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COP21 RIPPLES

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1. Changes with respect to the DoA

N/A.

2. Dissemination and uptake

Within the project: all tasks in Work Package 3
Outside the project: Policy-makers and other interested stakeholders

3. Short Summary of results (<250 words)

This report assesses the technology innovation implications of NDCs, technology portfolio choices, and international competitiveness in clean technologies. Chapter 1 consists of a quantitative analysis showing the export and innovative strength of countries in 14 low-carbon technologies. Most countries of the analyzed panel exhibit a specialization in at least one low-carbon technology. Chapter 2 estimates experience curves of energy technologies and finds that that it is likely that wind, solar and storage technologies will become much cheaper in the near future, and that this progress can be accelerated by increasing near-term investments. Fossil fuel and nuclear based technologies have only a low chance of significant future progress.

Country case studies present past experiences with low-carbon technologies, future possibilities, and discuss different policy options. Using the example of wind energy in Brazil and South Africa, the results of chapter 3 suggest that a rightly designed climate policy together with Local Content Requirements (LCR) can indeed be a driving force for a strong local industry supporting decarbonization. Chapter 4 highlights that industrial and technological competitiveness are not also always related and identifies the main barriers in China to further innovation in its PV sector. Chapter 5 determines the technological potential and competitiveness of electric mobility technologies in Italy. Chapter 6 presents an analysis of a technology innovation system (TIS) of concentrated solar power (CSP) in South Africa and identifies certain technologies in which South Africa can create a comparative advantage. Chapter 7 finds positive prospects for wind energy in the Brazilian climate policy.

4. Evidence of accomplishment

A report is submitted and uploaded in the COP21 RIPPLES website.

Contents

Introduction

Climate change is a challenge to society solvable only by a combination of policies. This comprises of policies which aim to cut emissions, change the way our economy works through new regulations and, very crucially, create innovative policies to foster technological change.

Crucial climate policies such as carbon prices and emission standards are in place to discourage carbon emissions. Such policies increase the cost of “brown industries” that currently rely on emitting activities. By creating “losers”, (employers and employees in “brown industries”) this makes such policies politically less attractive. In addition, high cost on carbon emissions – that trigger down the value chain – may put certain countries at a competitive disadvantage to countries with less stringent climate policies. As a result, policy-makers either try to delay aggressive policies or compensate the most visible “losers”. Consequently, there is a political limit to policies that discourage emissions in a heterogenous world. Besides putting a price on carbon, there is logical reasoning for policies that encourage low-carbon solutions. In contrast to policies that try to discourage emissions, they are less politically difficult as they do not generate direct losers and they may even help to develop new areas of competitiveness.[1] The improvement and development of low-carbon technologies is a key requirement to stay on the ‘well below 2°C’/1.5°C pathway to decarbonization. Current decarbonization scenarios rely heavily on advancements in innovation, and new technologies are needed to facilitate and enable the change from a fossil-based economy to a low-carbon economy. For example, a combination of public research and development in new low-carbon technologies and policies to support their own deployment is more effective in triggering innovation within these technologies than each of the policies on its own.[2] Such technological advancements in turn make decarbonisation cheaper in the country that conducted such policies, while also allowing other countries to embark on a steeper decarbonisation pathway.

But innovation policies might generate different results in different regions. One could assume that not all countries/regions have the same preconditions to innovate in each field, so that it makes sense for them to specialise in different technologies.

But decarbonisation also offers opportunities for new sectors – especially in the area of low-carbon technologies. To boost economic growth and to create jobs, countries seek to improve the competitiveness of its industries. There is a wide range of industrial policy tools that range from targeted subsidies aimed at individual companies and sectors to policies that are potentially supportive for all sectors (horizontal policies). Even horizontal policies, such as improving education or infrastructure, do not help all sectors in the same way. For instance, IT companies may benefit more from the roll-out of a fast internet infrastructure, while steel producers possibly have a larger benefit from port infrastructure. At a more detailed level, policy makers have to make choices that have a clear sectoral impact. For example, education policy prioritises investment within specific skills (e.g., university level education of world-class nuclear physicists vs. inclusive primary education to minimize

[1] Indirectly encouraging renewables might well put additional cost on consumers and increase competitive pressure for non-subsidized producers.
[2] Peruzzi et al. (2014).

low achievement). Thus, one can argue that policy makers decide (at least implicitly) on promoting competitiveness in one sector more than in another. At the same time, many policies also have a certain geographic scope. A road can be built to connect two places or two other places. The location of a newly established research centre is influential for that region.

