Policy Contribution
Issue n˚16 | 2016

An approach to identify the sources of low-carbon growth for Europe

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The research underlying this report has been financially supported by the European Climate Foundation's Industrial Innovation for Competitiveness Initiative (i24c).

Extensive research assistance by Luca Nocciola, Michele Peruzzi, Fabio Matera, Domenico Favoino and Robert Kalcik is gratefully acknowledged.

Executive Summary

FOR MANY YEARS the European Union's growth model has been to find new markets for the products and services it is able to produce cheaper and better than most other countries. This model is under pressure. The number of under-exploited markets is shrinking, while new competitors emerge quickly, challenging the comparative advantage of the EU even in higher value added goods and services. To secure growth and jobs in Europe, it is likely to be necessary to move to a new growth model built on developing emerging sectors with high value added. But in which sectors can Europe grow, and what economic policies would work?

WE PROPOSE a general approach that can be used to prioritise policies based on quantitatively localising sectors and regions with measurable growth potential. Sectors can be identified based on recent and expected growth of their global markets and the technology dynamics. We assess the potential of countries to excel in these emerging sectors based on their current export specialisation in this sector. This revealed comparative advantage indicates whether a country is better able than others to compete in this particular field. But even if a country is not yet specialised in a certain sector it might develop a comparative advantage over time, especially if the sector is based on rapid innovation. We thus propose to identify whether countries are particularly specialised in innovating in the identified sector based on patent data. Finally, certain sectors have commonalities. Even if a country is currently not good at exporting and patenting in a certain sector, it might easily acquire this capability if it is strong in nearby sectors. So we propose to also investigate the strength of countries in sectors found to be close to the identified sector, as a proxy for whether the country might have the potential to develop a comparative advantage in the identified sector.

GIVEN GLOBAL DECARBONISATION CONCERNS, the wide array of low-carbon technologies offers significant growth potential. Some EU countries have already been able to develop a comparative advantage in wind turbines and electric vehicles, though the EU is less effective at exporting solar panels and batteries. Based on patenting activities we, however, see some potential – maybe not for entire countries but for some regions – to further specialise in all of these four low-carbon technologies.

A REGIONAL OVERVIEW is valuable because it can help in targeting public investment (eg in infrastructure, research and education) to enable development in the most promising sectors/regions.

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Introduction

The European Commission's call in 2014 for a European Industrial Renaissance[1] stressed that Europe urgently needs to lay the foundations for post-crisis growth and the modernisation of its industry. However, European policymakers are struggling to identify economic policies that can create new jobs and return their economies to a stable growth path.

The aim of this report is to examine how Europe can gain a competitive edge in new products and services with higher value added that can form the basis for future growth and jobs. In light of limited fiscal and political capital, the crucial issue is prioritisation in terms of technologies, regions and policies.

This report is organised as follows. In the first section we argue that in order to achieve long-term growth goals, policymakers should focus on those sectors that provide products and services characterised by growth potential and high value added, rather than those 'traditional' sectors where demand is often saturated and that face increasing competition from both incumbents and new players. In the second section we line out that especially after the Paris Agreement, in which 195 countries agreed to limit greenhouse gas emissions, low-carbon technologies represent a highly relevant area on which policymakers and investors might concentrate their attention. Hence we focus on four particular low-carbon technologies: electric vehicles, wind turbines, energy storage and photovoltaic generation.

These technologies are characterised by increasing exports and investment, making them appealing and promising areas in which additional investment in innovation could generate promising returns in the future.

In the third and fourth sections we show which European countries already have a comparative advantage in one or more of these four different technologies, and which might develop an advantage in the future, by building on their technological specialisation in related fields.

We then provide in the fifth section quantitative criteria to identify the regions within countries on which efforts would be concentrated, in order to take advantage of the geographical spillovers from existing industrial regional clusters.

In the concluding section, we summarise the four criteria we used to identify promising specialisation avenues and provide policy recommendations how to prioretise policies accordingly.

Setting the scene: from quantity to quality-based growth

Policymakers in the EU and elsewhere are concerned about jobs and growth. Growth is about generating higher value added[2]. There are essentially two strategies to increase the value added a country produces:

- **Quantity: Producing more of the same**. The problem with a quantity strategy is that margins for existing products tend to be squeezed for two reasons. First, there is **saturation**. When everybody owns a TV, the willingness to pay for a second TV, or even a better model,

1 See Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, *For a European Industrial Renaissance* (COM/2014/014 final).

2 To be clear, we write here about long-term growth prospects and not about short-term macroeconomic discussions on whether the slow recovery is an issue of secular stagnation (saving > investment), a liquidity trap or debt overhang. It might be related to Gordon (2012).

keeps reducing. Second there is **competition**. If a product is successful, more and more other producers will produce the same, increasing competition. An effective quantity strategy thus requires the constant opening up of new markets (either new consumers within the domestic market, or new export markets).

- **Quality: Producing new products and services with higher value added.** Disruptive new products and services can provide substantial margins for first movers. Moreover, agglomeration effects entail the possibility to extend the first-mover advantage in one technology to a whole ecosystem of related new products and services. The classic example of such virtuous agglomeration is Silicon Valley.

The EU was able to rely for a long time on a quantity-based growth strategy, in particular by supplying the emerging central and eastern European countries and China. However, growth in those countries is slowing and they no longer demand an ever-increasing volume of Europe's current export products and services. The emerging economies now export to the world many of the goods Europe was previously good at exporting. So even if Europe could hope for the emergence of other economies, such as Iran or in Africa, margins are falling because of increasing competition. China in particular managed to rapidly develop the complexity of its exports and to compete with developed economies in export markets for quite sophisticated goods.

Two observations illustrate this increasing competition in markets that were dominated by western countries two decades ago. First, there has been a notable convergence in the complexity of products exported by western and eastern countries. The Economic Complexity Indicator (ECI) developed by Harvard's Center for International Development[3] ranks how diversified and complex countries' export baskets are based on their diversity (how many different products each country can produce) and the ubiquity of those products (the number of countries able to make those products[4]). For almost all of the more than 100 ranked countries the indicator is between -2.5 and +2.5. In 2014, the ECI score for the United States was 1.36 and 1.10 for China. For EU countries[5] it ranges from 0.22 for Greece and 1.92 for Germany. The most striking observation is the rapid increase in the complexity of Chinese exports. While ranked below Bulgaria in 2000, China had surpassed Denmark and Belgium by 2014. Over the same period, the US and major EU economies gradually lost some of their advantage as new players – including from central and eastern Europe – started to export products that were previously only exported by the most-developed countries. This signals that incumbent exporters face increasing competitive pressure (see also Box 1).

Table 1: Economic complexity indicator

	USA	China	Germany	France	Spain	UK	Poland	Hungary
1995	2.05	0.21	2.65	1.94	1.40	2.05	0.80	0.99
2014	1.36	1.10	1.92	1.29	0.82	1.48	0.93	1.50
Change 1995-2014	-34%	424%	-28%	-34%	-41%	-28%	16%	52%

Source: CID.

3 http://atlas.cid.harvard.edu/rankings/.

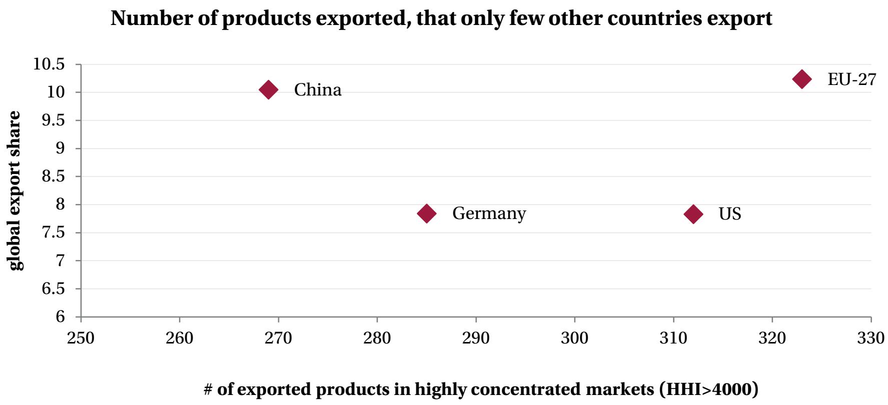
4 Consequently, the ECI is a relative indicator. That is, it might go down even if the country does not change its export basket, as soon as other countries start to also export some of those products.

5 The rankings do not cover Cyprus, Luxembourg and Malta.

Box 1: EU exports are in product markets that are under competitive pressure

To further illustrate the point highlighted by Table 1, we made an assessment for the products that are mainly produced in a limited number of countries. As a criterion we used the Herfindahl-Hirschman Index (HHI), which measures the concentration of suppliers in a market[6]. If a certain product category is only exported by a single country, it has an HHI of 10,000. If the product category has an equal share in the exports of 100 countries, the HHI for this product category is 100. A high HHI means that only a few countries export this product and the few exporters might have some market power, ie the ability to extract some extra margin by demanding a price that significantly exceeds the cost. For illustration, we chose an HHI threshold of 4000. If we count the number of product categories with an HHI above 4000 for all major economies, we find that the US exports many products that only a few countries export, while China – despite its significantly greater share of global exports – exports fewer products that are only exported from a limited number of countries. The EU's global export market share is almost a quarter larger than that of the US, but compared to the US, the EU only exports 11 more products that are only exported by a limited number of players. So while the US seems to strongly focus on quality exports, China's export strategy is focused on quantity, while EU is in between.

Figure 1: Number of high HHI product categories exported, selected economies



Source: Bruegel based on Comtrade.

Second, the transformation of China into an economy that can compete with incumbent exporters is impressively illustrated by the change in its export basket. While in 1990, electric machinery already made up 10 percent of German and 12 percent of US exports, it only accounted for 6 percent of Chinese exports. By 2015, electric machinery had become the backbone of Chinese exports, accounting for a quarter of the country's huge foreign sales. At the same time the US – after a surge around the year 2000 – dramatically shifted its export focus away from electric machinery to other products.

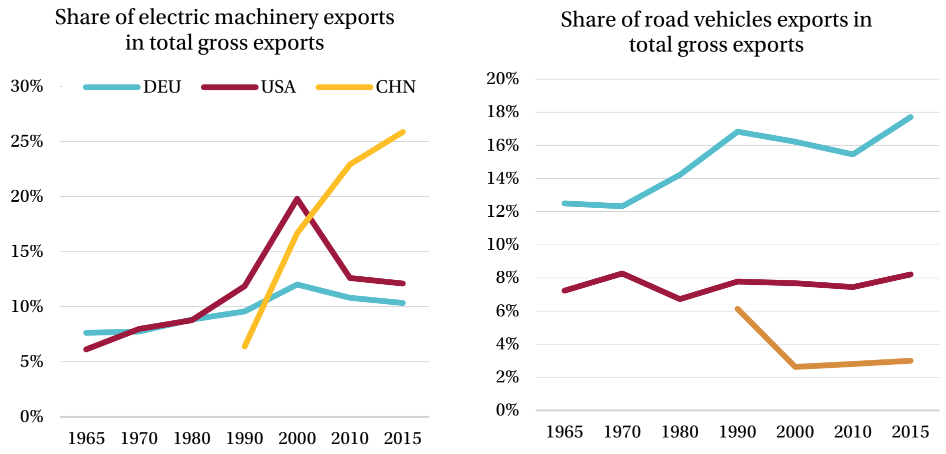
Europe's growth for a long time rested on finding new markets for its incumbent export industry. German car exports are a striking example of this development. The share of road vehicles in German gross exports grew from 12 percent in 1965 to 15 percent in 2010 and to 18 percent in 2015. German export-based industry is thus extremely vulnerable to just one single product. So far, China (and other emerging countries) remains a sleeping dragon. But if China[7] – which has developed a significant car industry for the massive domestic market

6 The HHI is the sum of the squared market share of all competitors.

7 In Annex 5 we provide a nice illustration of how China moved up the export value chain from bicycles, to motorcycles, to vehicles.

