of European Patent Convention contracting and extension states

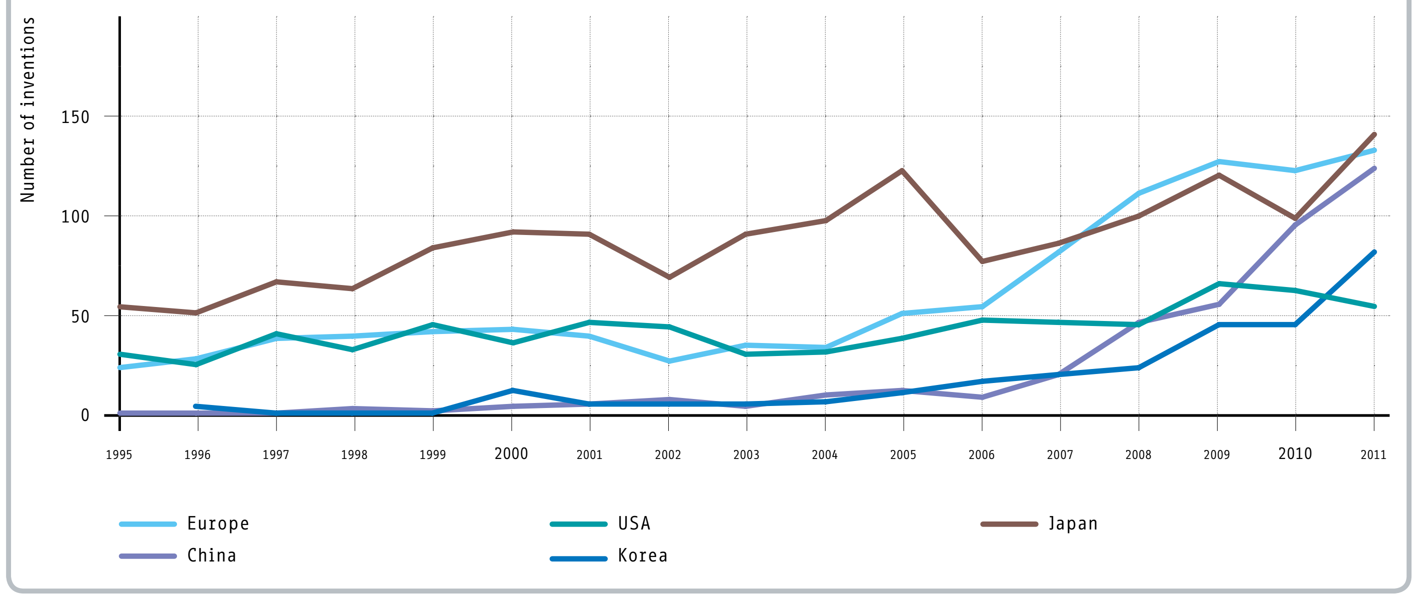
Country name	PATSTAT code	ISO code
Albania	AL	ALB
Austria	AT	AUT
Belgium	BE	BEL
Bosnia and Herzegovina (extension state)	BA	BIH
Bulgaria	BG	BGR
Croatia	HR	HRV
Cyprus	CY	CYP
Czech Republic	CZ	CZE
Denmark	DK	DNK
Estonia	EE	EST
Finland	FI	FIN
France	FR	FRA
Germany	DE	DEU
Greece	GR	GRC
Hungary	HU	HUN
Iceland	IS	ISL
Ireland	IE	IRL
Italy	IT	ITA
Latvia	LV	LVA
Liechtenstein	LI	LIE
Lithuania	LT	LTU
Luxembourg	LU	LUX
Macedonia	MK	MKD
Malta	MT	MLT
Monaco	MC	MCO
Montenegro (extension state)	ME	MNE
Netherlands	NL	NLD
Norway	NO	NOR
Poland	PL	POL
Portugal	PT	PRT
Romania	RO	ROM
San Marino	SM	SMR
Serbia	RS	SRB
Slovak Republic	SK	SVK
Slovenia	SI	SVN
Spain	ES	ESP
Sweden	SE	SWE
Switzerland	CH	CHE
Turkey	TR	TUR
United Kingdom	GB	GBR

Annex 2

A Inventions in CCMTs related to buildings (Y02B) in the major innovation centres 1995-2011

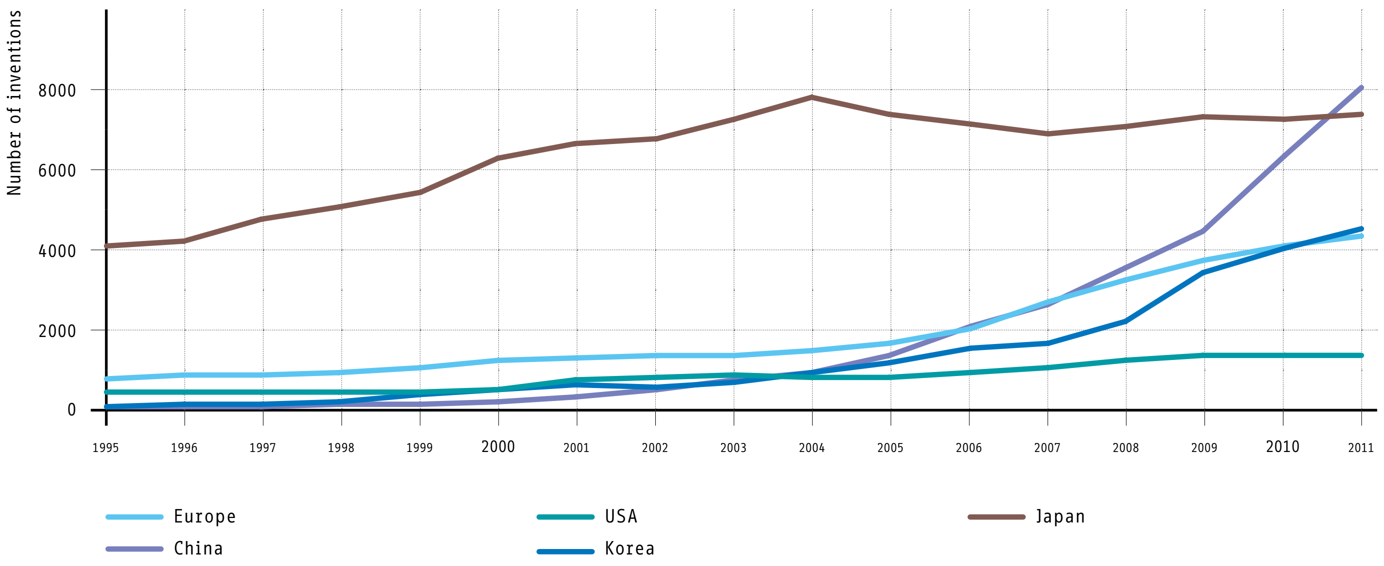


B Inventions in carbon capture and storage (Y02C) in the major innovation centres 1995-2011

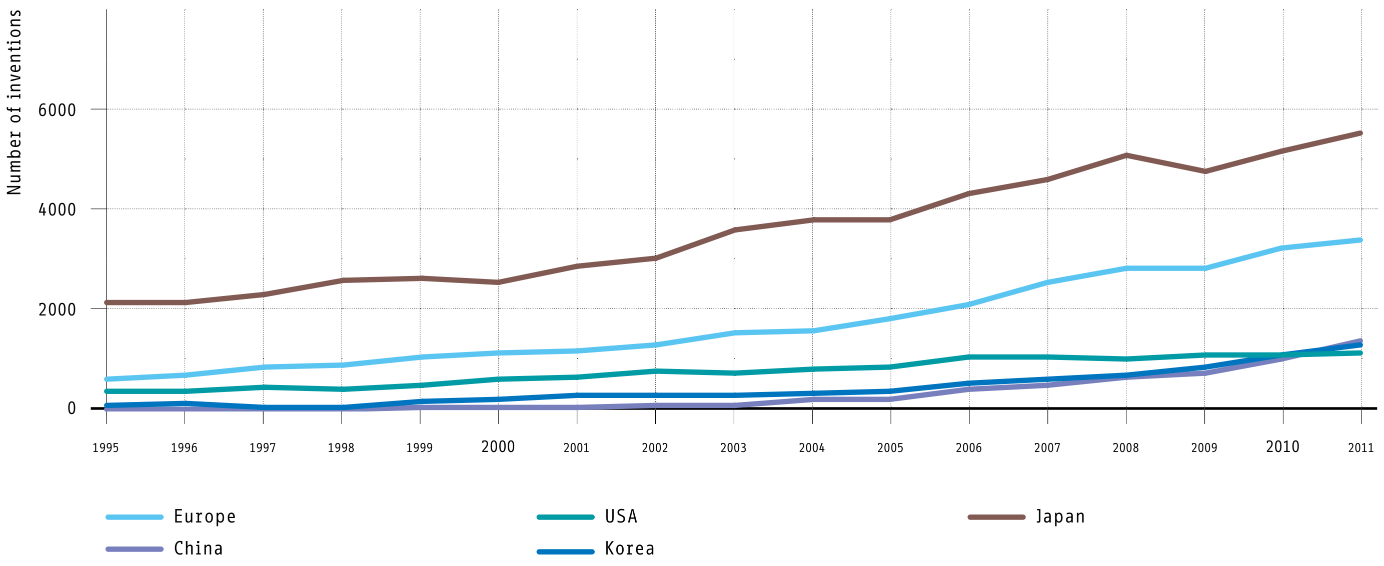


Annex 2 (contd.)