Based on historic, geographic and other factors, countries and regions have different competitive strengths in various sectors. For instance, the south-west of Germany specializes in producing expensive cars while southern Poland is strong in coal mining, and the city of London is a hub for financial services. However, it is also evident that regions which specialise in specific sectors may find it challenging to develop strengths in other sectors. This implies that policy makers have influence to shape a potential strength of a sector within a region, but the success of such policies will depend on the underlying potential of the region to develop a strength in this sector.

This report, drafted for the COP21 RIPPLES project, strives to answer which country can establish an export and technological specialization in low-carbon technology. Chapter 1 presents a quantitative analysis which aims to identify potential strengths in technologies based on the strength in related products and patents. Prior research has shown that countries often exhibit competitive advantages in similar technology clusters, as technologies require each other or there are spill over effects. Using data on gross exports and patent counts, we construct technology networks that measure the strength between these technologies and use these as a basis to estimate the potential in low-carbon technologies.

Another important aspect of the decarbonization-innovation nexus is not only the potential strength in a technology, but also the speed of innovation. If clean technologies become cheaper than traditional technologies, then not only will the speed of decarbonization be increased, but also the economic and political sphere will be easier to navigate. Chapter 2 takes a look at this issue and tries to estimate experience curves of low-carbon technologies.

While chapter 1 and 2 take a more macro-perspective, chapters 3 to 7 zoom in and present country case studies about past experiences with low-carbon technologies and future possibilities. Different policies are discussed as well.

Chapter 3 analyses local content requirements (LCR) and financial incentives to boost the wind sector in Brazil and South Africa. Local content requirements mandate deployers to use products that contain a certain minimum amount of locally produced products. Together with other climate policies, LCR can be policy tool to steer decarbonization in an economically viable direction. Using the example of wind energy in Brazil and South Africa, the results of chapter 3 suggest that a rightly designed climate policy together with LCR can indeed be a driving force for a strong local industry supporting decarbonization.

Chapter 4 looks at the challenges and opportunities of the Chinese PV sector. This chapter highlights that industrial and technological competitiveness are not also always related. Although China has developed a very strong PV sector that supplies large parts of the global PV market, it still faces challenges to build up a PV sector that operates at the technological frontier. The chapter tries to identify the main barriers in China to further innovation.

Chapter 5 determines the technological potential and competitiveness of electric mobility technologies in Italy. Although Italy has a traditionally strong automotive sector, it struggles to keep up with the trend of battery electric cars. Chapter 5 aims to explain that situation and tries to identify low-carbon business opportunities in the electric vehicle sector for Italy.

Chapter 6 presents an analysis of a technology innovation system (TIS) of concentrated solar power (CSP) in South Africa. This chapter, using interviews as input, is able to identify certain technologies in which South Africa can create a comparative advantage.

Chapter 7, an addendum, sets out the prospects for wind energy in the Brazilian climate policy.

The report finishes with concluding remarks.

1. Determining future comparative and technological advantage in low-carbon technologies

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Abstract

This chapter provides an overview about countries' competitiveness in 14 low-carbon technologies. We calculate the "revealed comparative advantage" (RCA), which measures a country's degree of export specialization by using gross export data, and the "revealed technological advantage" (RTA), which assess a country's specialization in innovation by using patent count data. We find that larger countries sustain specializations in several technologies, while smaller countries specialize in fewer technologies. Most countries of the analyzed panel exhibit a specialization in at least one low-carbon technology. Through reliance on a method by Hausmann et al. (2014), we are also able to estimate the "potential revealed comparative advantage" (pRCA) and "potential revealed technological advantage" (pRTA) of a country per low-carbon technology. Certain technologies, such as nuclear, remain exclusive for a small number of countries which are already strong in exporting or innovating nuclear technology. Other technologies, such as "efficient heating and cooling", "efficient combustion technologies" and "insulation" are promising for several countries in terms of export specialization. The results of this chapter should be interpreted as an indication of where export and innovation potentials exist and could be further exploited. Subsequent country-level analysis is needed to translate these results into concrete recommendations and policy actions.