(25 million cars per year[8]) – manages to increase the share of cars in its export basket from the current 3 percent at the same pace as it did for electric machinery, the German economy would come under massive pressure.

Figure 2: Export specialisations of China, Germany and the US



Source: Bruegel based on UN Comtrade. Note: trade categories for road vehicles changed slightly between 1970 and 1980.

The natural conclusion would be that to keep growing in the longer term, Europe should embrace a growth strategy that develops and exports new products and services. But to date, Europe seems ill equipped to move away from incumbent sectors that could come under pressure from competition from emerging countries. While Europe hosted most of the world leaders in the disruptive technologies of the nineteenth and early twentieth centuries, such as manufacturers of railways and trains, chemicals, pharmaceuticals, electrical appliances and cars, it seems to have fallen behind in terms of the disruptive technologies of the late twentieth and early twenty-first centuries, such as electronics, computers and software. A look at the largest non-financial companies by market value seems to confirm this. In early 2016, there were only seven EU companies among the 50 largest in the world, and the average year of their incorporation was 1913 (compared to 1943 in the US and 1964 in the rest of the world). The five largest companies in the world are all US companies, and four of them are IT companies formed after 1975.

What can Europe do to gain a competitive edge in new products and services with higher value added, which will form the basis for future growth and jobs? As fiscal and political capital is limited, the crucial issue is prioritisation of policies[9]. Our aim is to provide some criteria to help decide which policies (at which level of government) could have the largest aggregate impact on growth by resolving growth-bottlenecks for individual sectors and regions. We suggest a four-step approach:

1. **Identify promising sectors**

To support the transition to new sectors, policymakers need to have an idea of the destination they want to reach. This is because different sectors require different policies: supporting bulky machinery with geographically disbursed value chains (eg wind turbines or electric vehicles) might primarily require investment in transport infrastructure, while developing new services (eg sharing platforms or electricity demand aggregators) might primarily require deep changes to outdated regulations, and smart appliances (eg smart meters) might primar-

8 According to the China Association of Automobile Manufacturers, 25 million vehicles were sold in China in 2015, of which 41 percent were a Chinese brand: http://www.caam.org.cn/AutomotivesStatistics/20160120/1305184264.html.

9 See also i24c (2016) Scaling Up innovation in the Energy union to meet climate, competitiveness and societal goals, i24c for a wider discussion on the need for Europe to prioritise its funding support and align policies.

ily require investment in research and education. Technology selection should not be driven by incumbent players, but by potential, in the sense of the possible contribution of the technology to future growth and the as-yet untapped potential for a country/region to thrive in this sector. We present in the next section some criteria to evaluate the possible contribution of sectors to future growth: namely technology and export market dynamics, and expected future market size. From a growth perspective, there is little value in investing public money in interesting, but barely-marketable technologies, such as nuclear fusion.

2. **Identify the appropriate regions**

Strength in new products and services is typically built on pre-existing strengths. This might be direct spillovers from existing strengths (eg using an existing customer base, logistics or knowledge), but could also be very indirect spillovers from specialisation cycles of regions or entire countries. In practice we observe ecosystems of companies, infrastructure, education facilities, financial institutions, regulations and so on, that contribute to the favouring of a certain sector. The classic example is Silicon Valley, but there are also examples in the EU, such as the automotive cluster in south-west Germany or the chemical industry cluster in Belgium. Supporting any new sector is therefore most promising in countries/regions that already have some of the elements of success present. In this paper we identify countries and regions that might have the potential to grow in one of the four low-carbon technologies we focus on.

3. **Identify the barriers**

What holds back a country or region from developing/exploiting its competitive edge in a growing technology? Finding the true bottleneck is important because otherwise policymakers risk deploying valuable resources to non-issues. Shortcomings in, for example, education, infrastructure or regulation, can be overcome within a certain time period; while other areas such as the cost of capital, labour or energy can often not be addressed in a neutral way (we would strongly advise against permanent subsidies that change the relative factor cost for certain sectors). This step is not addressed in the present study.

4. **Identify the policies to overcome the barriers**

The final step is to identify the right policy and layer of government to remove barriers. This involves comparing different policy options and conducting cost-benefit analyses. Policies that deliver only limited benefits at excessive cost should obviously not be deployed.

It is very important to highlight again that policy interventions should be as 'horizontal' as possible. That is, they should not be targeted at individual companies (let alone incumbents) and should not grant benefits only to 'desired' sectors.

Policymakers should only obtain a tool to strategically prioritise public investments and regulatory reforms that are in anyway meaningful. That is, a reform or public investment should not only be conducted to help one particular sector (eg granting tax exemptions or providing exclusive infrastructure) – let alone to intentionally disfavour other sectors, but it should be sensible beyond the sector.

The final step in designing any good policy should be evaluation in order to fine-tune future implementation[10].

10 Our approach closely relates to the smart specialisation strategy which builds on the fact that different countries and regions tend to specialise in different sectors, depending on their capabilities and industrial structure (McCann-Argilés, 2015). Therefore, in order to promote regional growth by strengthening links between the R&D capabilities and the industrial structure of each region, no 'one-size-fits-all' policy can be identified; rather, tailored actions have to be studied at the local level (David et al, 2009). In this context, energy plays an important role, and the Smart Specialisation Platform on Energy (S3PEnergy) has been created to make better use of Cohesion Funds to support the EU's energy policy priorities.

Table 2: 50 largest non-financial companies according to market capitalisation, 2016

Company	Country	Year Est.	Sector	Market value ($ billions)
Apple	US	1976	Computer Hardware	586
Alphabet/google	US	1998	Computer Services	500.1
Microsoft	US	1975	Software & Programming	407
ExxonMobil	US	1881	Oil & Gas Operations	363.3
Facebook	US	2004	Computer Services	314.8
Johnson & Johnson	US	1886	Medical Equipment & Supplies	312.6
Amazon.com	US	1994	Internet Retail	292.6
General Electric	US	1892	Conglomerates	285.6
China Mobile	China	1997	Telecommunications services	241
Nestle	Switzerland	1866	Food Processing	235.7
AT&T	US	1983	Telecommunications services	234.2
Roche Holding	Switzerland	1896	Pharmaceuticals	222.2
Procter & Gamble	US	1837	Household/Personal Care	218.9
Wal-Mart Stores	US	1962	Discount Stores	215.7
Royal Dutch Shell	Netherlands	1890	Oil & Gas Operations	210
Verizon Communications	US	1983	Telecommunications services	206.2
Pfizer	US	1849	Pharmaceuticals	205.7
Anheuser-Bush InBev	Belgium	1852	Beverages	204.6
PetroChina	China	1999	Oil & Gas Operations	203.8
Novartis	Switzerland	1996	Pharmaceuticals	203.8
Alibaba	China	1999	Internet Retail	200.7
Tencent Holdings	China	1998	Computer Services	197.4
Coca-Cola	US	1886	Beverages	192.8
Chevron	US	1879	Oil & Gas Operations	192.3
Toyota	Japan	1937	Auto & Truck Manufacturers	177
Home Depot	US	1978	Home Improvement Retail	169.8
Walt Disney	US	1923	Broadcasting & Cable	169.3
Oracle	US	1977	Software & Programming	168.9
Samsung Electronics	South Korea	1969	Semiconductors	161.6
Merck	US	1891	Pharmaceuticals	157.2
Phillip Morris International	US	1923	Tobacco	150.3
Intel	US	1968	Semiconductors	149.3
Comcast	US	1963	Broadcasting & Cable	148.2
PepsiCo	US	1898	Beverages	147.3
Novo Nordisk	Denmark	1923	Pharmaceuticals	144.9
IBM	US	1911	Computer Services	142.7

Cisco Systems	US	1984	Communications Equipment	141.7
Gilead Sciences	US	1988	Biotech	138.1
Unilever	Netherlands	1930	Food Processing	137.2
UnitedHealth group	US	1977	Managed Health Care	127.5
Taiwan Semiconductor	Taiwan	1987	Semiconductors	125.6
Amgen	US	1980	Biotech	122.4
Total	France	1924	Oil & Gas Operations	121.9
Altria Group	US	1985	Tobacco	118.4
Bristol-Myers Squibb	US	1887	Pharmaceuticals	118.2
Sanofi	France	1973	Pharmaceuticals	115.4
Schlumberger	US	1926	Oil Services & Equipment	111.1
British American Tobacco	UK	1902	Tobacco	111
CVS Health	US	1996	Drug Retail	110.8
Medtronic	US	1949	Medical Equipment & Supplies	110.7

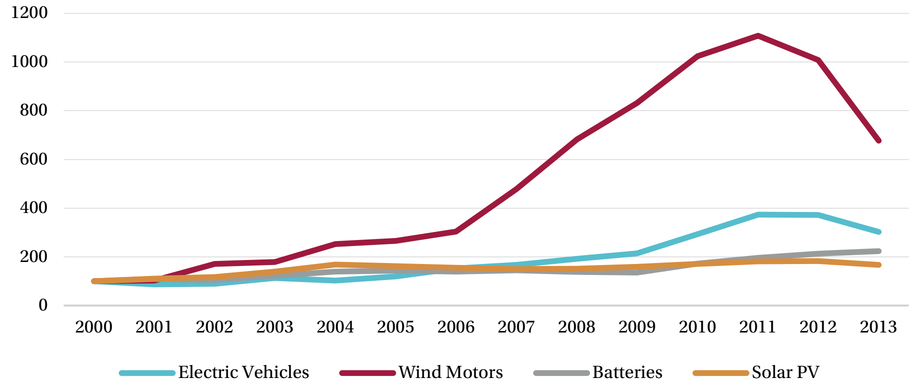
Source: Bruegel based on Forbes 2016 and complementary sources.

Figure 3: Four-step filter for prioritising policies that promise the greatest growth potential

Low-carbon technologies remain promising

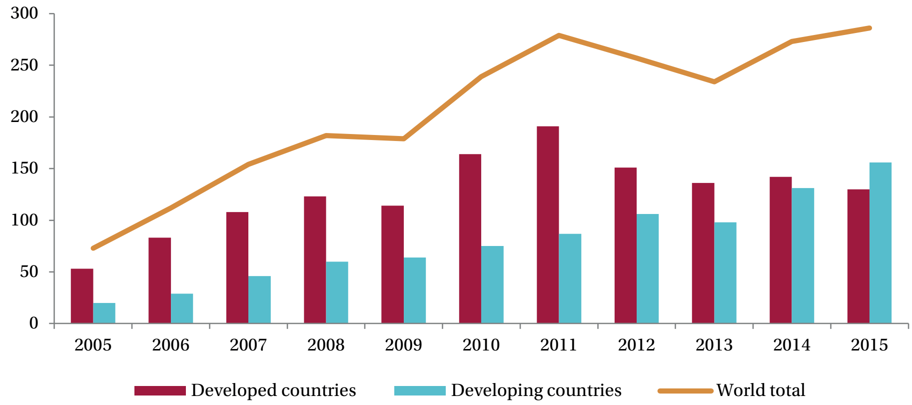
The low-carbon technology sector is seeing disruptive innovation (Figure 4) and strongly increased investment (Figure 5), which is likely to continue (Figure 6). In addition, the low-carbon share of EU exports is increasing (Figure 7). The share of electric vehicle technology patents in all patents has increased eightfold since 2000, while it has quadrupled for wind turbines and doubled for photovoltaics. In the same period, the share of exports of wind turbines and electric vehicles in global gross exports increased six fold, while export of photovoltaic cells increased threefold (despite massively falling prices).