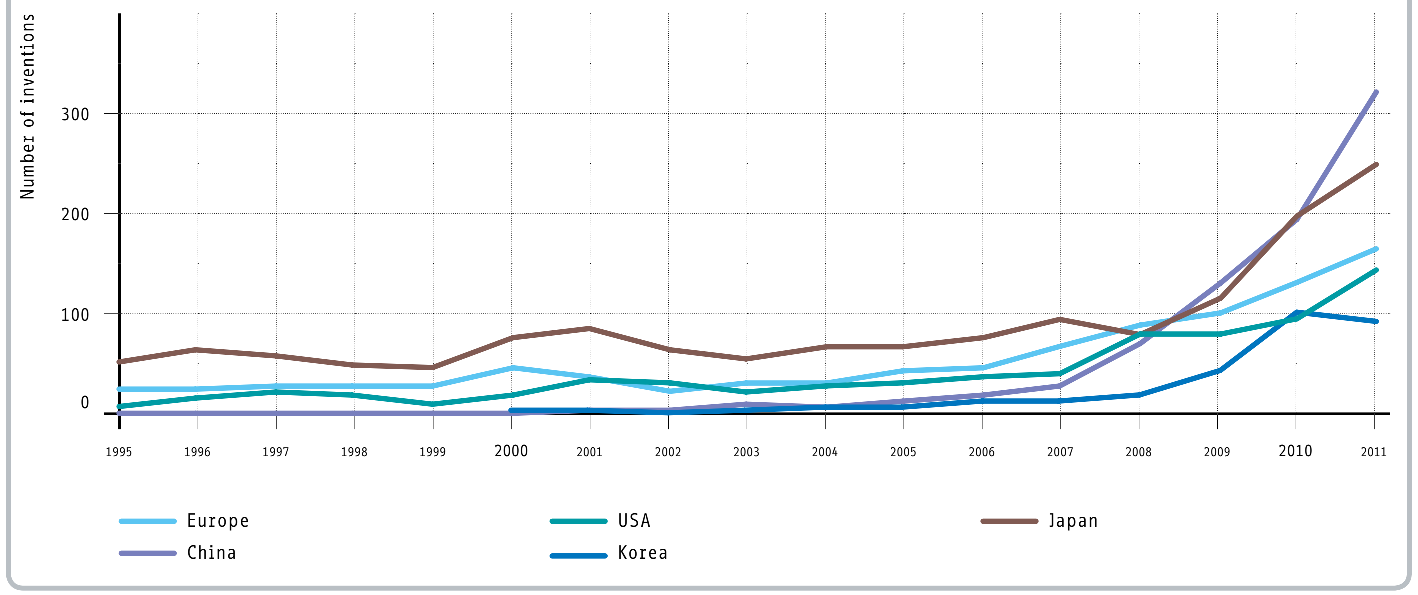
C Inventions in clean energy technologies (Y02E) in the major innovation centres 1995–2011



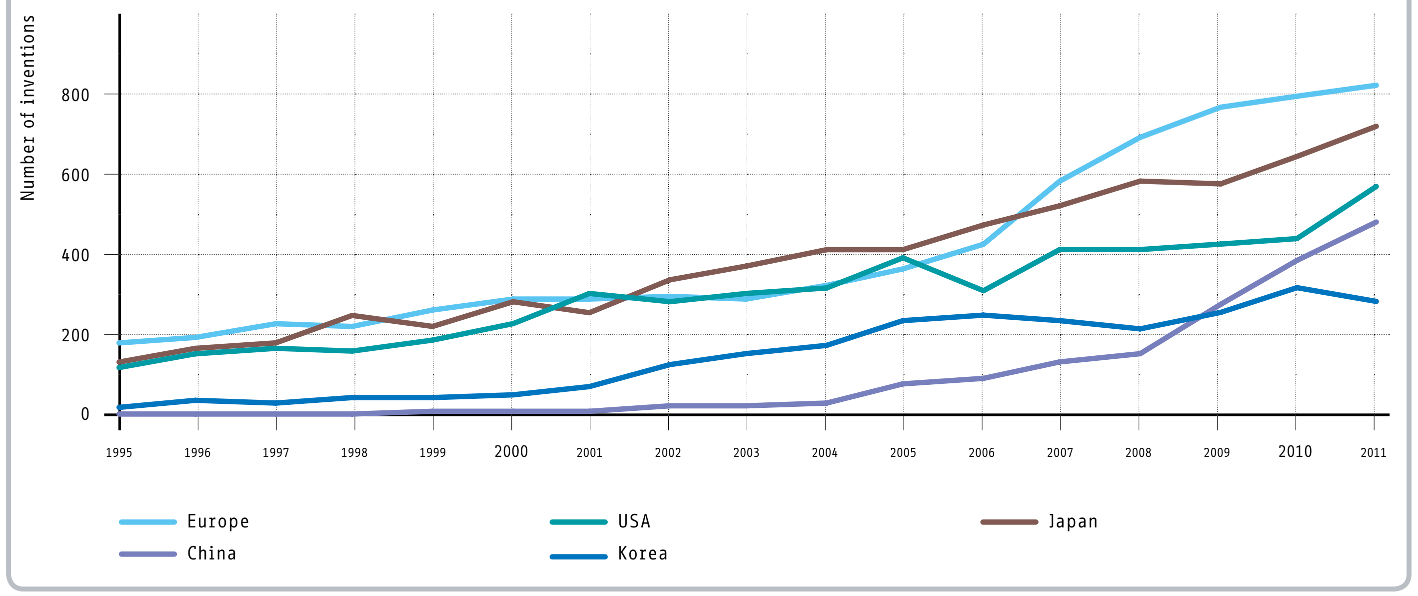
D Inventions in CCMTs related to transportation (Y02T) in the major innovation centres 1995–2011



E Inventions in smart grids (Y04S) in the major innovation centres 1995–2011

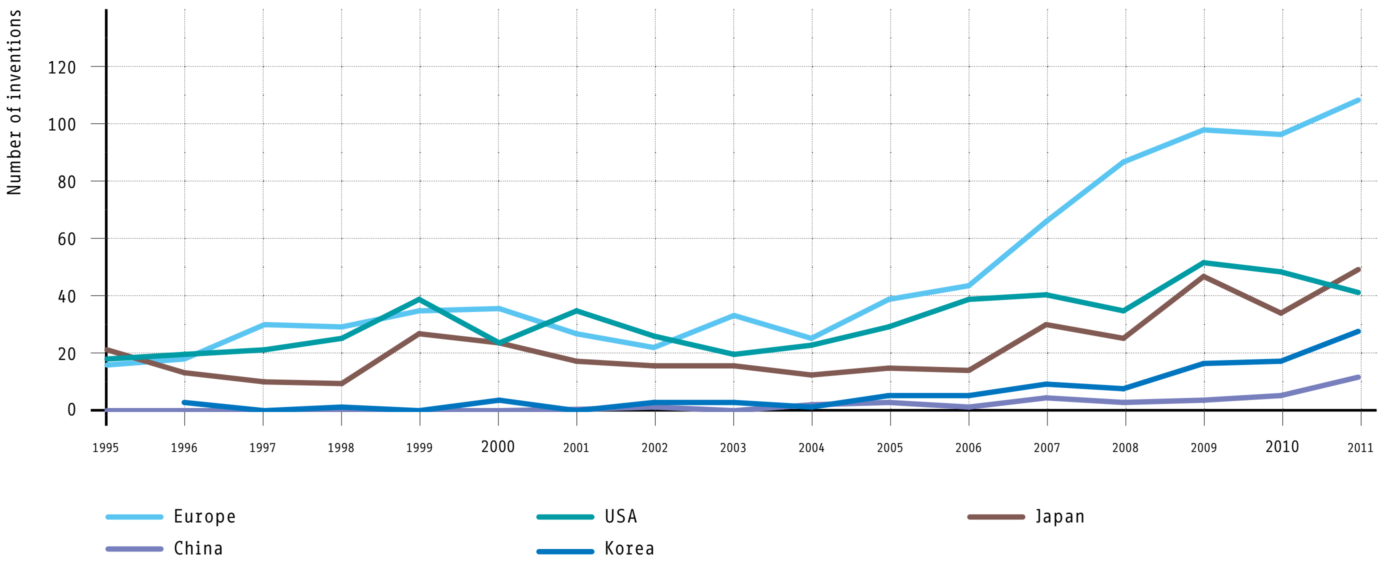


F High-value inventions in CCMTs related to buildings (Y02B) in the major innovation centres 1995–2011

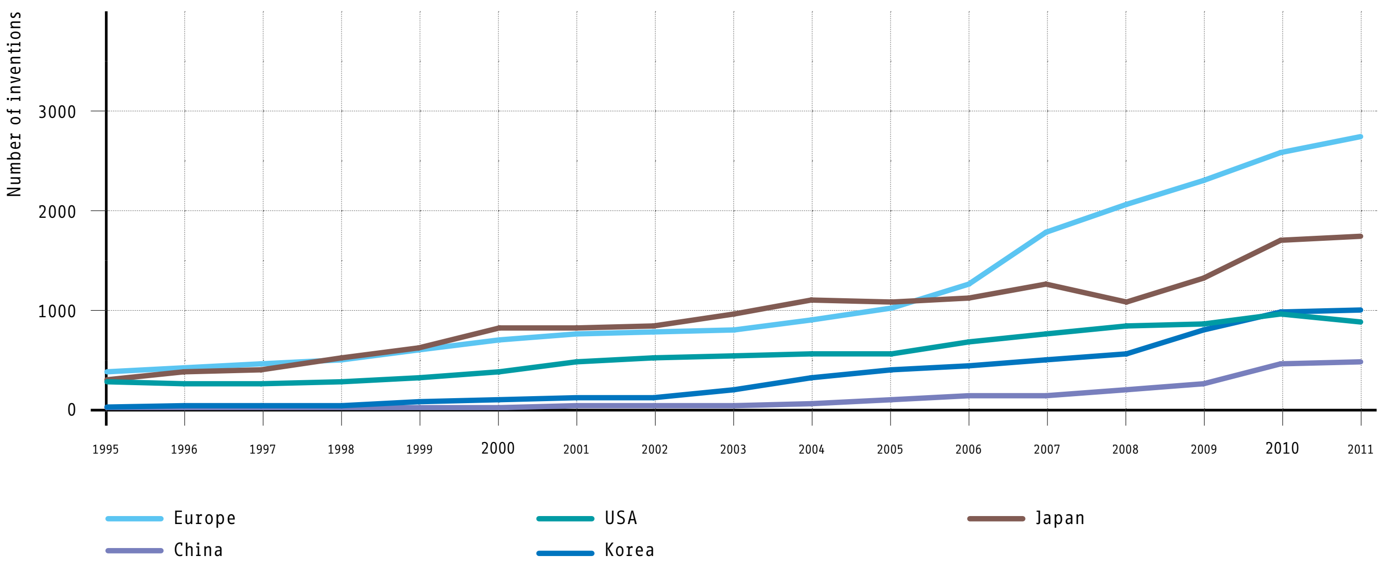


Annex 2 (contd.)