1.1. Introduction

In order to facilitate the transition to a carbon-neutral economy and economic system, countries and their policy-makers have to see the economic advantages in order start the transition. The necessary policy-change is much easier to pass and implement if co-benefits in terms of economic advantages can be reached. This chapter takes this perspective and tries to identify current strengths in low-carbon technologies which is measured in innovation and trade, as well as to estimate future potential strengths.

We focus on a choice of fourteen low-carbon technologies by assessing gross exports as well as the number of granted patents of the given technology. In the following, we use the term "technology" to describe either the products associated with that technology or the patents granted to protect that technology. Therefore, we use the term "export of technology" to describe the exports of products associated with that technology rather than technological transfer.

Following the theory of revealed comparative advantage, every country has a set of technologies it can relatively specialize in. Larger countries will be able to export more of any technology in general, but nonetheless some kind of specialization will be happening. Smaller countries have to think carefully in which technology they have a relative advantage as resources to build up an advantage through industrial policy measures are scarce.

A country's strength in a technology can be measured by its success of exporting that technology. Larger countries tend to export more, but, the relative export strength of a country in each technology reveals information about the underlying comparative advantages of the country in the individual technologies. For example, if one of two otherwise similar countries exports ten times as many solar panels than wind turbines, while another one exports ten times as many wind turbines as solar panels, the first one appears to exhibit a comparative advantage in solar panels while the second one in wind turbines.

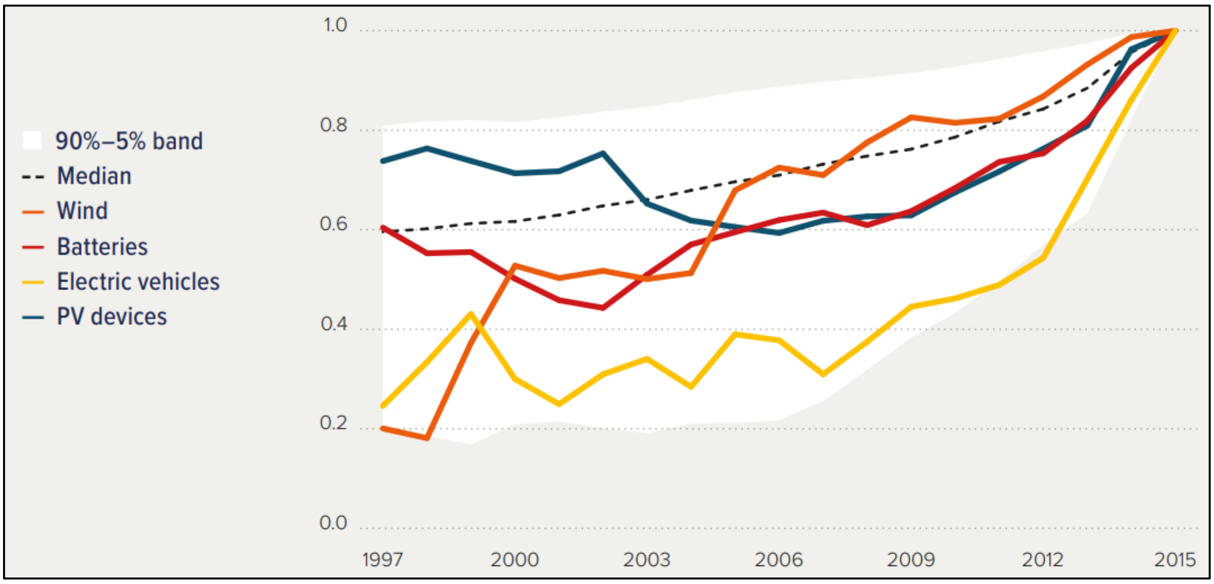
We assess a country's relative strength in a technology with two measures: gross export figures to determine the revealed comparative advantage (RCA) and patenting numbers to determine the revealed technological advantage (RTA). The revealed advantage in a technology of a country is defined by a fraction of two shares. For the RCA, the technology's share of export on total exports of that country is divided by the global export share that the technology exhibits worldwide (sum of worldwide export of that technology divided by the sum of all worldwide exports). The same methodology is used to calculate the RTA using patents counts instead of gross exports.