Figure 4: Share of certain low-carbon patents in total patents (index: 2000=100)



Source: Bruegel based on OECD.

Figure 5: Global new investment in renewable power and fuels ($ billions)



Source: REN21 (2016).

On the demand side, investment in renewable power and fuels has quadrupled over the last decade. And this development is only starting. Global investment in renewable power and fuels reached a new record of $286 billion in 2015 (Figure 5). While wind and solar power needed big subsidies everywhere 10 years ago, they have started to be competitive under specific conditions that are mainly defined by the climatic conditions, the structure of the incumbent system and local fuel and emissions costs. By 2015, wind and solar had become a mainstream option for power generation investment, accounting for more than 60 percent of investment in generation capacity globally[11]. This trend will continue as long as technology cost keep falling (which they have massively in the past decade) and/or countries continue to support renewables to reduce the negative effects of fossil fuels, including greenhouse gas emissions.

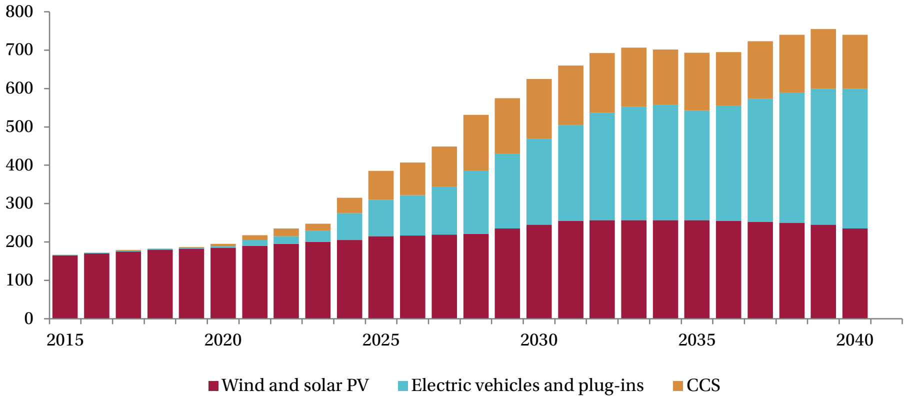
The political momentum to combat climate change was reconfirmed and reinforced in 2015, when for the first time all countries agreed in the Paris Agreement to limit carbon emissions and to aim for carbon neutrality in the second half of the century[12]. According to most current projections, deep decarbonisation will coincide with massive investment in renewable

11 According to REN21 (2016, footnote 80), 63 gigawatts of wind power, 50 GW of PV, 28 GW of hydro and 3.8 GW of other renewable generation were installed in 2015, compared to 42 GW of coal, 40 GW of natural gas and 6.5 GW of nuclear.

12 The US and China – which are responsible for 40 percent of global emissions – already formally joined the Paris Agreement in September 2016.

electricity generation and the parallel electrification of transport and heating. Together with growing electricity demand in emerging countries, the market for low-carbon energy will continue to increase[13]. But low-carbon technology investment will not be limited to power generation. Goldman Sachs (Korooshy *et al*, 2015) estimates the market opportunity for electric vehicles and plug-in hybrids to be in the order of $240 billion by 2025. On top of that, there will be investment in other areas, such as $200 billion per year in building energy efficiency. The International Energy Agency in its 450 ppm scenario – keeping the concentration of greenhouse gases below 450 parts per million of CO2 equivalent and hence global warming below 2°C above preindustrial levels – forecasts a need to ramp up annual investment in wind, solar, electric vehicles and carbon sequestration to about $750 billion after 2030 (Figure 6).

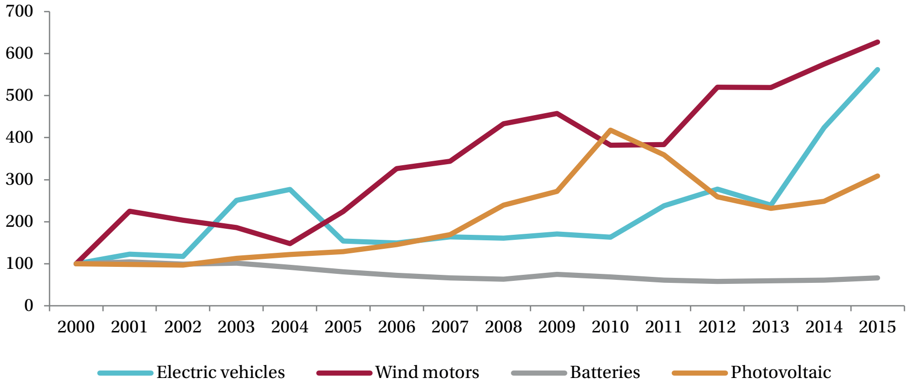
Figure 6: Global investment in variable renewables, carbon sequestration (CCS) and electric vehicles in the 450 scenario ($ billions, 2013)



Source: IEA (2015).

To illustrate our four-step approach, we picked four technologies deemed essential for the low-carbon transition: electric vehicles, batteries, wind turbines and photovoltaic cells. All four are tradable; trade in them (apart from batteries) has grown faster than total international trade (Figure 7) and patenting activity has also outpaced activity in other areas (Figure 4). While the four categories do not perfectly fit into past trade and patenting statistics, existing statistical categories provide quite useful proxies (see Annex 2).

Figure 7: Share of certain low-carbon exports in total global gross exports (index: 2000=100)



Source: Bruegel based on Comtrade.

13 Low-carbon technologies typically refer to very different types of technology that all compete with high-carbon alternatives. Examples are energy generation technologies such as renewables, but also nuclear; energy consumption technologies such as clean fuel vehicles, and technologies to make more efficient use of energy such as smart meters.

Which countries have a comparative advantage in low-carbon technologies?

We first investigate which countries already have a comparative advantage in our four low-carbon technologies. Revealed comparative advantage (RCA) assumes that market-based economies reveal their underlying comparative advantages by exporting those goods and services in which they are comparatively good[14]. As open market economies would not focus on exporting goods that they are not relatively good at producing, the RCA is not only a measure of what a country can sensibly export, but also an indicator of what a country is good at producing. The RCA is defined as the share of a good in a country's overall exports, divided by the share in all global exports of global exports of this good. Hence, the RCA is more than one if a country exports more of this good than one would expect relative to the size of the exports of this country (see Annex). For example, between 2004 and 2009 Germany, Denmark and Spain exported more than twice as many wind turbines (RCA>2) than one would expect from the size of each country's exports. In contrast, France, Poland, Italy and the UK exported less than half (RCA<0.5) as many wind turbines than one would expect from the size of each country's exports.

Box 2: Why exports matter?

Countries that specialise in the production and export of goods associated with higher productivity levels perform better in terms of economic growth. Therefore, if a country manages to export many goods that are typically exported by highly-productive countries, it is more likely to grow (Hausmann *et al*, 2005).

The use of revealed comparative advantage in defining which goods a country is good at producing ensures that country size does not distort the ranking of the different goods under consideration. Policymakers should therefore stimulate investments in those sectors that show the highest productivity levels, considering also the 'cost uncertainty' faced by those entrepreneurs that move first into those sectors where the production activity is still unexplored (Hausmann *et al*, 2005).

When moving into new sectors, countries tend to move to those that are related or 'nearby' the goods in which they already have a comparative advantage, in order to take advantage of their current productive structure strengths. This would give an important indication to policymakers by showing that the current productive structure is a fundamental factor to take into consideration when deciding on moves towards the production of new technologies (Barabási *et al*, 2007).

In the past decade, developments within and outside the EU have changed the comparative advantage of EU countries in the four low-carbon products of interest:

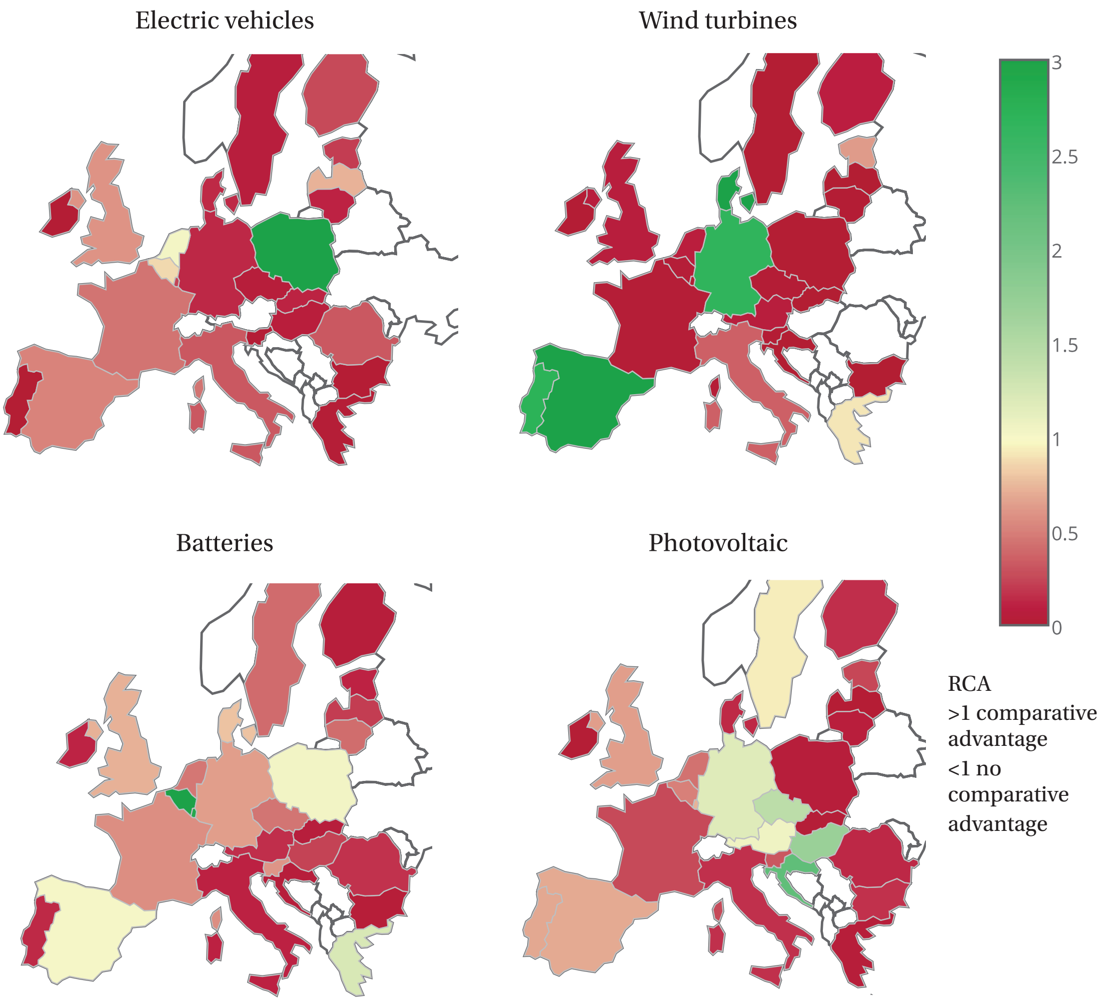
- No change was observed for **wind turbines**: the comparative advantage enjoyed by Denmark, Germany and Spain has been maintained[15].

14 Note that a comparative advantage in a good does not necessarily mean that a country is more productive than other countries in producing this good. It only means that relative to all other goods produced by a country, it is better at producing this good.