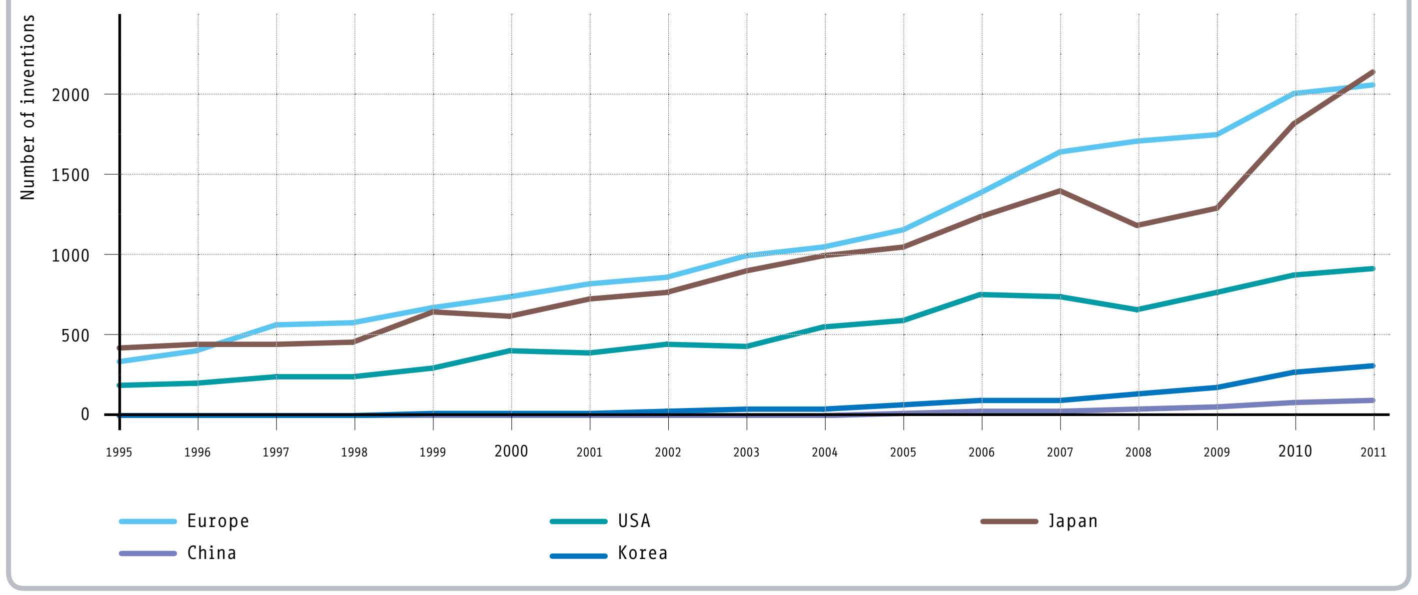
G High-value inventions in carbon capture and storage (Y02C) in the major innovation centres 1995-2011



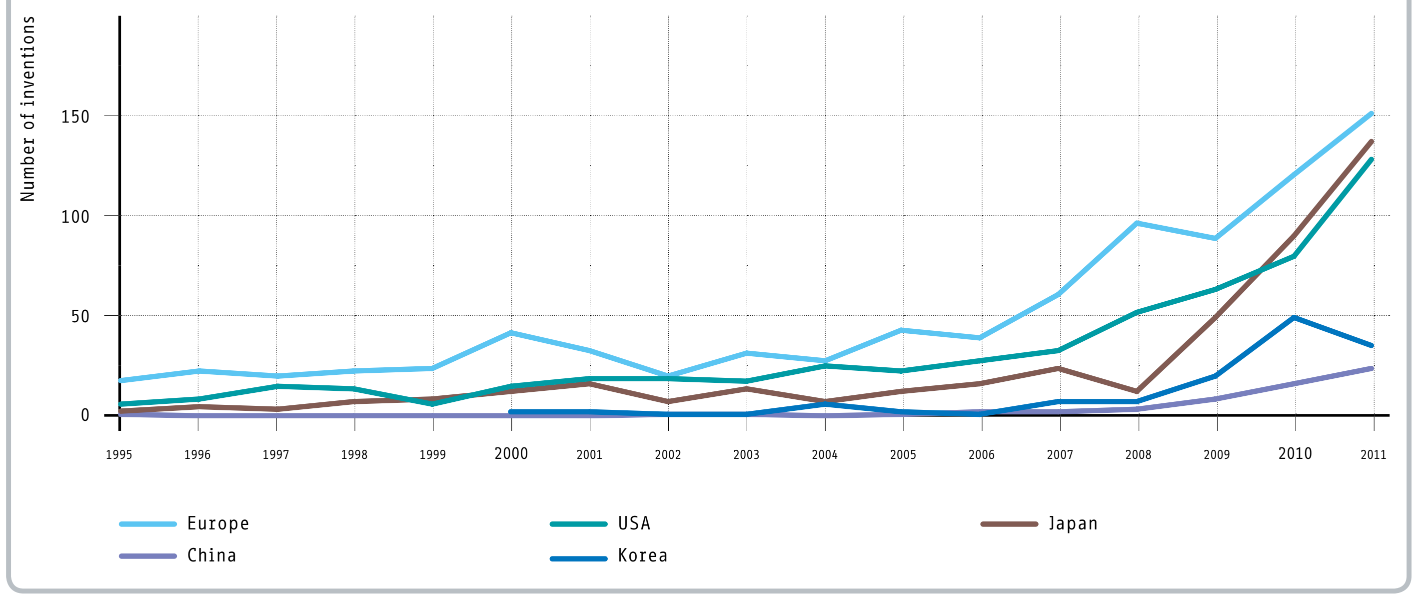
H High-value inventions in clean energy technologies (Y02E) in the major innovation centres 1995-2011



I High-value inventions in CCMTs related to transportation (Y02T) in the major innovation centres 1995-2011

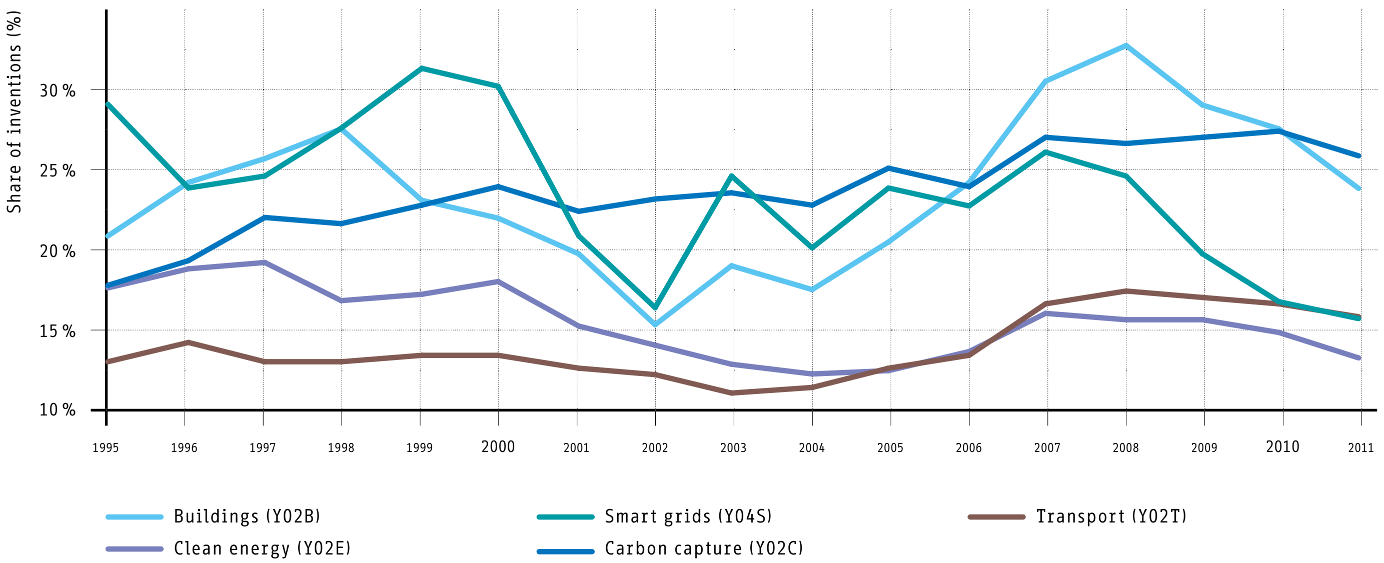


J High-value inventions in smart grids (Y04S) in the major innovation centres 1995-2011