A country that has a higher share of exports of a specific technology than the world-wide share thus has a revealed comparative advantage and with a share below the worldwide share a disadvantage (same holds true for patents for the RTA). The RCA indicates a country's relative specialization in exporting a good, while the relative technological advantage (RTA) measures a country's relative specialization in patenting a technology. The next section 1.2 will go into more detail regarding the definition of these metrics and the underlying data.

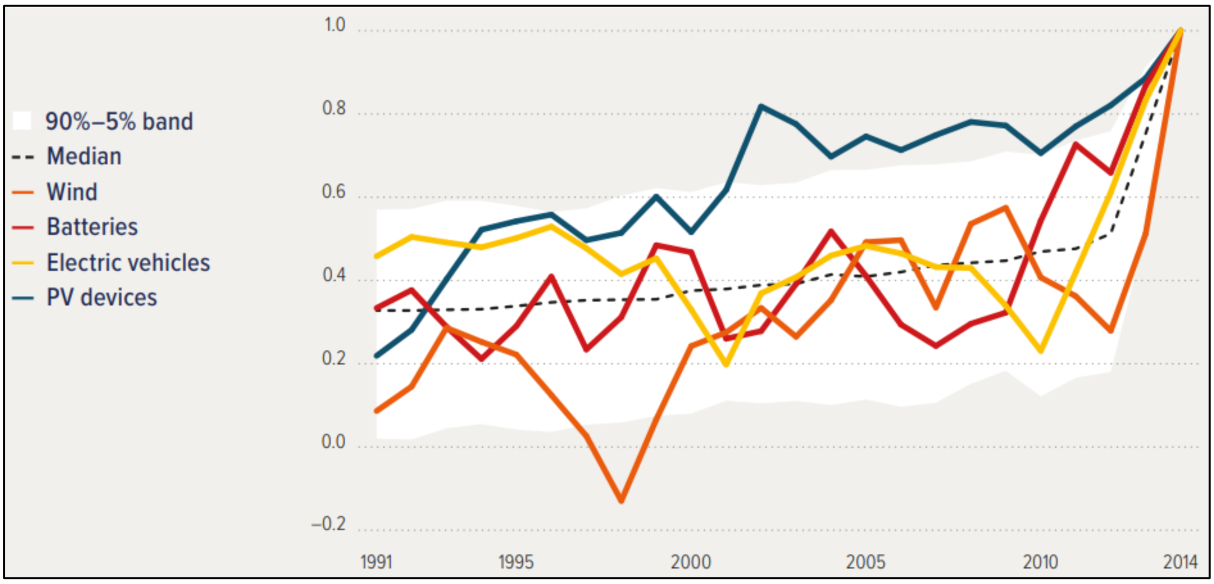
Export specialization patterns are found to be quite path-dependent. Figure 1-1 shows that for half of the products (the median), the correlation between the 2015 revealed comparative advantage (RCA, specialization in exports) and the RCA in the same product 10 years earlier is 0.7 or higher. This persistency implies that countries rarely make large jumps in terms of the products that they are particularly good or bad at exporting. However, compared to other exported products, the path dependency in low-carbon exports such as wind turbines, electric vehicles and batteries appears to be relatively low. This indicates that certain countries might find it easier to develop new strength in these sectors and that countries can still develop new specializations in low-carbon technologies.