15 Some small countries have highly volatile wind turbine exports: Bulgaria had virtually no exports up to 2010, but $190 million in 2011, $14 million 2012 and $500,000 in 2014. Greece's wind turbine exports stood at $10-20 million up to 2010, then $55 million in 2011 and $32 million in 2012.

- Poland had a comparative advantage in **electric vehicles**, which was a very narrow niche market in 2004-09[16]. This comparative advantage vanished when the market grew. Then the west European car-making countries – primarily Germany, France, Belgium and Spain, but also the UK, the Netherlands and Finland – gained a competitive edge in the emerging segment. One interesting case is Slovakia. Slovakia's electric car exports grew fast: from $12 million in 2012 to $68 million in 2015. And with Volkswagen, PSA and Kia having major operations in Slovakia, the country is by far the global leader in car production per 1000 inhabitants (178 compared to 68 in Germany). In 2013, the Volkswagen plant in Bratislava began to produce the group's first fully electric-powered vehicle – the Volkswagen e-up! – making Slovakia one of the main European producers of electric vehicles.

Figure 8a: EU revealed comparative advantage (RCA) in four product categories, 2004-09

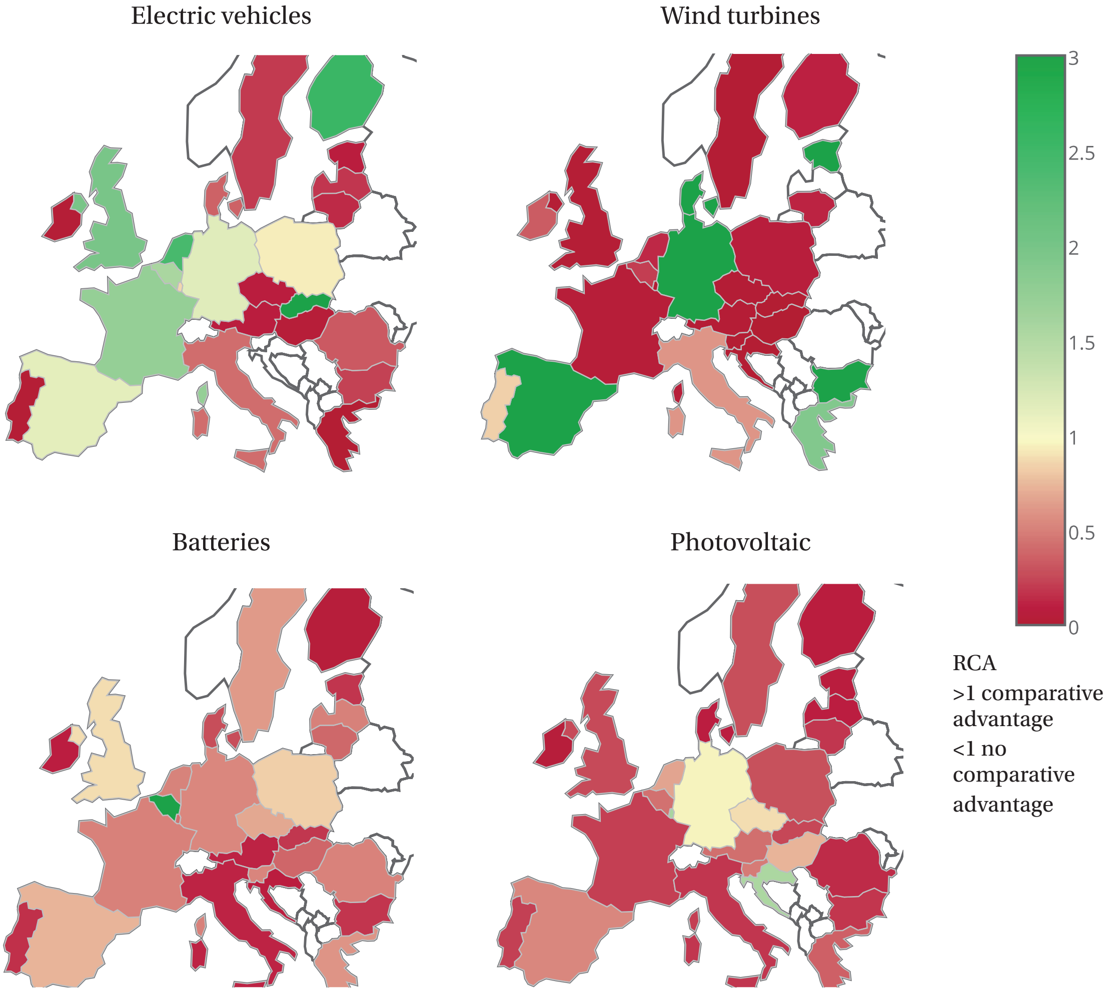


Source: Bruegel based on UN Comtrade.

16 Melex has been producing electric vehicles for niche applications (golf courses, hotels) in Poland since 1971. Poland's exports in this category were $240 million before 2010, but dropped to $1.4 million in 2011 and thereafter, indicating an apparent data issue.

- The picture is very different for **photovoltaic cells**. Despite significant support for solar PV deployment in many EU countries (most notably the feed-in tariffs in Germany, Italy and Spain), none have been able to defend their comparative advantage in this technology. The early comparative advantages enjoyed by Germany and the Czech Republic vanished after 2010, when Asian suppliers managed to undercut EU production costs. The comparative advantage of Croatia has arguably also vanished, with only one remaining manufacturer reported in 2015[17].
- For **batteries** the EU as a whole has no comparative advantage. Only Belgium – with a global chemical industry cluster (including Umicore and Solvay) – has remained a main battery exporter (2005: $750 million; 2010: $720 million; 2015: $640 million)[18]. Luxembourg seems to have lost its battery exporting business (2005: $46 million, 2010:$3 million). The largest Luxembourgish battery producer we found, ACCUMALUX, had by 2010 outsourced battery production to the Czech Republic and Bulgaria.

Figure 8b: EU revealed comparative advantage (RCA) in four product categories, 2010-15



Source: Bruegel based on UN Comtrade.

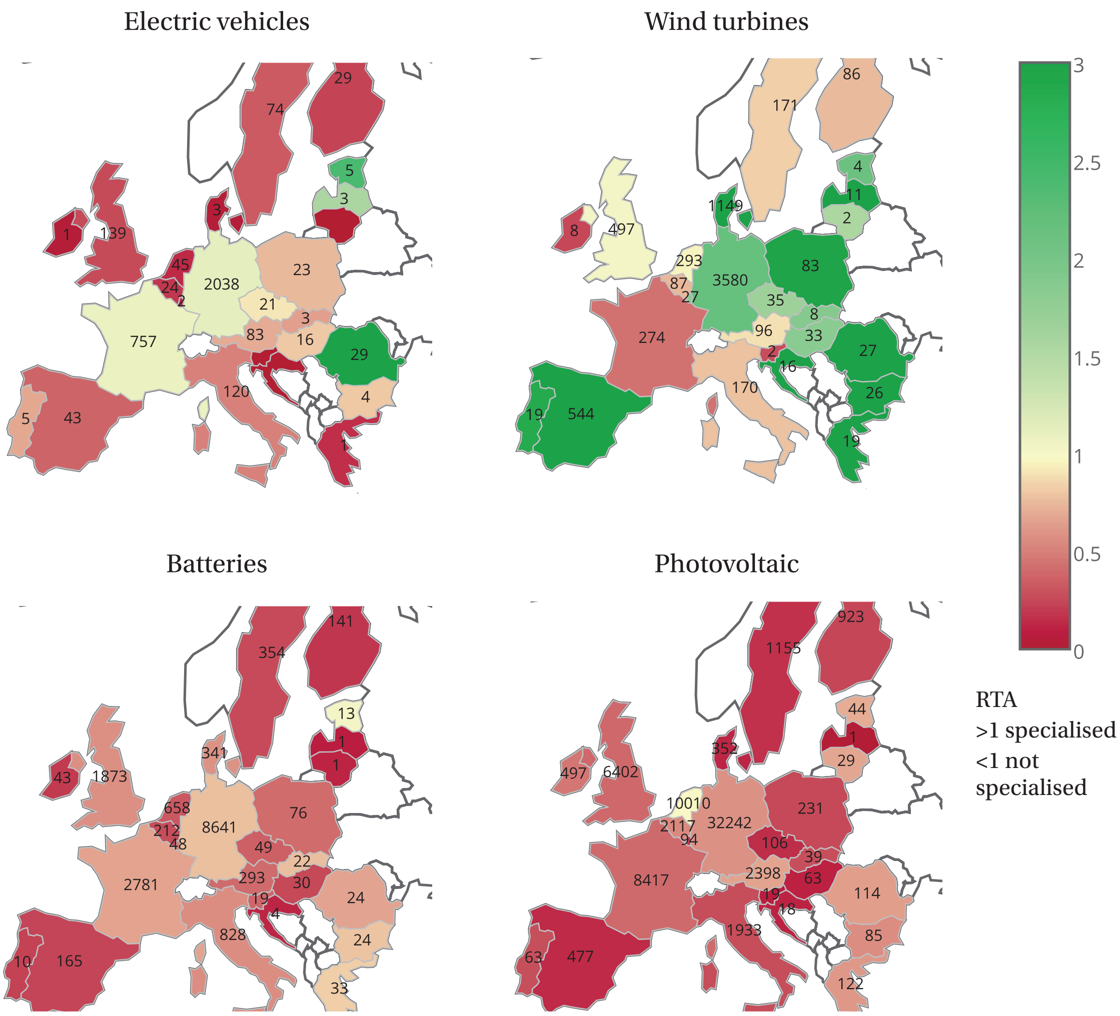
17 http://www.enfsolar.com/directory/panel/other_europe only reports SOLVIS. Other companies previously reported (http://www.cres.gr/biocogen/pdf/coutries/Croatia.pdf), such as Solar Cells LTD and SOLARIS, seem to have left the market.

18 Also hidden champions such as Prayon – a €700 million turnover phosphate-chemicals company – moved into battery technology.

Which countries might develop a comparative advantage in low-carbon technologies?

In a market economy environment, current strength is a good predictor of future strength in producing and exporting certain products. Current strength indicates that crucial factors are available and their prices are appropriate, that knowledge and a network of suppliers are established and that the regulatory environment is conducive. While having a comparative advantage in a product provides some indication that a sector might grow in a country, the absence of a revealed comparative advantage does not imply that a country is unable to develop new strengths in the future. One of the building blocks of future comparative advantage – especially in new technologies – is innovation. Thus, countries that focus their patenting activity on specific technologies are likely to also have a comparative advantage in exporting the corresponding products.