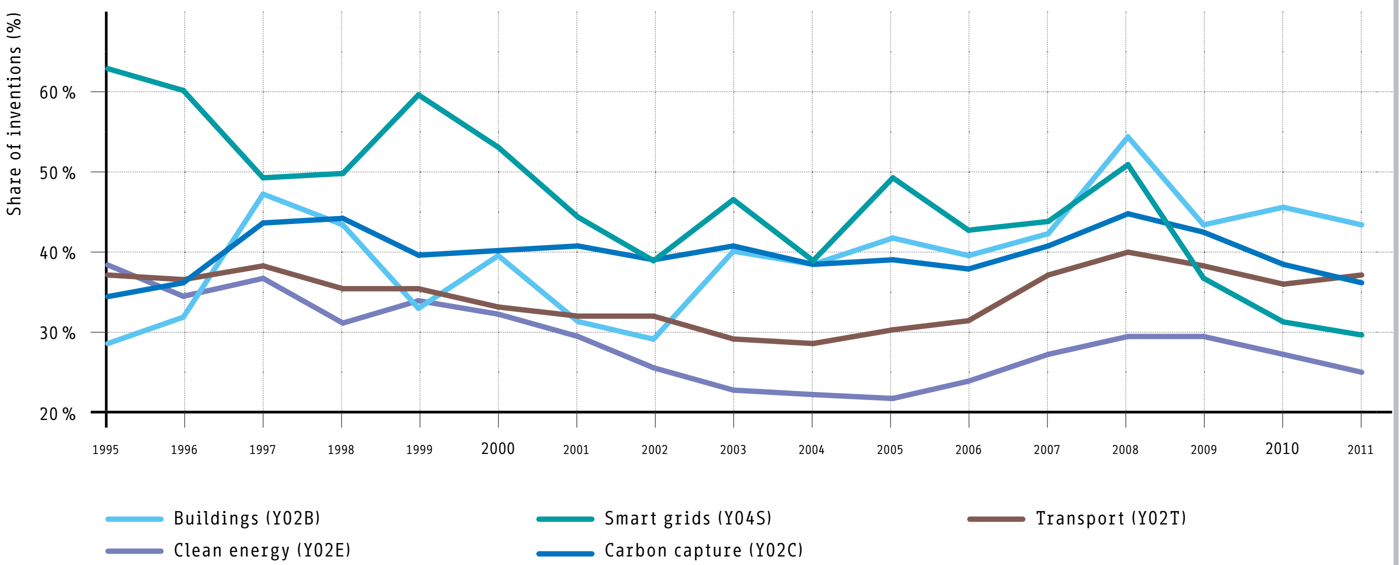


Annex 3

A European share of global CCMT inventions by technology 1995-2011

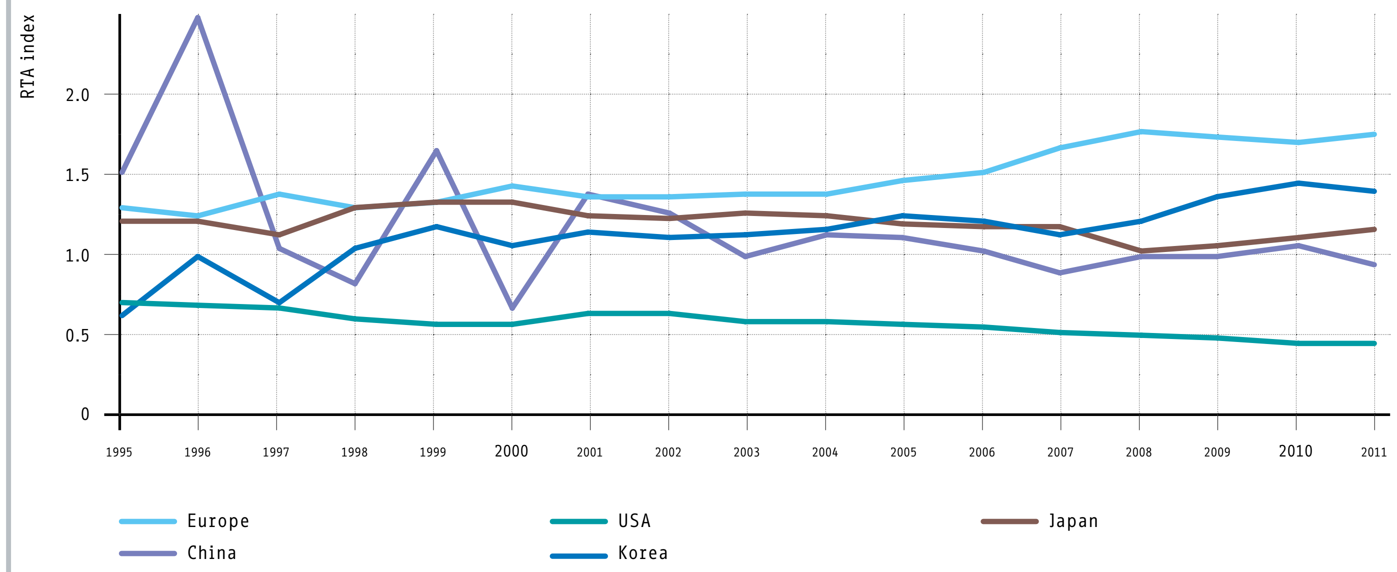


B European share of global high-value CCMT inventions 1995-2011



Annex 4

Relative technological advantage (RTA) in CCMTs of major innovation centres 1995-2011 – high-value inventions



Annex 5

A CCMT inventions co-developed by inventors from different countries/regions 1995-2011

inventor country	Africa	Canada	China	Europe	India	Japan	Korea	Oce-ania	Latin Ame-rica	Rest of Asia	Russia	USA	Total
Africa		2	2	41	1	3	7	0	1	7	1	9	74
Canada	2		17	179	9	20	83	4	4	23	14	385	740
China	2	17		181	15	115	173	7	5	343	4	319	1181
Europe	41	179	181		160	301	115	54	132	170	228	1926	3487
India	1	9	15	160		11	90	8	2	19	2	385	702
Japan	3	20	115	301	11		291	8	6	78	14	304	1151
Korea	7	83	173	115	90	291		6	3	103	193	306	1370
Oceania	0	4	7	54	8	8	6		1	11	0	40	139
Latin America	1	4	5	132	2	6	3	1		3	1	54	212
Rest of Asia	7	23	343	170	19	78	103	11	3		32	401	1190
Russia	1	14	4	228	2	14	193	0	1	32		67	556
USA	9	385	319	1926	385	304	306	40	54	401	67		4196

B CCMT inventions co-developed by inventors from different European countries 1995-2011

Inventor country	Austria	Swit-zerland	Ger-many	Den-mark	Spain	France	United King-dom	Italy	Nether-lands	Rest of Europe	Sweden	Total
Austria		31	293	4	4	3	8	10	3	19	5	380
Switzerland	31		335	3	16	69	14	30	3	55	19	575
Germany	293	335		63	71	323	168	96	285	338	52	2024
Denmark	4	3	63		12	10	27	2	7	19	23	170
Spain	4	16	71	12		50	27	12	21	35	2	250
France	3	69	323	10	50		79	62	26	178	13	813
United Kingdom	8	14	168	27	27	79		27	35	109	11	505
Italy	10	30	96	2	12	62	27		8	60	15	322
Netherlands	3	3	285	7	21	26	35	8		56	14	458
Rest of Europe	19	55	338	19	35	178	109	60	56		52	921
Sweden	5	19	52	23	2	13	11	15	14	52		206

Annex 6

Top 5 European applicants – CCMTs related to buildings (Y02B) 1995-2011

Applicant	Country	Inventions
Philips Electronics	Netherlands	920
Siemens	Germany	543
Telefonaktiebolaget L.M. Ericsson (Publ)	Sweden	523
Robert Bosch	Germany	427
BSH (Bosch und Siemens Hausgeräte)	Germany	390

Top 5 European applicants – CCMTs related to transportation (Y02T) 1995-2011

Applicant	Country	Inventions
Robert Bosch	Germany	4699
Siemens	Germany	1816
Renault	France	1613
Peugeot Citroën Automobiles	France	1331
Snecma (Société nationale d'études et de constructions de moteurs d'aviation)	France	1211

Top 5 European applicants – carbon capture and storage (Y02C) 1995-2011

Applicant	Country	Inventions
Air Liquide	France	283
IFPEN (IFP Energies nouvelles)	France	129
Alstom Technology	Switzerland	94
Siemens	Germany	93
BASF (Badische Anilin & Soda Fabrik)	Germany	90

Top 5 European applicants – smart grids (Y04S) 1995-2011

Applicant	Country	Inventions
Siemens	Germany	359
ABB Research	Switzerland	102
ABB (Asea Brown Boveri)	Sweden	73
ABB Technology (Asea Brown Boveri Technology)	Switzerland	73
Robert Bosch	Germany	59

Top 5 European applicants – clean energy technologies (Y02E) 1995-2011

Applicant	Country	Inventions
Siemens	Germany	2444
Robert Bosch	Germany	940
CEA (Commissariat à l'énergie atomique)	France	922
Vestas	Denmark	846
Fraunhofer	Germany	626

Top 5 worldwide applicants – CCMTs related to buildings (Y02B) 1995-2011

Applicant	Country	Inventions
Samsung Electronics Company	Korea	1833
Qualcomm	USA	1478
Panasonic Corporation	Japan	1469
LG Electronics	Korea	1169
Philips Electronics	Netherlands	1077

Top 5 worldwide applicants – CCMTs related to transportation (Y02T) 1995-2011

Applicant	Country	Inventions
Toyota Motor Corporation	Japan	8706
Robert Bosch	Germany	4842
Honda Motor Company	Japan	3215
Nissan Motor Company	Japan	2655
GE (General Electric Company)	USA	2135

Top 5 worldwide applicants – carbon capture and storage (Y02C) 1995-2011

Applicant	Country	Inventions
Air Liquide	France	330
Mitsubishi Heavy Industries	Japan	184
Alstom Technology	Switzerland	155
Praxair Technology	USA	137
IFPEN (IFP Energies nouvelles)	France	129

Top 5 worldwide applicants – smart grids (Y04S) 1995-2011

Applicant	Country	Inventions
Siemens	Germany	383
GE (General Electric Company)	USA	278
Toyota Motor Corporation	Japan	162
Panasonic Corporation	Japan	155
Toshiba Corporation	Japan	136