Figure 1-1: Correlation between current (2015) and past specialization

Exports, 1997 – 2015, showing RCA



Technology, 1997 – 2015, showing RTA



Source: Zachmann and Kalcik (2017), based on UN Comtrade and EPO PATSTAT.
Note: The dashed line is the median correlation, across 5,842 export products and 640 technologies/patent codes. The shaded area comprises the RCA and RTA correlations of all technologies between the 5th and the 95th percentiles of the distribution.

The reasons for a revealed comparative advantage can be manifold reaching from capital and labour endowment, human capital and skills, to geography and resources. This chapter will neither cover the theory and nor does it try to identify the exact reasons for a technological specialisation. Instead, it investigates countries' potential to develop a specialization — both in terms of exports and patenting — in certain low-carbon technologies based on their strength in related sectors and developments in similar countries. The analysis relies on systematic evidence originating from the regional growth literature triggered by Hidalgo et al. (2007), which found that countries diversify into industries that are closely related to current export strengths.

The rest of the chapter is structured as follows. Section 1.2 discusses the choice of technologies and the data used for the analysis. Section 1.3 outlines the methodology, section 0 presents and discusses the results and section 1.5 concludes.

1.2. Technologies and Data

Our analysis is based on data from 188 countries between 2003 and 2012. Results of the analysis are only shown for selected countries (EU28, EEA, G20, and Israel), yet our calculations are based on the full dataset.

To our knowledge, no consistent list of products exists which define "green" or "low-carbon" products. There are numerous sets with different scopes, levels of depths, and ambition areas used by different actors. For this paper, we chose to rely on a list of "low-carbon products" used in a report by Dechezleprêtre et al. (2015) that defines 14 product/technology groups. It consists of one or several 6-digit HS codes per group (see Table 1-1 for an overview and Table 1-4 in the annex for the products and patents used).

Table 1-1: List of low-carbon technologies

Technology
Solar PV energy
Solar thermal energy
Wind energy
Hydro energy
Energy management
Efficient lighting
Heating and cooling
Combustion
Residential insulation
Biofuels
Batteries
Electric cars
Efficient rail transport
Nuclear

Source: Dechezleprêtre et al. (2015).

These 14 product groups are matched to (groups of) patents that are based on technology categories which are a part of the *Research & Innovation Priorities* of the EU Energy Union. See Fiorini et al. (2017) for an overview of the technologies covered and the associated patent codes.

1.2.1. Products

To measure a country's export specialization and its potential comparative advantage, we rely on export data by the UN Comtrade database. Exports are measured in gross terms and are denoted in US Dollars for all countries. The harmonised system (HS) is a tariff nomenclature that classifies traded products using a digit system. We use the 6-digit level to classify our products to the prior mentioned low-carbon technology groups. In total, 5477 HS codes are used to classify the products into different categories. 14 low-carbon technologies, comprised out of one or more HS-codes, are added to this panel.

Table 1-2 provides an overview over the exports of low-carbon technologies as recorded in the UN Comtrade database. We show aggregated exports in the period of 2008 to 2012. On the country side, China, Germany, Japan and the US, dominate low-carbon technology exports with each country exporting over USD 100 billion in that five-year period. China and Japan exported products related solar PV technologies and batteries while Germany mainly exported solar PV and efficient combustion while the US exported efficient combustion technologies. That is reflected by the technology side as products related to solar PV, efficient combustion technologies, and batteries make up for most low-carbon exports.