Figure 9a: Technologic specialisation (RTA) and number of patents in four technologies 2002-07

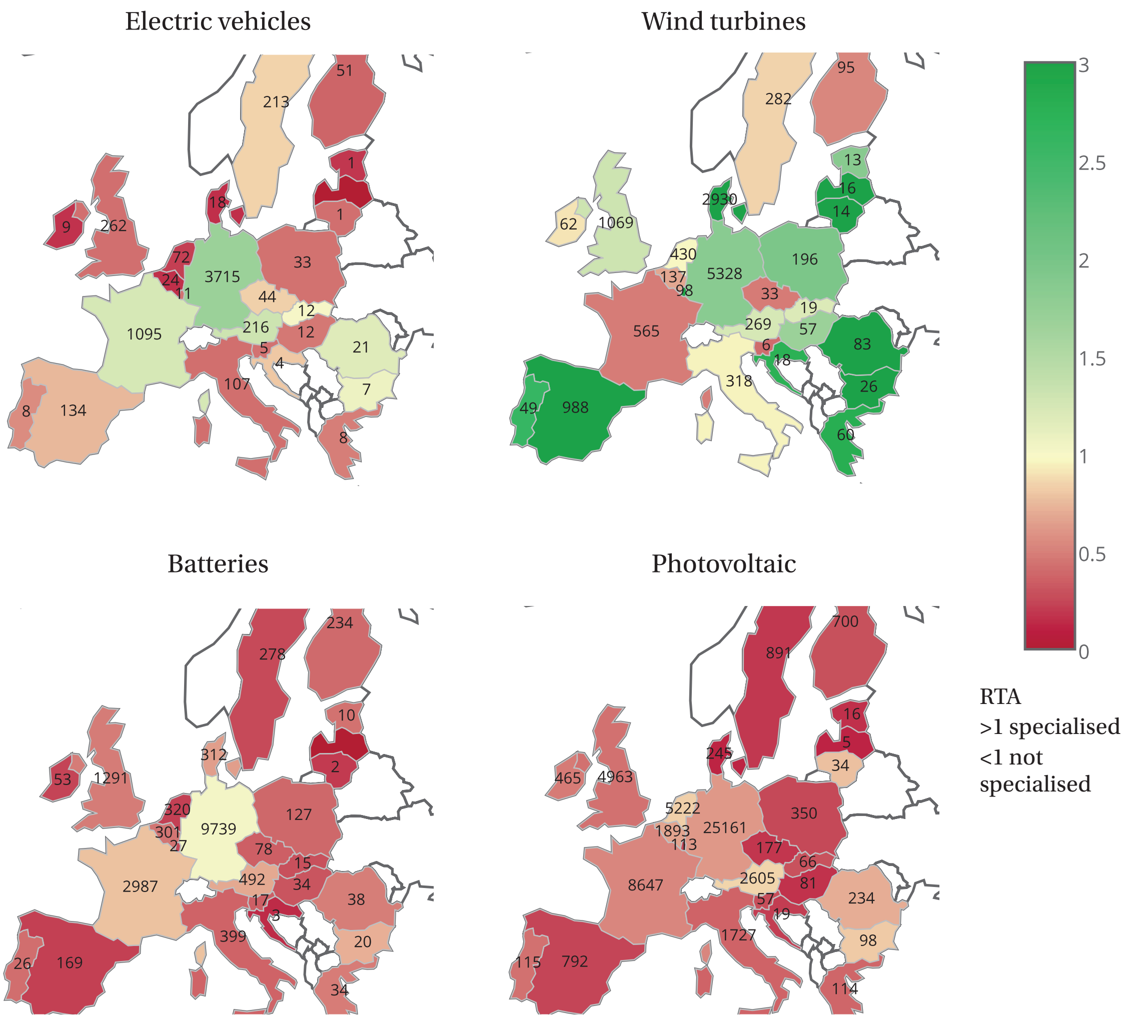


Source: Bruegel based on Patstat.

In line with this, we find that some countries that specialised in innovation in certain technologies managed to build comparative advantages in these areas. Thereby, the revealed technology advantage (RTA) is the equivalent to the revealed comparative advantage in terms of patenting. It is defined as the share of a technology in a country's overall patents, divided by the global share of this technology in all patents. Hence, the RTA is greater than one if a country is patenting more in this technology than would be expected from the total number of patents from the country (see Annex).

For example, Greece's patenting related to wind turbines (RTA>2 in 2002-07 and 2008-15) was accompanied by a comparative advantage (RCA > 1.1 in 2010-15). As many factors influence the development of competitiveness (eg deployment and presence of similar technologies – see Huberty and Zachmann, 2011) and companies that produce/export a certain product are also more likely to generate patents in this area, we cannot establish causality. But, RCA and RTA are complementary indicators for the potential of future competitiveness.

Figure 9b: Technologic specialisation (RTA) and number of patents in four technologies 2008-13



Source: Bruegel based on Patstat.

In some low-carbon technology areas such as batteries and photovoltaics, the number of patents is high, because they are types of technology for which there is more patenting, commercial interest in the technologies are high and the categories are broadly defined. In electric vehicle and wind turbines, much less patenting occurs, though EU member states have embarked more on specialisation in the latter fields.

Patenting data is no perfect measure for innovative activity. It only measures a specific step in the innovation process and, because patents are a legal instrument to enforce intellectual property, they are only applied for if an inventor requires this protection. Not all innovation is patented. However, companies might also decide to patent very minor technological improvements in order to enjoy protection for their intellectual property. Thus the quality of patents can be quite variable[19].

As expected, countries that are good at exporting certain products are often also good at patenting in related technologies.

- For **electric vehicles,** we find that almost all EU countries significantly increased the number of patents in electric propulsion technology. This helped France and Germany keep pace with the growing patenting field and develop a comparative advantage in exporting electric vehicles. Romania is also responsible for relatively more patents in electric propulsion than in other technology fields but is yet to develop a comparative advantage at exporting electric vehicles[20]. Finally Austria managed to develop a revealed advantage in electric propulsion technology by significantly increasing its number of patents from 83 in 2002-07 to 216 in 2008-13.
- With a few notable exemptions, most EU countries have a technology advantage in **wind turbines**. This is even true for countries such as the UK, which were not strong exporters of wind turbines. Many central and eastern European countries also patent more than twice as much in wind turbines than their small number of total patents would suggest. Then there are the global wind powerhouses Denmark, Germany and Spain, which together accounted for 37 percent of worldwide wind turbine patents from 2000-13. The most notable exception is France, which has only filed about half as many patents as the average country in wind turbines, relative to its overall patenting activity. The Netherlands, Belgium, Sweden and Finland also do not focus on wind turbines.
- The picture is completely different for **battery technology**. No EU country has a revealed technology advantage – not even Belgium, which does quite well exporting batteries. The reason is the dominance of Japan (RTA = 2.11) and South Korea (RTA = 1.89), which both have twice as many batteries patents as one would expect from their overall patenting activity. Furthermore, thanks to their patenting legislation and sectoral focus[21] Japan and South Korea are among the strongest patent producers in the world. Japan has 14 percent and Korea 8 percent of all patents considered (by comparison France accounts for 5 percent).
- But even if these two battery patent powerhouses are excluded from the analysis, the only EU country that has an above-average share of battery patents in total patents is Germany (RTA = 1.25), while other overseas countries (notably China RTA = 1.26) are much more specialised in this emerging technology field.
- **Photovoltaic** technology patents illustrate well that our RTA measure does not capture absolute patent numbers, but countries' relative specialisations. Germany and France generate many photovoltaic patents – many more than for wind turbines – but that is largely because the patent category is much wider. The photovoltaic patents category accounts for 4 percent of global patents, while wind turbines accounts for only 0.08 percent.

19 The use of additional data sources and patent quality indicators (such as citations) is warranted to increase the reliability of the analysis. This, however, often implies working very far from real time – because the quality of a patent is only revealed over time. This calls for improved innovation statistics at EU level, for example through a European energy information service, which would collect and administer energy innovation statistics.

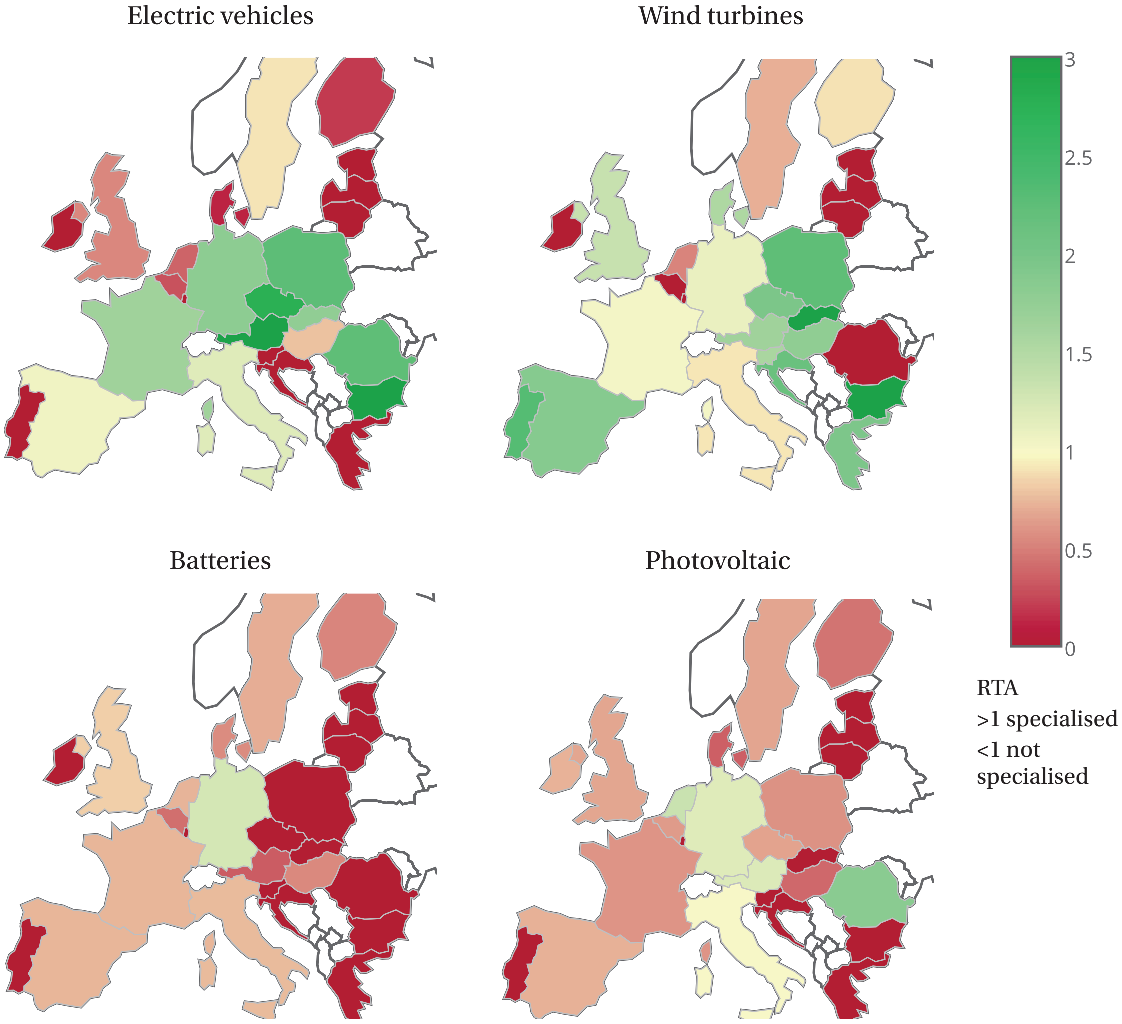
20 Given the small number of patents produced by Romania, these numbers have to be interpreted with caution, as a relative technology advantage (RTA>1) is already driven by an absolute number of only 29 electric propulsion patents over 6 years.

21 Japan's patent figures are likely to be inflated by the greater tendency to patent incremental innovations and by double counting, as well as the concentration in Japan of patenting-intensive sectors, such as manufacturing and, in particular, electronics. See 'Mother of invention – Why is Japan the source of so many bright ideas?' The Economist, 3 August 2007.

So although between 2008 and 2013 France has produced 8,647 patents and Germany 25,161, no EU country has a revealed technology advantage in this technology class. The most specialised countries are Indonesia (RTA = 2.78), Taiwan (RTA = 2.37), South Korea (RTA = 2.36) and Japan (RTA = 2.01), while interestingly China is under-specialised in this category (RTA = 0.52).