Top 5 worldwide applicants – clean energy technologies (Y02E) 1995-2011

Applicant	Country	Inventions
Toyota Motor Corporation	Japan	2753
Samsung SDI Company	Korea	2565
Siemens	Germany	2512
Panasonic Corporation	Japan	2456
GE (General Electric Company)	USA	2389

Annex 7

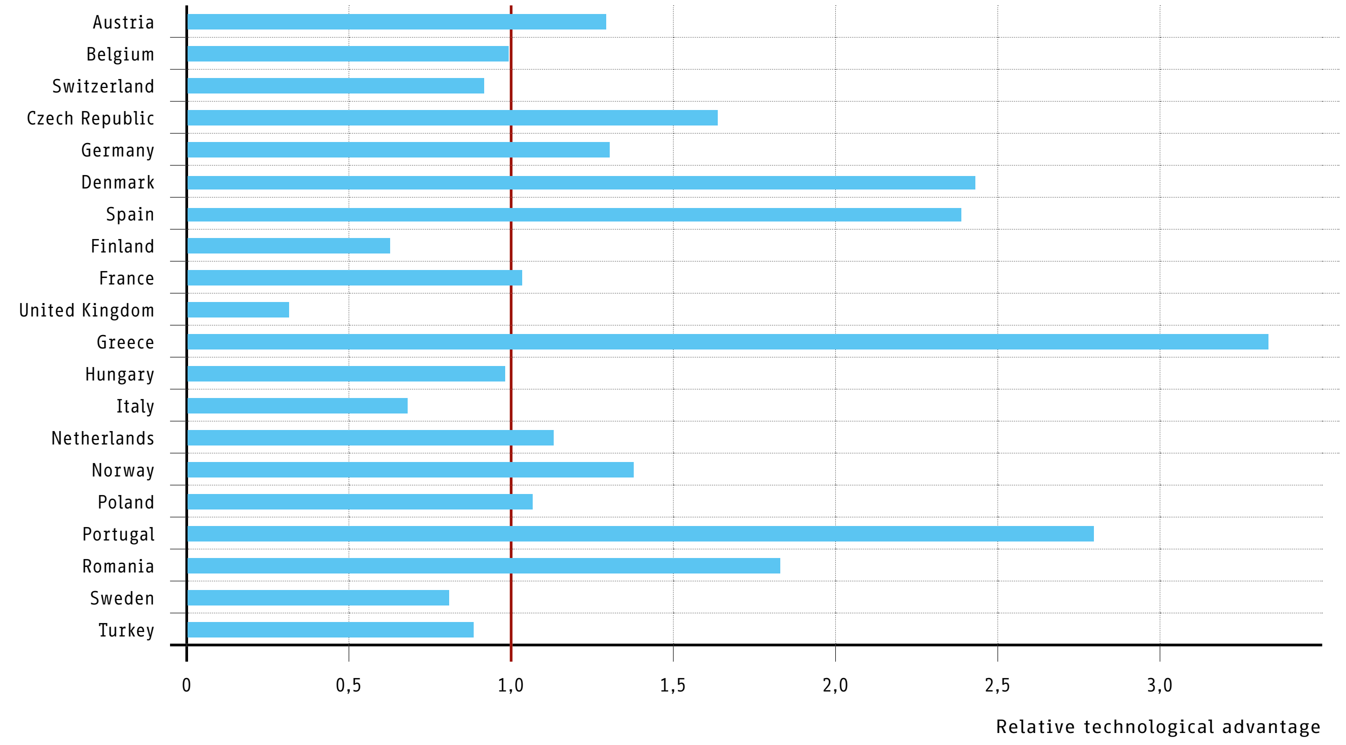
European CCMT inventions by country 1995-2011

Country		1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	SUM
Albania	AL	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	2
Austria	AT	29	39	43	48	59	61	72	50	75	86	96	127	139	158	218	227	209	1734
Belgium	BE	13	17	21	27	28	34	40	35	37	42	44	41	75	60	80	87	71	752
Bulgaria	BG	2	4	12	1	5	2	7	5	7	7	17	20	11	16	12	3	18	149
Switzerland	CH	49	59	59	51	42	47	57	57	50	61	75	67	90	129	171	165	191	1418
Cyprus	CY	0	0	0	2	0	0	0	0	1	1	3	2	1	1	0	0	1	10
Czech Republic	CZ	22	20	18	17	14	18	22	13	19	30	30	28	53	39	35	42	51	468
Germany	DE	953	1097	1233	1317	1540	1776	1754	1804	1804	1896	2094	2403	2995	3569	3726	4232	4382	38575
Denmark	DK	12	12	18	25	18	26	28	31	39	37	55	63	111	130	127	192	252	1175
Estonia	EE	2	1	0	0	0	0	0	0	2	3	2	0	10	1	3	6	2	32
Spain	ES	30	37	35	40	62	57	65	60	78	101	143	173	232	266	324	314	314	2328
Finland	FI	42	26	22	27	33	19	40	45	39	50	59	54	64	113	90	136	134	992
France	FR	232	259	294	326	364	405	423	476	599	686	776	891	1114	1229	1290	1403	1578	12345
United Kingdom	GB	104	93	107	105	123	116	139	166	198	169	229	258	373	401	412	483	498	3972
Greece	GR	13	14	15	10	12	14	17	8	27	19	19	51	55	60	60	72	74	536
Croatia	HR	2	5	4	4	4	11	9	7	5	14	6	9	6	8	9	14	15	131
Hungary	HU	21	16	25	10	18	8	9	13	12	11	11	20	34	33	36	48	34	356
Ireland	IE	1	2	3	4	5	5	2	3	2	5	7	12	14	27	16	15	16	137
Iceland	IS	5	0	0	2	0	1	1	0	2	0	0	1	1	0	0	1	1	14
Italy	IT	57	55	66	49	65	98	111	133	155	147	150	212	296	398	552	509	551	3603
Liechtenstein	LI	0	0	0	1	1	1	1	3	0	1	1	1	1	1	2	2	1	16
Lithuania	LT	3	3	3	7	1	5	4	8	3	2	5	2	2	11	9	10	4	79
Luxembourg	LU	2	2	2	2	2	6	4	4	3	5	7	7	4	6	7	8	17	85
Latvia	LV	10	18	4	5	2	4	1	4	2	3	2	8	7	10	7	5	5	97
Monaco	MC	0	1	0	0	0	0	0	0	0	1	0	0	0	1	4	1	2	9
Former Yugoslav Republic of Macedonia	MK	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0	0	3
Malta	MT	0	0	0	1	0	0	0	1	0	0	1	0	0	2	0	1	0	5
Netherlands	NL	41	47	64	83	71	91	67	84	62	68	98	112	132	178	194	174	183	1745
Norway	NO	10	10	18	22	18	27	24	24	32	31	38	50	68	65	82	68	71	656
Poland	PL	17	24	16	28	21	29	26	32	34	35	36	39	62	81	119	128	174	898
Portugal	PT	4	4	4	6	7	3	7	6	7	5	16	20	25	34	30	30	17	220
Romania	RO	9	14	11	17	14	15	16	24	12	18	26	25	22	38	45	69	107	481
Serbia	RS	0	0	0	0	0	0	0	1	1	3	7	11	15	12	9	12	9	79
Sweden	SE	75	104	112	90	114	102	102	75	87	104	117	147	207	224	235	254	221	2369
Slovenia	SI	2	8	3	3	4	4	6	4	9	4	7	6	9	8	11	19	7	112
Slovakia	SK	4	6	9	3	4	9	10	8	5	7	7	16	14	6	6	10	18	140
San Marino	SM	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	3
Turkey	TR	3	0	1	5	2	2	3	0	5	6	13	13	26	28	39	30	37	212

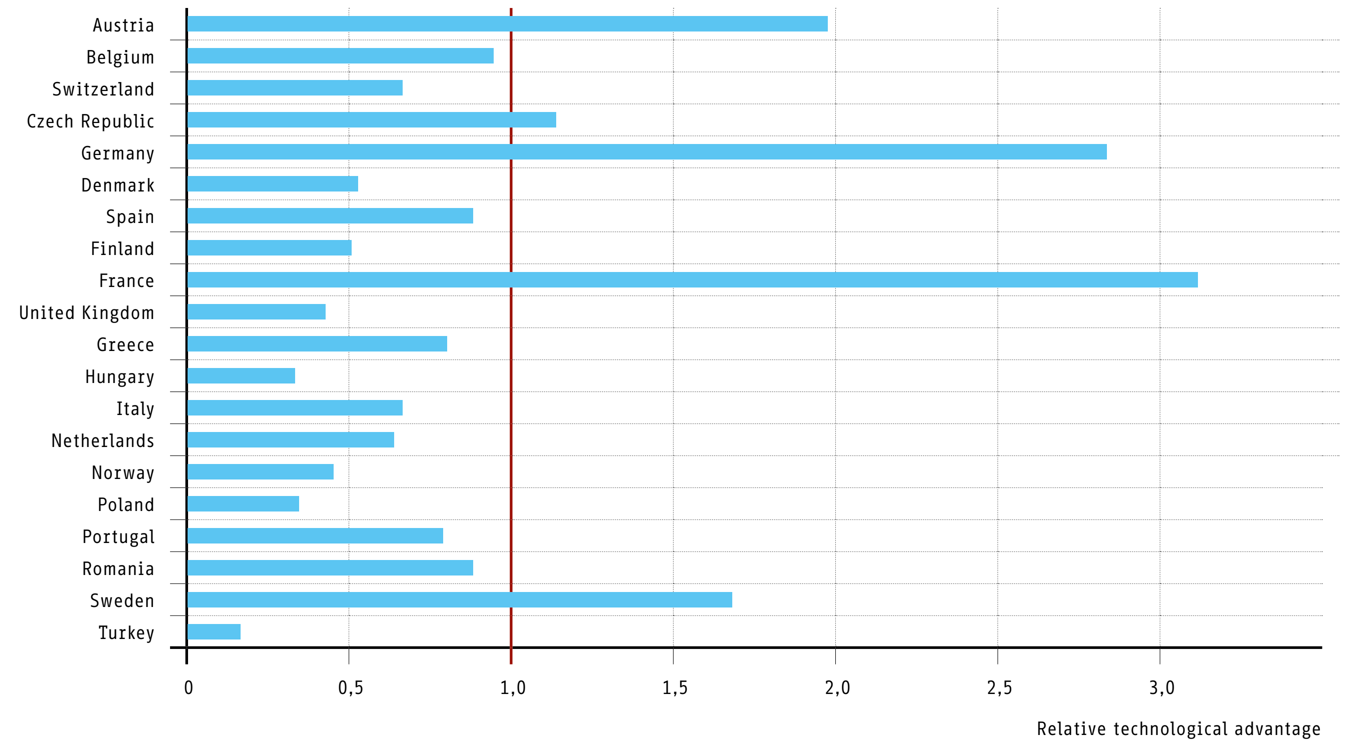
Annexes

Annex 8

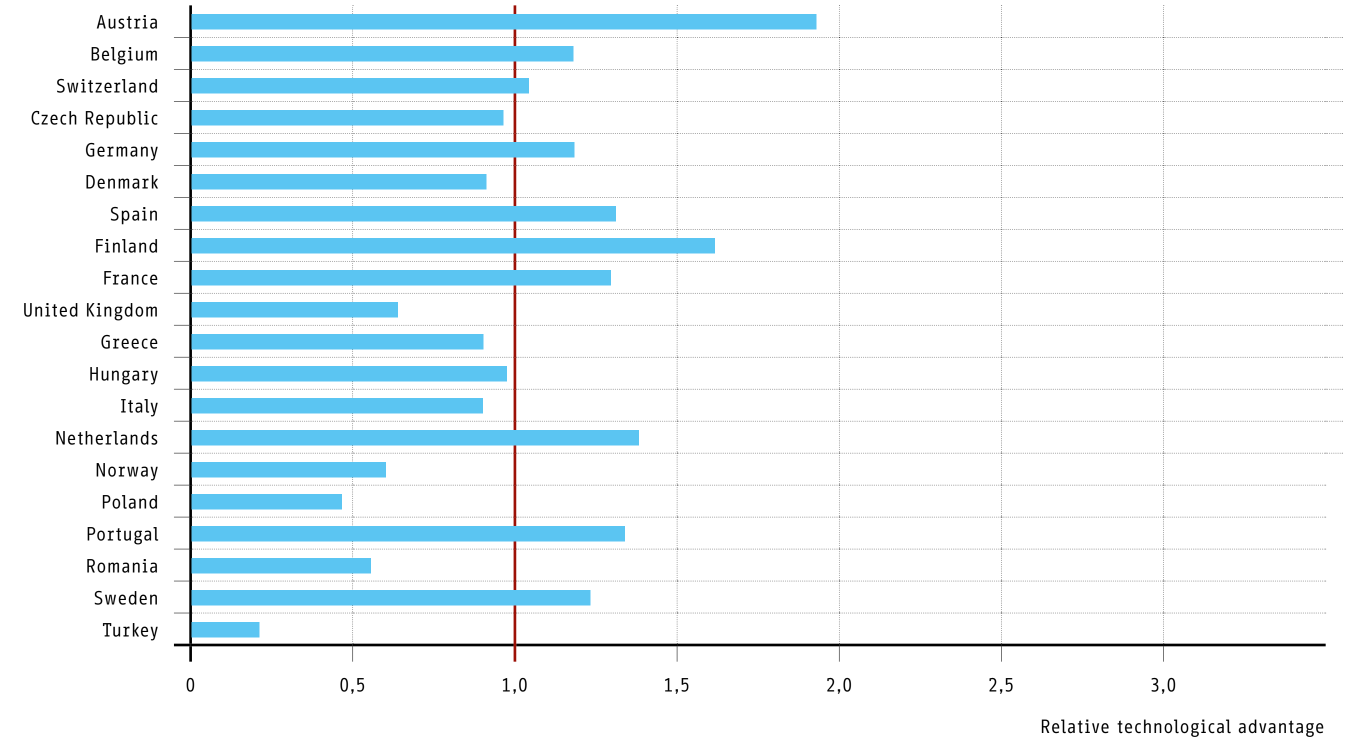
A Relative technological advantage (RTA) in clean energy technologies (Y02E) by European country 1995–2011



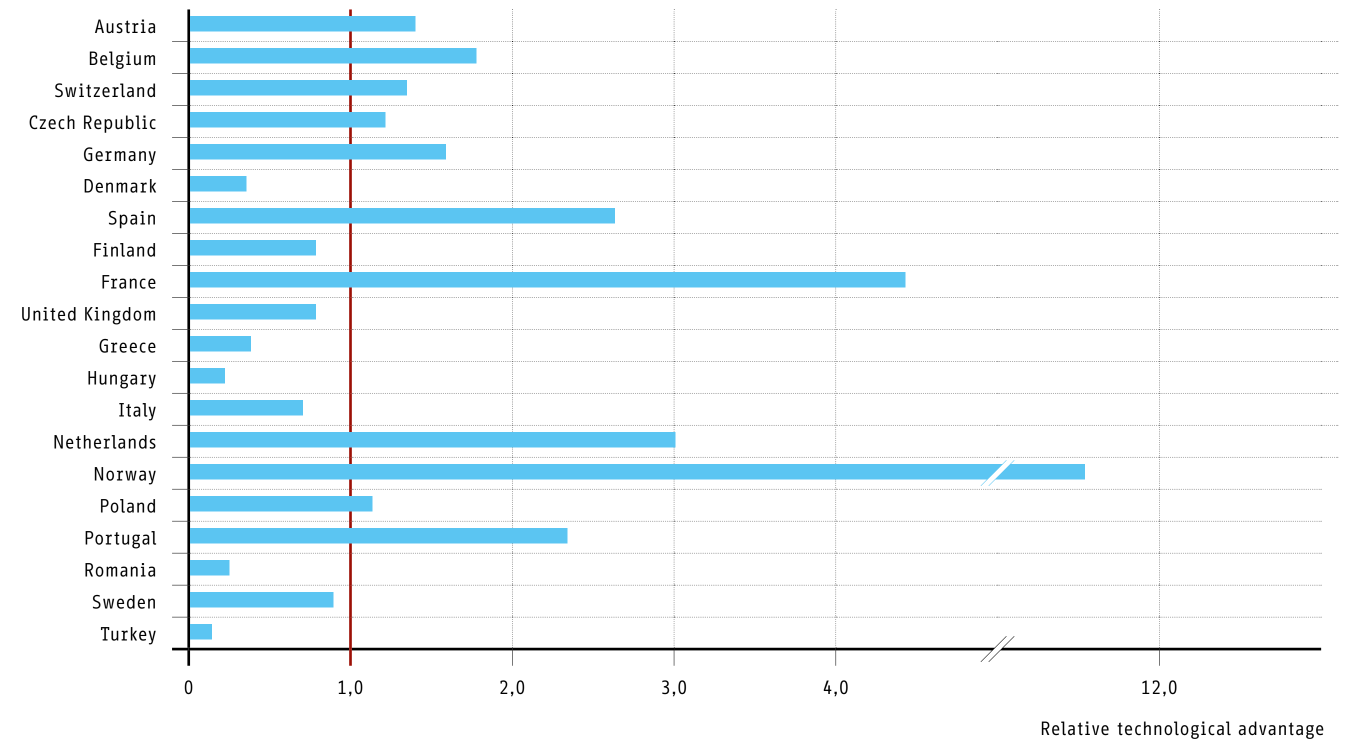
B Relative technological advantage (RTA) in CCMTs related to transportation (Y02T) by European country 1995–2011



C Relative technological advantage (RTA) in CCMTs related to buildings (Y02B) by European country 1995–2011

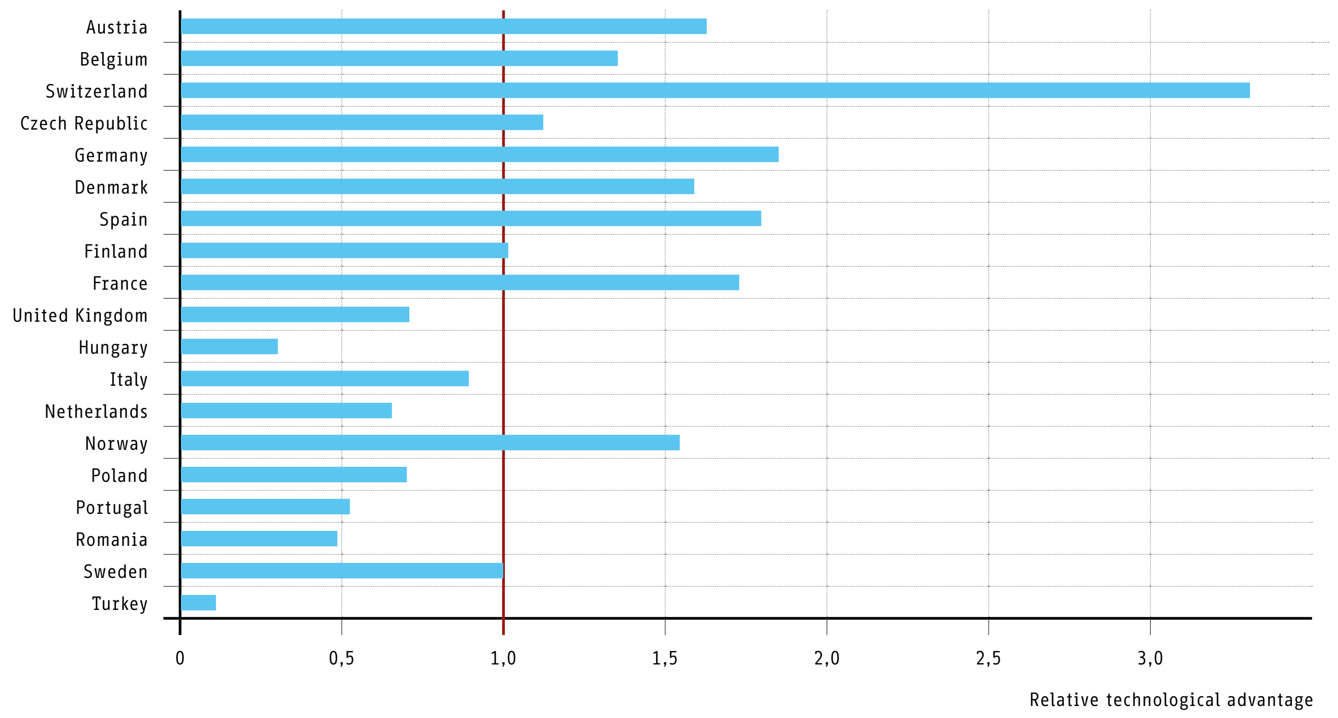


D Relative technological advantage (RTA) in carbon capture and storage (Y02C) by European country 1995–2011



Annex 8 (contd.)