- Even if the top-four Asian countries are dropped from the sample, only the Netherlands (RTA = 1.48) and Austria (RTA = 1.18) have an advantage in the photovoltaics technology category. The strong Dutch position is partly explained by the strong position of Philips, which applied for at least a fifth of the patents in this category[22]. Despite massive solar subsidies, Germany has not strongly specialised in photovoltaic technology innovation (RTA = 0.59). Interestingly, China is also responsible for only about half as many patents in solar PV as would be expected for a country with China's number of patent applications.

Figure 10: Technology specialisation in related technologies 2000-13



Source: Bruegel based on Patstat.

22 Including in lighting technology because the PV category H01L also includes LEDs. A quick inspection of the only partly-cleaned data shows that Philips applied for about 7000 of around 36,000 patents that included the H01L technology code in the Netherlands between 2000 and 2013.

Almost all EU countries are, in global terms, disproportionally innovative in either electric vehicles and/or wind turbines, while almost no EU country has a technology advantage in battery and photovoltaic technology. But this picture could change because countries can alter the focus of their innovative activity[23]. We want to determine which countries might have some of the prerequisites for developing an advantage in the four technologies of interest.

We build on the fact that countries find it easier to innovate in technologies that are related to technologies they are already good at[24]. As a measure of technology proximity, we use the relative frequency with which two technology classes (in fact technology codes) appear as part of the same patent (for more information see Annex 4). We then analyse which countries are good at patenting the technologies we identified as being 'nearby' our four low-carbon technologies (for more information see Annex 5).

To give one example, to establish Slovakia's potential for wind turbine innovation, we look at the two most-related technologies, namely 'machines or engines for liquids' and 'control or regulation of electric motors'. We find that the potential RTA of Slovakia for wind turbines is rather high, because it is already specialised in the two nearby technologies. In fact, Slovakia is also already specialised in wind turbines.

In general we find that countries that specialise in nearby technologies are already also specialised in the low-carbon technology of interest – somewhat validating our approach. The interesting cases are, however, those countries that are good at innovating in nearby technologies, but which have not yet developed a specialisation in the technology of interest.

- For **wind turbines,** Denmark, Germany and Spain (but also Greece and Bulgaria) have revealed comparative advantages and revealed technology advantages, and also have revealed technology advantages in related technologies. Austria, Slovakia, Portugal, and Poland have both a revealed technology advantage in wind turbines and a revealed technology advantage in related technologies. The Czech Republic and the UK so far have not excelled in patenting and exporting wind turbines – but the specialisation in innovation in nearby technologies suggests that some of the technological prerequisites for strengthening innovation in wind technology are present.
- While currently European countries are at best modestly focused on innovation in **electric vehicles** (RTA in Germany = 1.38), many countries are doing well in related fields. We find that several of the big car-producing countries (Spain, France, Germany, the Czech Republic and Slovakia) perform well in technologies close to electric propulsion. The most notable exception is Italy, which does not seem to have great potential in electric propulsion. At the same time, even Austria, Romania and Bulgaria are focusing their (sometimes small) innovation activity on related technologies. Many EU countries seem thus to have some of the technological prerequisites for developing a competitive edge in generating electric propulsion patents.
- For **photovoltaic cells,** the initial finding – that EU countries are neither good at exporting nor at patenting photovoltaic cells – is largely confirmed. Only the Netherlands (possibly partly because of the activities of Philips in the LED segment) and Romania are relatively strong at patenting technologies that are close to photovoltaic cells.
- For **batteries** the picture is even less encouraging – no EU country is strong in patenting battery technology or in technologies close to battery technology.

23 For example, Austria developed a technology advantage in electric propulsion and Ireland in wind turbines between 2002-07 and 2008-13.

24 For a recent discussion on different measures of technology proximity see Alstott *et al* (2016).

Which regions might develop a comparative advantage in low-carbon technologies?

Innovative activity is not evenly distributed within countries. It largely follows the concentration of industrial activity. Consequently, patent data is helpful data in identifying regional industrial strengths (clusters). The advantage over other types of data is that patent data is available for concrete locations (the address of the applicant), with a narrowly categorised technology description (the IPC code). The data is also rather consistent over many years. To properly analyse patent data we applied a machine-learning algorithm (Peruzzi *et al*, 2014) to attribute individual patents to companies, to categorise the inventors into different types (companies, individuals, universities) and to locate the inventors. This was done by combining the sometimes sketchy patent data with the comprehensive up-to-date company database Orbis. The algorithm in general works very well in attributing 2.6 million patents to about 150,000 inventors and fixing a location for 1.5 million of the patents.

When we plot the location of patents in our four technology categories, significant regional clusters emerge. For **electric vehicles** in France, for example, the automotive clusters around Lyon (Renault), Paris (PSA and Renault) and Lille (Renault) stand out. These innovative clusters feature large companies and also smaller competitors and an ecosystem of suppliers. In Germany, the entire south-west (Daimler, Porsche, Bosch), the Ruhr (Opel, Mercedes, Ford) and the area around Munich (Audi, BMW, Siemens) are clusters of electric propulsion innovation.

For **wind turbines** the three largest innovation cluster are Midtjylland (Denmark: Vestas, Siemens), Hamburg (Germany: Nordex, Senvion) and Oviedo (Spain: EDP Renováveis). But we also observe numerous smaller clusters of wind turbine innovation in other parts of Germany and Spain, and in the UK, Belgium and the Netherlands.

Not completely unexpectedly, the clustering of innovative activity related to **batteries** matches the innovation clusters for electric propulsion, with the addition of a cluster south of Berlin (the Daimler subsidiary Li-Tec Batteries in Kamenz[25]) and around London. In contrast to the country view there appear to be several smaller innovation hubs on a regional level that might develop further.

Among our four technologies, **photovoltaic** innovation appears least densely clustered, with a large number of small clusters across western Europe. This might partly be because the photovoltaic technology category is broadly defined – but could also be a consequence of the industry structure, which consists of more smaller-scale companies than the car or the wind industries.

Clusters matter

Regional clusters of patenting activity in certain technology areas are not just a result of clustered industrial activity. They also point to innovation spillovers – the most fascinating example being Silicon Valley[26].

To understand the importance of geographic spillovers for our four technologies, we analysed the distance between inventors and other patents cited in our patents. Such citations, which identify significant previous patents on which the new patent builds, are part of patent filings. Our findings are in line with the literature[27], indicating a strong concentration of spillovers within clusters. For all four technologies, between a quarter and a half of the cited

25 https://de.wikipedia.org/wiki/Li-Tec_Battery. But Li-Tec might also serve as a warning. Despite public support and strong initial investment, production was stopped in 2015. Because of its location, Li-Tec was unable to build on a cluster in similar or nearby technologies or a strong academic research centre focusing on corresponding technologies.

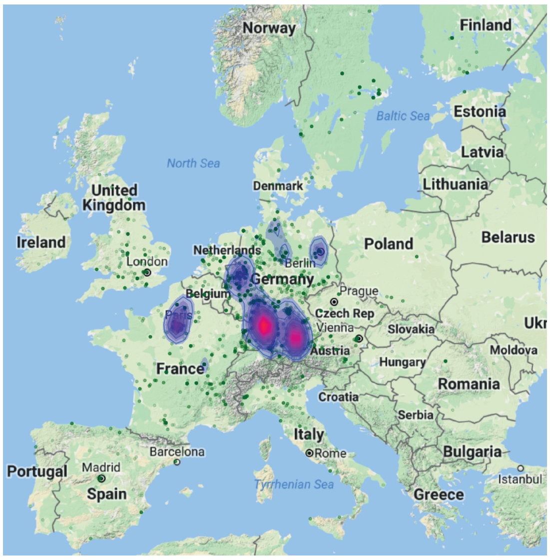
26 http://www.grips.ac.jp/r-center/wp-content/uploads/12-18.pdf.

27 For a summary of the literature see Carlino and Kerr (2014).

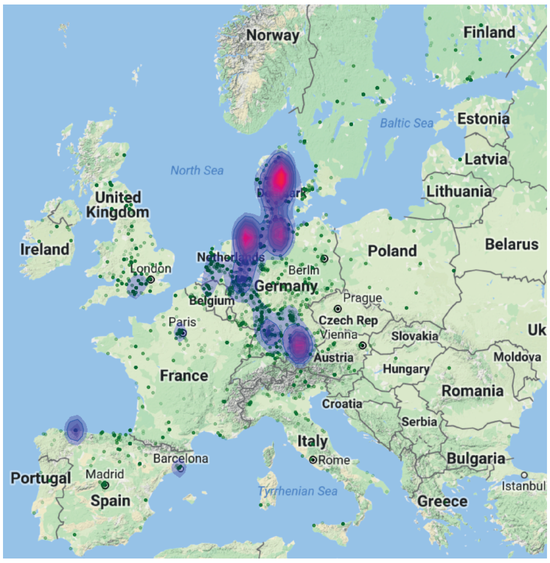
patents are applied for by person or company whose address is less than 50 kilometres away from the address given in cited relevant patents[28]. Innovators tend to climb on the shoulders of nearby giants.