E Relative technological advantage (RTA) in smart grids (Y04S) by European country 1995-2011



Annexes

Annex 9

Top 25 target countries in patent applications worldwide 1995–2011

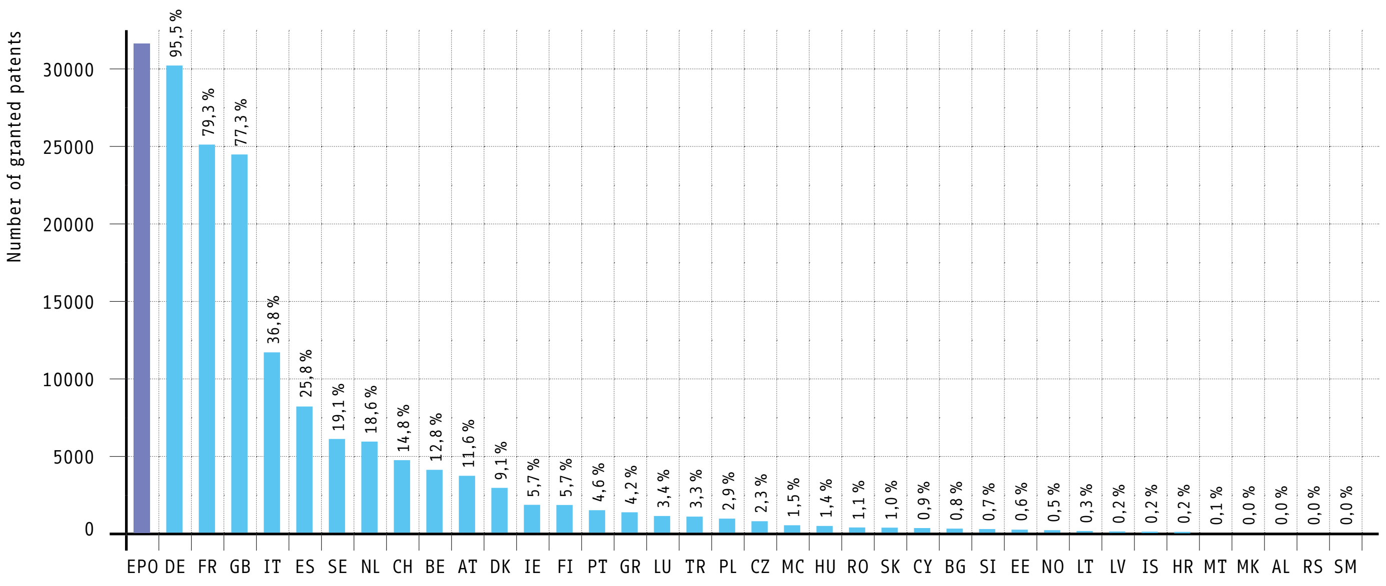
Country		1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	SUM
Europe[1]	EPC	7903	8354	9666	10156	12006	13706	14834	15624	15822	15489	16652	18202	20802	23478	23832	26037	27528	280091
Japan	JP	8772	9073	10198	11237	11869	13330	14356	15001	16517	17987	18448	19259	19474	20851	21453	23390	25109	276324
USA	US	3898	4044	4605	4839	5268	6403	8596	9351	10172	12283	14509	15336	16999	19295	20381	23904	25853	205736
China	CN	605	752	969	1151	1248	1596	2041	2932	3893	5164	6542	8555	10165	12687	15107	20282	25030	118719
Germany	DE	3341	3647	4077	4144	4786	5516	5685	5710	5478	4596	4766	4948	5443	5713	5321	5853	6342	85366
Korea	KR	456	619	558	625	1119	1426	1797	2384	3219	3136	4351	5701	6448	7985	9383	10879	11904	71990
Canada	CA	644	675	778	911	1161	1320	1433	1636	1702	1805	1861	2003	2289	2321	2423	2659	2590	28211
Australia	AU	949	990	1208	1409	1663	2107	2453	1577	3437	795	827	909	1159	1357	1579	1834	1723	25976
France	FR	351	399	466	538	560	662	694	747	930	1034	1166	1254	1485	1633	1751	1874	2062	17606
Taiwan	TW	177	139	111	275	348	437	574	635	836	859	847	944	1694	1946	2271	2546	2917	17556
Russia	RU	420	395	378	391	458	546	570	591	719	744	843	1082	1278	1440	1534	1533	1244	14166
Austria	AT	381	365	421	443	711	920	989	1097	1105	1124	1153	1093	1151	1164	709	362	207	13395
Spain	ES	409	366	436	479	571	618	576	708	665	731	736	852	902	1042	1071	899	662	11723
UK	GB	380	289	376	360	461	407	522	599	604	566	624	692	928	1070	1038	1106	1158	11180
Brazil	BR	167	204	261	336	430	422	465	469	496	600	660	820	1096	684	286	266	286	7948
Denmark	DK	179	148	173	158	212	233	222	295	267	282	276	318	331	433	432	349	427	4735
Mexico	MX	28	77	152	60	14	75	254	281	283	299	303	262	422	352	505	504	580	4451
Italy	IT	93	98	126	99	103	137	159	166	208	144	174	226	266	324	507	480	487	3797
Sweden	SE	154	176	209	147	196	182	193	156	142	164	173	196	223	264	272	285	289	3421
Norway	NO	84	89	94	136	127	171	157	161	182	180	193	201	301	248	222	136	95	2777
Netherlands	NL	70	83	99	119	117	127	106	134	116	85	117	152	131	177	220	195	220	2268
Israel	IL	48	45	53	58	60	46	51	51	109	90	93	195	215	251	259	317	326	2267
New Zealand	NZ	58	58	55	78	69	65	95	123	90	105	117	169	155	173	243	214	150	2017
Hong Kong	HK	20	25	33	184	70	92	114	114	101	137	158	182	153	180	169	143	136	2011
Poland	PL	82	80	82	120	119	114	154	197	174	68	62	57	72	118	157	158	183	1997
South Africa	ZA	77	92	78	115	38	61	108	118	119	147	163	162	201	212	156	32	14	1893

[1] Patent applications at the EPO and national IP offices of the EPC contracting and extension states.

Annexes

Annex 10

Market coverage of CCMT patents granted by the EPO 1995–2011



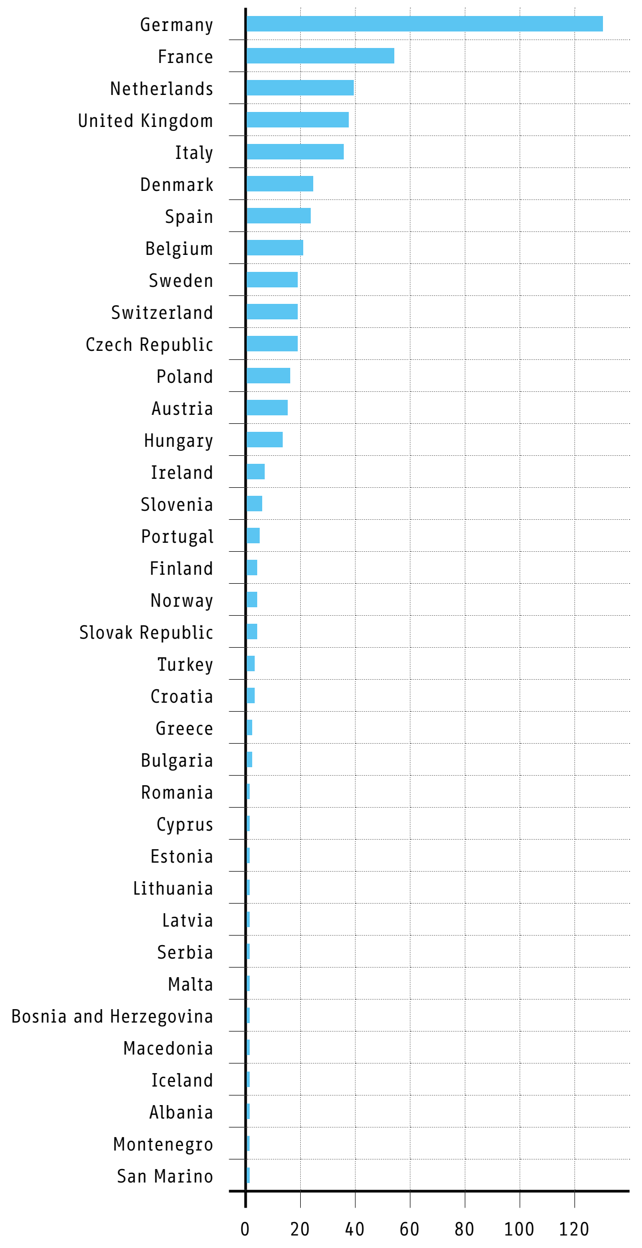
Annex 11

Origins of European patent applications (EPO and national patent offices) in CCMT by country 1995-2011

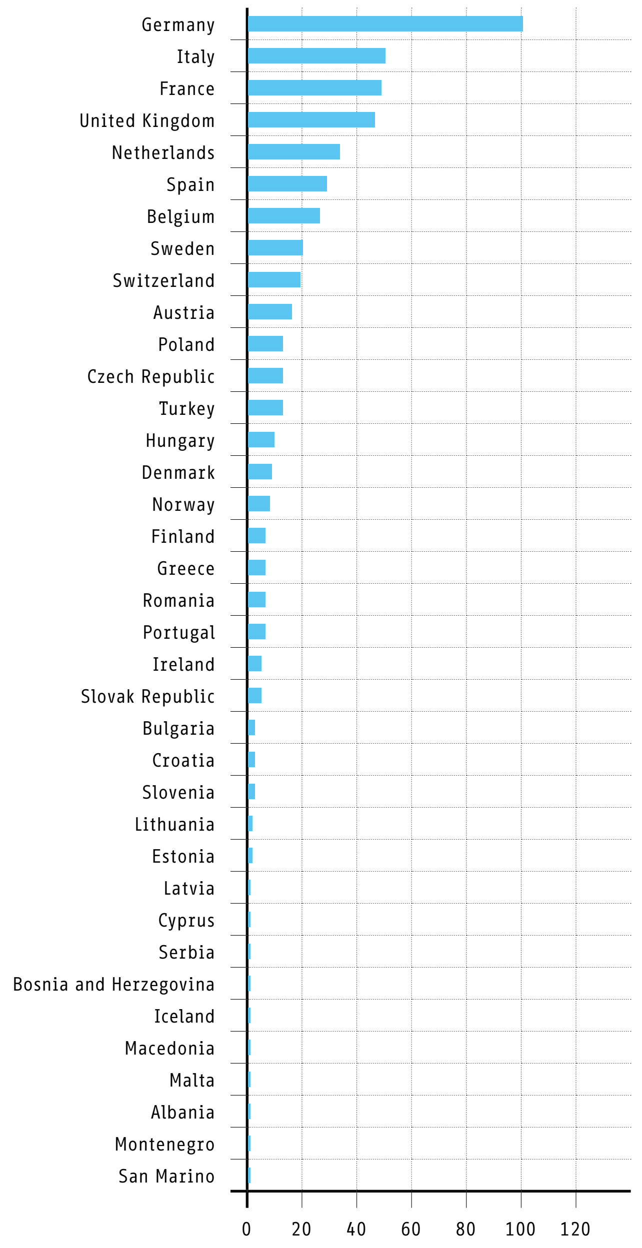
Country		1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	SUM
Germany	DE	2053	2278	2651	3041	3571	4215	4685	4983	4778	4726	4869	5469	6497	7453	7564	8176	8635	85643
Japan	JP	1183	1463	1800	1856	2114	2630	2770	2703	2524	2540	2534	2498	2698	2840	2484	2941	3494	41073
USA	US	1670	1484	1572	1634	1808	2102	2284	2340	2511	2307	2505	2685	2817	3068	2853	3186	3248	40075
France	FR	617	654	900	888	1108	1159	1150	1261	1450	1665	1818	2051	2282	2653	2713	2828	2935	28129
UK	GB	488	436	435	431	642	639	744	786	808	709	761	895	1113	1240	1319	1335	1429	14207
Italy	IT	225	241	226	250	255	302	367	506	526	485	457	510	633	736	867	914	868	8365
Sweden	SE	294	284	429	351	426	394	395	369	305	374	379	386	411	509	512	556	632	7006
Netherlands	NL	180	183	227	302	355	359	387	383	369	260	295	292	450	506	576	485	492	6101
Denmark	DK	107	86	104	85	183	154	182	200	278	240	266	341	408	565	515	631	618	4961
Korea	KR	52	41	99	48	121	78	127	178	199	261	334	503	427	427	426	638	781	4737
Austria	AT	114	115	126	173	174	178	278	225	243	215	279	291	366	425	467	539	501	4707
Switzerland	CH	201	239	233	186	169	218	220	239	266	194	244	261	270	316	449	433	437	4575
Spain	ES	65	53	73	69	111	146	149	151	146	177	242	381	420	510	597	621	598	4507
Canada	CA	77	98	120	181	193	200	200	194	262	239	278	189	235	166	156	199	194	3180
Finland	FI	145	156	99	95	99	135	102	151	183	135	159	170	141	212	267	283	324	2857
Norway	NO	49	37	78	52	89	87	91	99	128	112	134	139	175	194	214	226	176	2078
Belgium	BE	34	39	76	68	74	79	111	149	84	99	128	76	160	164	177	195	198	1913
China	CN	3	3	15	16	6	19	23	42	47	57	77	127	133	140	183	369	363	1622
Taiwan	TW	8	23	19	26	21	22	19	65	57	64	123	72	108	124	138	160	150	1194
Australia	AU	41	75	15	53	72	154	56	90	50	75	73	80	56	70	77	72	80	1187
Poland	PL	21	25	25	32	24	33	41	51	38	47	51	51	66	105	149	157	204	1117
Israel	IL	29	42	24	38	48	49	33	41	60	37	52	44	78	62	102	92	101	928
Greece	GR	23	28	21	26	27	19	23	18	33	31	19	69	86	80	72	90	90	752
Czech Republic	CZ	30	27	32	21	23	27	31	17	27	46	46	44	74	71	61	53	71	698
Russia	RU	45	28	41	22	37	57	22	23	46	38	39	32	33	35	32	26	29	584

Annex 12

Main European exporters of CCMT goods to other European countries 1995–2013



Main European importers of CCMT goods from other European countries 1995–2013



Annex 13

Number of subsidiaries of CCMT companies between pairs of regions in 2012

Subsidiary country	Africa	Canada	China	Europe	India	Japan	Korea	Oceania	Latin America	Rest of Asia	Russia	USA	Total
Owner country													
Africa		0	1	30	2	0	0	3	5	6	1	6	54
Canada	18		27	542	12	112	30	56	196	112	13	1682	2800
China	11	17		142	11	22	3	17	68	190	21	61	563
Europe	1853	778	2150		722	771	358	878	3637	3124	1145	5142	20558
India	29	6	9	196		2	6	16	19	58	5	44	390
Japan	78	173	1248	2472	161		268	237	492	2067	137	2010	9343
Korea	17	18	146	235	21	18		18	57	105	32	175	842
Oceania	68	64	88	342	78	18	22		183	333	14	458	1668
Latin America	20	6	220	137	9	7	4	4		131	7	94	639
Rest of Asia	16	13	314	264	9	35	12	25	186		20	247	1141
Russia	0	1	0	19	1	0	0	0	4	0		1	26
USA	569	1318	1177	9382	377	545	299	694	3257	2142	183		19943
Total	2679	2394	5380	13761	1403	1530	1002	1948	8104	8268	1578	9920	

Number of subsidiaries of CCMT companies between pairs of European countries in 2012

Subsidiary country	Austria	Switzerland	Germany	Denmark	Spain	France	United Kingdom	Italy	Netherlands	Rest of Europe	Sweden	Total
Owner country												
Austria		24	170	8	22	33	56	18	5	231	9	576
Switzerland	76		410	30	62	164	224	107	61	385	50	1569
Germany	469	385		155	466	602	1122	422	357	2478	191	6647
Denmark	29	35	144		51	73	203	42	77	439	89	1182
Spain	5	7	110	5		152	101	86	11	348	7	832
France	98	185	653	75	396		1249	360	226	1605	109	4956
United Kingdom	29	26	252	28	58	138		51	78	284	43	987
Italy	32	71	211	12	128	234	324		146	586	29	1773
Netherlands	3	7	48	2	5	13	24	13		26	6	147
Rest of Europe	70	74	357	74	116	258	307	148	119		208	1731
Sweden	51	60	214	125	73	126	193	71	109	702		1724
Total	862	874	2569	514	1377	1793	3803	1318	1189	7084	741	22124

ABBREVIATIONS AND ACRONYMS

Abbreviations and Acronyms	
BEE	Biomass Energy Europe
CCMT	Climate change mitigation technologies
CETs	Clean energy technologies
CHP	Combined heat and power
COP	Conference of the Parties (of the United Nations Framework Convention on Climate Change)
CPC	Cooperative Patent Classification
CSP	Concentrated solar power
EPO	European Patent Office
EU	European Union
EU ETS	EU Emissions Trading System
FDI	Foreign direct investment
GDP	Gross domestic product
GHG	Greenhouse gases
GSHP	Ground source heat pumps
HS	Harmonised system
ICTSD	International Centre for Trade and Sustainable Development
IP	Intellectual property
IP5	Five largest intellectual property offices (EPO, JPO, KIPO, SIPO, USPTO)
IPC	International Patent Classification
IPCC	Intergovernmental Panel on Climate Change
IPR	Intellectual property right
JPO	Japan Patent Office
KIPO	Korean Intellectual Property Office
NPA	Nature Protection Areas
OECD	Organisation for Economic Co-operation and Development
PACE	Pollution Abatement Control Expenditures
PATSTAT	Worldwide Patent Statistical Database
PCT	Patent Cooperation Treaty
PV	Photovoltaic
R&D	Research and development
RD&D	Research, development and deployment
RE	Renewable energy
ROSPATENT	Russian Federal Service for Intellectual Property
RTA	Relative technological advantage
SHP	Small hydropower plants
SIPO	State Intellectual Property Office of the Peoples' Republic of China
SMEs	Small and medium-sized enterprises
TRIPS	Agreement on Trade-Related Aspects of Intellectual Property Rights
UNCTAD TRAINS	United Nations Conference on Trade and Development's Trade Analysis and Information System
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USPTO	United States Patent and Trademark Office
WIPO	World Intellectual Property Organization
WTO	World Trade Organization
Y02/Y04S	Dedicated tagging scheme and searchable database for CCMTs

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