Figure 11: Regional clusters of innovation 2000-13

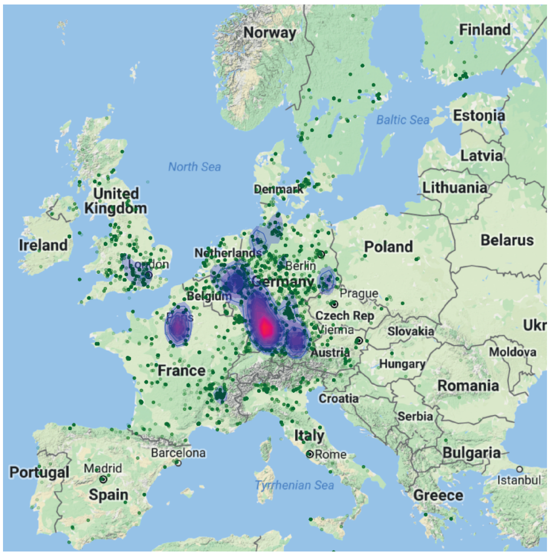
Electric vehicles



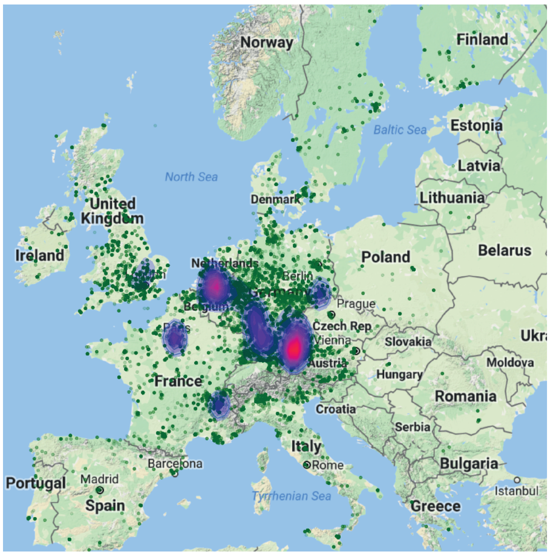
Wind turbines



Batteries



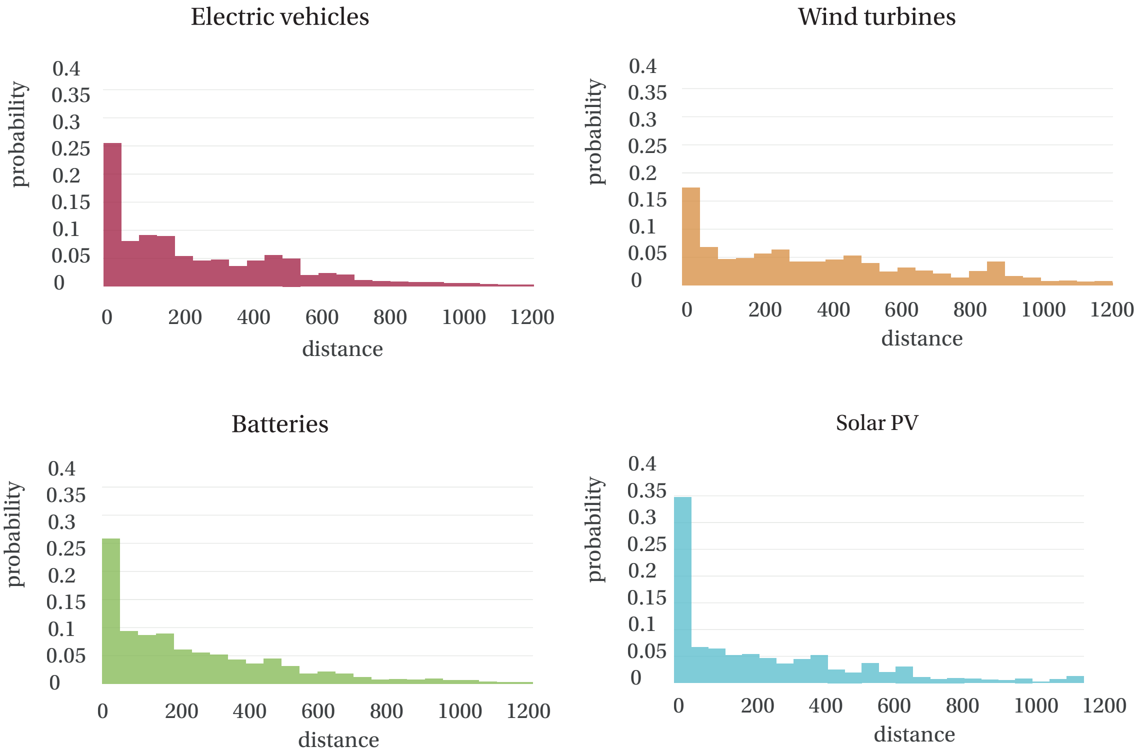
Photovoltaic



Source: Bruegel based on PATSTAT. Note: In the map that plots absolute numbers of patents, the concentration of low-carbon research activity in particular countries/regions appears even stronger than in the RTA maps (Figure 9). This is mainly because before we plotted the specialisations (RTA) of countries, which implies that a country can be good at a certain low-carbon technology even if it does not produce many patents in this technology class, just because it does produce very little patents overall (so its specialisation in this low-carbon technology is nevertheless high)

28 Compared to the academic literature, such as Jaffe *et al* (1993), Carlino *et al* (2012) and Murata *et al* (2014), we do not control for self-citation and other characteristics, and thus potentially overestimate the spillover effects, which those papers also found.

Figure 12: Histogram of geographic distance to other patents cited in patent applications



Source: Bruegel based on Patstat.

Conclusion

Europe's business model of selling more of the same in new markets is reaching its limits as the pace at which new markets emerge slows, while new competitors that sell the same products emerge quickly. One strategy to restore economic growth in Europe would be to embark on exporting new products that promise higher value added and growing markets. One such area could be low-carbon technologies. In the framework of global decarbonisation and the desire to reduce resource consumption, the market for low-carbon technologies has been growing fast – and is likely to continue to do so.

In terms of European potential we assessed different criteria:

1. **Strength of current exports**

Strong exports are a powerful signal that a country is (relatively) better at producing certain goods or services. Different EU countries already have comparative advantages in a number of low-carbon technologies. For example Denmark, Germany and Spain are major exporters of wind turbines.

2. **Strength of current innovation**

Other EU countries might have the potential to develop comparative advantages based on their specialisation in innovation in these new fields. For example, Germany is already strong in patenting electric vehicle technology and might turn this into a comparative advantage.

3. **Innovation strength in nearby technologies**

The Czech Republic and the UK have so far not excelled in patenting and exporting wind turbines – but their specialisation in innovation in nearby technologies suggests that some of the technological prerequisites for strengthening innovation in wind technology and ultimately boosting exports are present. Although modest in absolute terms, some central and east European countries exhibit specialisation in technologies related to electric vehicles and photovoltaic cells.

4. **Regional clusters**

Finally we find that – while only Belgium is good at exporting batteries and no EU country is good at inventing batteries – several regional clusters exist that are generating significant battery technology patents. These clusters might be the nuclei of future growth.

We can therefore conclude that the EU has potential, but that one-size-fits-all policies would ignore the complexity of the task of supporting the EU economy to gain a competitive edge in new products and services that will form the basis for future growth and jobs. To identify policies to foster future competitiveness we suggest a four-step filter (Figure 3), with each step, as much as possible, based on transparent criteria. This would also enable *ex-post* evaluation – which in the medium term allows the policy toolbox to be improved.

This paper contributes to two steps of the economic policy menu: first, providing some criteria for selecting technologies that have economic potential, and second providing quantitative criteria to identify regional strengths in selected technologies. Obviously, both steps could be substantially refined and 'policy learning' is an important element of developing successful economic policy. Two subsequent crucial steps have not been addressed here. We neither discussed how to identify bottlenecks that hold up the development of individual technologies in individual regions (Zachmann, 2012) nor did we provide tools for the comparison and cost-benefit analysis of different policies to address those bottlenecks.

The approach and criteria we have outlined could already inform the Energy Union Integrated Research, Innovation and Competitiveness Strategy (EURICS), though more criteria than what we have presented need to be considered. Even then, the approach will not guarantee success in each and every case. But this is not a bad thing when targeting disruptive sectoral change. Rather than supporting technologies in regions that will be guaranteed successes, policymakers should also take calculated risks. In that sense, funding should be based more on a venture capital model –the failures of four risky endeavours can be more than compensated for by the success of one risky but successful endeavour. But each failure should also be used to learn.

Annex 1: RTA-RCA methodology

We use data visualisation tools[29] to draw the cross-sectional distribution of RTAs/RCAs of selected technologies/exported goods across EU28 countries over the period 2002-15. To this end, we use OECD Science, Technology and Patents count data[30], by browsing patent statistics by technology and then downloading the data by International Patent Classification (IPC) section[31] for a selected set of countries over 2000-13, and UN COMTRADE data, by searching gross exports in goods for all countries over 2004-15.

In this exercise, we consider OECD Science, Technology and Patents count and UN COMTRADE data. As regards the first, we browse patent statistics by technology and then download the data by International Patent Classification (IPC) section, ie from A to H. We do this for a selected[32] set of countries, ie EU28 countries in addition to the US and Japan, over the period 2000-13. In addition to the country-time filter, we slice the data according to other three dimensions: reference date, patents office and reference country. We set the reference date to be the priority date, meaning that the date *"corresponds to the first filing worldwide and therefore closest to the invention date"*, as explained by the OECD. We use this date since *"to measure inventive activity, patent should be counted according to the priority date (in the case of patent families, the priority date corresponds to the earliest priority among the set of patents)"*, as suggested again by the OECD. We set then the patents' office to be the patent applications filed under the Patent Cooperation Treaty (PCT), ie those *"patents filed under the PCT, at international phase, that designate the European Patent Office (EPO)"*, since the OECD bases its RTA computation on this definition. Finally, we set the reference country to be the inventor(s)'s country(ies) of residence mainly because *"counting patents according to the inventor's country of residence is the most relevant for measuring the technological innovativeness of researchers and laboratories located in a given country"*, as suggested by the OECD. We automatically import and append the resulting databases into a unique dataset of patents count for all IPC codes ready for RTAs computation and visualization. A patent is equally attributed to all inventors' countries. This method of simple counts is in contrast to the fractional counts employed by the OECD whereby patents are counted as fractions relative to the number of inventors. Simple counts produce more stable RTA measures but totals are affected by increasing internationalisation.

The same procedure has been applied to the UN COMTRADE database, with few differences. We download gross exports values measured in USD for all countries since the filter involving EU28, US and Japan only does not capture many other big exporters. We do this for a selected set of commodity codes (see Annex 2), namely electric vehicles, wind motors, batteries and photovoltaic cells, which we will use then as additional criterion to slice the patent database. We apply several filters: we choose exports from all countries to the 'world' measured at annual frequency and classifying HS as reported.

Following the OECD definition[33] of RTA, *"the RTA index provides an indication of the relative specialisation of a given country in selected technological domains and is based on patent applications filed under the PCT. It is defined as a country's share of patents in a particular technology field divided by the country's share in all patent fields. The index is equal to zero when the country holds no patent in a given sector; is equal to one when the country's share in the sector equals its share in all fields (no specialisation); and above one when a positive specialisation is observed"*. We employ this definition in our exploratory analysis. Indeed, letting be the number of patents in technology in country at time , the

29 R software for statistical computing.

30 http://stats.oecd.org/ and http://comtrade.un.org/data/.

31 http://web2.wipo.int/classifications/ipc/ipcpub/#refresh=page.

32 The selection criterion is guided by patent data relevance and reliability for this study.

33 http://www.oecd-ilibrary.org/science-and-technology/data/oecd-science-technology-and-industry-outlook/revealed-technology-advantage-in-selected-fields_data-00673-en.

RTA index is expressed as:

$$RTA_{ijt} = \frac{p_{ijt} \Big/ \sum_j p_{ijt}}{\sum_i p_{ijt} \Big/ \sum_{ij} p_{ijt}}$$

If we switch the terms and , the RTA index could be also defined as a technology's share in a given country divided by the technology's share in all countries. Given their equivalence, the two definitions are therefore complementary. As the OECD definition emphasises, the RTA index has domain:

$$RTA_{ijt} = \begin{cases} \in [0,1] & 0 \leq \frac{p_{ijt}}{\sum_j p_{ijt}} \leq \frac{\sum_i p_{ijt}}{\sum_{ij} p_{ijt}} \\ > 1 & \frac{p_{ijt}}{\sum_j p_{ijt}} > \frac{\sum_i p_{ijt}}{\sum_{ij} p_{ijt}} \end{cases}$$

That is, the index is equal to zero when the country holds no patent in a given technology; is equal to one when the country's share in the sector equals its share in all fields (no specialisation); and above one when a positive specialisation is observed. We aggregate therefore by summing the number of patents first and then re-compute the RTA index with the new aggregated data for two selected periods, 2002-07 and 2008-13. Letting , the aggregate RTA index is given by:

$$RTA_{ij} = \frac{p_{ij} \Big/ \sum_j p_{ij}}{\sum_i p_{ij} \Big/ \sum_{ij} p_{ij}}$$

In this way we are able to reduce the dimensionality of the index, while increasing the observations used in computing and visualizing the index.

We then repeat the procedure for RCA, which is defined as a country's share of exports in a particular good divided by the country's share in all commodities. The index is equal to zero when the country holds no export in a given good; is equal to one when the country's share in the commodity equals its share in all fields (no specialisation); and above one when a positive specialisation is observed. Letting be the value of gross exports in commodity in country at time , the RCA index is expressed similarly and has the same domain as the RTA index. We then aggregate over time for period 2004-09 and 2010-15. We lag our aggregation of the RCA index compared to the RTA index because we assume there could be a lagged relation between the two measures, possibly being innovation engines of comparative advantage.

Annex 2: IPC and HS codes used to measure the selected products

IPC code	Description	HS code	Description	Short name
B60L	Propulsion of electrically-propelled vehicles	870390	Automobiles including gas turbine powered	**Electric vehicles**
F03D	Wind motors	850231	Wind-powered generating	**Wind turbines**
H01M	Processes or means, eg batteries, for the direct conversion of chemical energy into electrical energy	8506	Primary cells and primary batteries	**Batteries**
H01L	Semiconductor devices; electric solid state devices not otherwise provided for	854140	Photosensitive/ photovoltaic/LED semiconductor devices	**Photovoltaic**

Annex 3: One way of determining related technologies

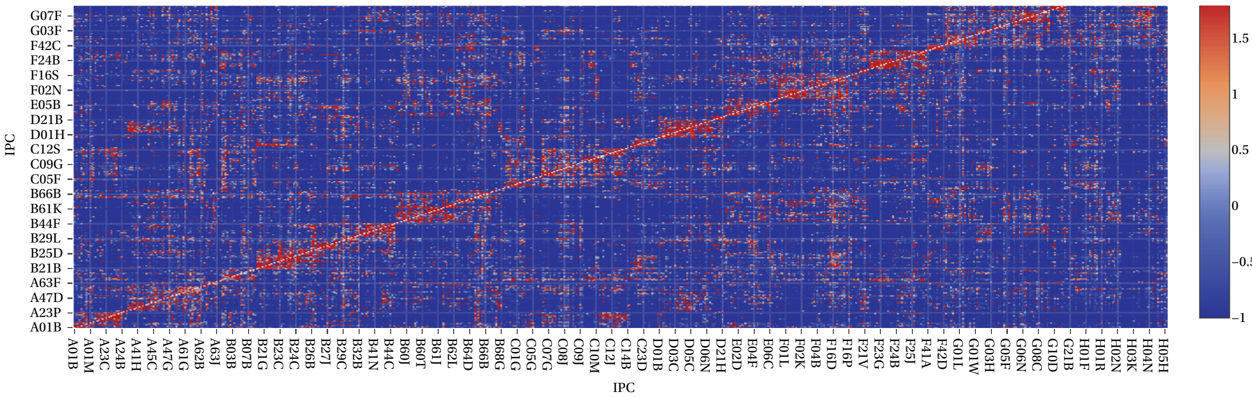
To identify the potential strengths of a country we assume that strength in one technology implies the potential for development in a related technology. Thus we first identify which technologies are related. To do this we exploit 15.7 million patents from 2000-14 in 45 countries (EU countries and G20 countries). We first assume that IPC codes (ie the technology categories ascribed to a patent by the patent officer) that often occur together on one patent are more likely to be related, than IPC codes that are rarely together on one patent. To do this we built a table with 15.7 million rows for each patent and around 623 columns for each IPC code[34]. We then calculated the concurrence of two IPC codes by matrix-multiplying the table with itself. The elements of the resulting 623 x 623 matrix can be interpreted as the number of times a combination of the column-IPC and the row-IPC appear in one patent. So the second element of the matrix corresponds to the number of times A01B and A01C appear on the same patent, 57,144 times. As self-concurrence is not meaningful, we replace the main diagonal (where the row and the column IPC are the same) of the square matrix with zeros. Then we divide each element of the matrix by the sum of all elements. Hence, the sum of the resulting matrix is one, and each element is the share of this combination of IPCs in the total number of combinations of IPCs. This share does not directly allow us to infer which combinations of IPC codes are related as some IPC codes are far more likely than others. The most frequent IPC code A61K appears 15.2 million times in patents, while the least frequent IPC code C06F only appears 228 times in patens. Hence, the share of IPC combinations involving A61K is naturally much higher. So to spot relations, we for each combination of IPC codes

34 The entries in the table are not necessarily zero-one, as the same IPC code might appear several times on a patent because we shrink the more detailed IPC codes (such as F03D 3/0427 and F03D 9/37) to four digits (eg F03D).

control for the frequency of the two IPC codes that form this combination. To do this, we calculate the expected share of each combination of IPC codes by multiplying the frequency of the first and the second IPC code (eg for C06F and A61K there should be 3.5 billion combinations). We than again delete the main diagonal and divide each element by the sum of all elements. We now have two matrices: one matrix with the observed share of each combination and one with the expected share of each combination (if they were solely distributed according to the frequency of the forming IPC codes). Based on the two we can assess which combinations of IPC codes occur more often than expected by subtracting the expected share from the observed share and dividing the difference by the expected share. This can be represented as a heatmap. The heatmap illustrates that IPC codes are more likely to concur with IPC codes that are classified close to them (ie that share the same first two digits), as the areas of high concurrence are close to the main diagonal. We name the elements of the matrix the 'relationship coefficient' between the IPC codes.

Similar concurrence tables can be established for the most likely combinations of IPC codes applied by the same person and the most likely combinations of IPC codes by applicants of the same country.

Figure 13: Concurrence of technology (IPC) codes on the same patent application



Source: Bruegel based on Patstat.

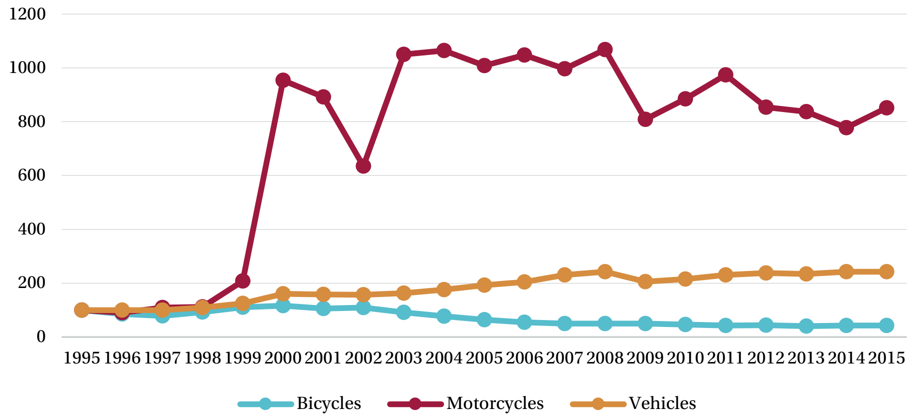
Annex 4: Strength in related technologies

Proximity between different technologies can be exploited to explore which additional technology strength a country might develop based on existing strength. The idea is that countries are more likely to also develop strength in technologies that are close to technologies the country is already good at. Based on the above-introduced concurrence tables we identify a set of technologies that are close to our technologies of interest. We chose all technologies that are among the 5 percent technologies with the highest relation to our technology of interest. For them, we normalize the relation-coefficients for these technologies, so that the sum of the relation-coefficients of the related technologies is equal to 1. Then we calculate the weighted average of each country's RTAs in the related technologies. We use a weighted geometric average, as RTA's follow a logarithmic distribution. The result is a proximity-weighted average of the related RTA's, which we interpret as the potential RTA for the technology of interest. To give one example, to find out the potential in wind engine innovation (F03D) in Slovakia, we identify the nearby technologies of wind engines. The two most related are F03B 'machines or engines for liquids' with a relation coefficient of 124 and H02P 'control or regulation of electric motors' with a relation coefficient of 57. If we only consider those two related technologies, their normalised coefficients are 124/181 and 57/181. As the RTA of F03B and H02P in Slovakia are 10.6 and 0.5, the potential F03D RTA is (10.6^(124/181)*0.5^(57/181)) = 4.1. So the potential RTA of Slovakia for wind motors is rather high, as it is already specialised in two nearby technologies. In fact, Slovakia also already specialised in wind motors (RTA=2.3).

But this also means that if a country does not innovate at all (RTA=0) in one of the nearby technologies – it is considered unlikely to excel in the technology of interest (pRTA=0). Our approach allows for a high degree of discretion. The definition of the relation coefficients (number of digits of the IPC code considered, concurrence on the same patent or by the same person), the number of nearby technologies considered and how they are weighted – all this can be determined by the user. Thus we try to carefully document our choices. At this point, calibration is still *ad hoc* – based on intuition and results for some technologies/countries being in line with the priors of the author – at a later stage some data-based calibration would be desirable.

Annex 5: China's move up the value chain

Figure 14: China's move from lower to higher value goods



Source: Bruegel based on UN Comtrade.

Figure 14 illustrates how the share of lower value goods (bicycles) in Chinese exports has fallen, while the share of medium value goods (motorcycles) peaked in 2008, and the share of higher value goods (vehicles) continued to increase.

References

Alstott, J., G. Triulzi, B. Yan and J. Luo (2016) 'Mapping Technology Space by Normalizing Patent Networks', available at http://arxiv.org/pdf/1509.07285.pdf

Barabási, A. L., R. Hausmann, C. A. Hidalgo and B. Klinger (2007) 'The Product Space Conditions the Development of Nations', *Science* 317 (5837): 482-487

Carlino, G., J. Carr, R. Hunt and T. Smith (2012) 'The agglomeration of R&D labs', *Working Paper* 12-22, Federal Reserve Bank of Philadelphia

Carlino, G. and W. R. Kerr (2014) 'Agglomeration and Innovation', *Working Paper* No. 20367, National Bureau of Economic Research

David, P., D. Foray and B. H. Hall (2009) *Measuring Smart Specialisation: The Concept and the Need for Indicators*, Knowledge for Growth Expert Group

Gordon, R. J. (2012) 'Is U.S. Economic Growth Over? Faltering Innovation Confronts the Six Headwinds', *Working Paper* No. 18315, National Bureau of Economic Research

Hausmann, R., J. Hwang and D. Rodrik (2005) 'What you Export Matters', *Working Paper* No. 11905, National Bureau of Economic Research

i24c (2016) Scaling Up innovation in the Energy union to meet climate, competitiveness and societal goals, Industrial Innovation for Competitiveness i24c

International Energy Agency (2015) *Energy and Climate Change*, World Energy Outlook Special Report

Jaffe, A., M. Trajtenberg and R. Henderson (1993) 'Geographic localization of knowledge spillovers as evidenced by patent citations', *Quarterly Journal of Economics*, 108 (3): 577-598

Kooroshy, J., A. Ibbotson, B. Lee, D. R. Bingham and W. Simons (2015) *The Low Carbon Economy: GS SUSTAIN equity investor's guide to a low carbon world, 2015-25*, Goldman Sachs, available at http://www.goldmansachs.com/our-thinking/pages/new-energy-landscape-folder/report-the-low-carbon-economy/report.pdf

McCann, P. and R. Ortega-Argilés (2015) 'Smart specialization, regional growth and applications to European Union cohesion policy', *Regional Studies* 49 (8): 1291-1302.

Murata, Y., R. Nakajima, R. Okamoto and R. Tamura (2014) 'Localized knowledge spillovers and patent citations: a distance-based approach', *Review of Economics and Statistics*, 96 (5): 967-985

Murata, Y., R. Nakajima, R. Okamoto and R. Tamura (2013) 'Localized knowledge spillovers and patent citations: A distance-based approach (revised version)', GRIPS *Discussion Paper* 12-18, National Graduate Institute for Policy Studies

Ortega-Argilé, R. (2012) 'The transatlantic productivity gap: a survey of the main causes', *Journal of Economic Surveys* 26 (3): 395–419

Peruzzi, M., G. Zachmann and R. Veugelers (2014) 'Remerge: regression-based record linkage with an application to PATSTAT', *Working Paper* 2014/10iii, Bruegel

REN21 (2016) *Renewables Global Status Report*, available at http://www.ren21.net/wp-content/uploads/2016/05/GSR_2016_Full_Report_lowres.pdf

The Economist (2007) 'Mother of invention – Why is Japan the source of so many bright ideas?', 3 August

Zachmann, G. (2012) 'Smart choices for growth', *Policy Contribution* 2012/21, Bruegel

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