Table 1-2: Sum of exports in billion USD (2008-2012) of low-carbon technologies

	Solar PV	Solar thermal	Wind	Hydro	Energy management	Efficient lighting	Efficient heating and	Efficient combustion	Residential insulation	Biofuels	Batteries	Electric cars	Efficient rail transport	Nuclear	*Sum per country*
Argentina	0.00	0.01	0.06	0.19	0.02	0.01	0.10	0.19	0.04	0.12	0.06	0.00	0.00	0.00	*1*
Australia	0.26	0.02	0.06	0.02	0.02	0.13	0.14	0.58	0.07	0.08	0.12	0.04	0.00	0.01	*2*
Austria	1.93	1.05	0.09	0.70	0.01	0.29	1.75	2.15	0.60	0.46	2.26	0.01	0.00	0.04	*11*
Belgium	5.19	0.17	0.26	0.08	0.03	0.79	1.41	3.15	2.31	1.92	2.26	0.77	0.00	0.07	*18*
Bulgaria	0.12	0.02	0.30	0.05	0.04	0.02	0.05	0.05	0.02	0.15	1.09	0.01	0.00	0.00	*2*
Brazil	0.01	0.01	0.28	0.58	0.08	0.10	0.28	0.37	0.07	10.29	0.87	0.08	0.00	0.00	*13*
Canada	0.73	0.06	0.65	0.19	0.11	0.85	1.23	7.73	0.88	0.51	0.76	0.18	0.00	0.31	*14*
Chile	0.64	0.21	0.02	0.49	0.35	0.21	1.12	13.61	0.41	0.01	0.73	0.02	0.00	0.00	*18*
China	108.83	0.75	3.95	2.34	2.41	24.48	5.19	9.79	4.10	0.35	53.67	0.25	0.05	0.07	*216*
Cyprus	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	*0*
Czech Republic	4.10	0.09	0.30	0.27	0.04	0.53	2.19	2.26	1.01	0.22	4.66	0.01	0.00	0.26	*16*
Germany	34.66	2.13	12.29	0.92	0.32	4.95	13.55	32.99	6.42	1.25	12.67	0.19	0.01	1.63	*124*
Denmark	0.23	0.17	15.66	0.04	0.04	0.10	1.95	2.38	0.23	0.05	0.27	0.02	0.00	0.00	*21*
Spain	4.50	0.19	6.69	0.52	0.02	0.23	1.26	1.72	0.55	1.20	3.92	0.26	0.04	0.04	*21*
Estonia	0.03	0.00	0.10	0.01	0.00	0.02	0.12	0.07	0.11	0.00	0.05	0.00	0.00	0.00	*1*
Finland	0.15	0.02	0.04	0.02	0.06	0.13	0.53	0.70	0.42	0.02	0.11	0.27	0.00	0.02	*2*
France	2.86	0.95	0.24	0.73	0.41	2.24	8.29	15.73	1.51	4.87	5.20	0.86	0.00	1.55	*45*
United Kingdom	4.24	0.22	0.16	0.13	0.54	0.77	1.81	19.77	1.77	0.76	3.05	0.78	0.00	0.25	*34*
Greece	0.23	0.21	0.19	0.00	0.26	0.02	0.07	0.15	0.10	0.00	0.55	0.00	0.00	0.00	*2*
Croatia	0.54	0.00	0.06	0.01	0.00	0.01	0.06	0.48	0.42	0.03	0.16	0.00	0.00	0.00	*2*
Hungary	2.42	0.04	0.01	0.01	0.27	0.95	1.02	3.45	0.40	0.81	1.14	0.01	0.00	0.00	*11*
Indonesia	0.19	0.01	0.70	0.00	0.17	0.97	0.09	0.48	0.05	0.23	2.29	0.02	0.00	0.00	*5*
India	2.19	0.06	2.65	0.19	0.32	0.15	0.74	2.24	0.10	0.51	0.81	0.13	0.00	0.01	*10*
Ireland	0.12	0.01	0.08	0.00	0.00	0.07	2.09	0.11	0.20	0.03	0.12	0.00	0.00	0.00	*3*
Iceland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	*0*
Israel	0.02	0.18	0.09	0.02	0.00	0.01	0.58	1.69	0.01	0.00	0.34	0.02	0.00	0.00	*3*
Italy	2.09	0.53	1.35	0.55	0.16	0.93	9.20	26.40	0.55	0.36	4.67	0.29	0.00	0.02	*47*
Japan	34.47	0.02	1.06	0.26	0.01	0.68	5.39	16.71	1.60	0.02	37.84	2.46	0.00	0.95	*101*
South Korea	17.47	0.06	0.14	0.07	0.02	4.68	4.80	6.79	0.23	0.02	27.54	0.07	0.01	0.22	*62*
Lithuania	0.03	0.01	0.02	0.00	0.08	0.03	0.11	0.08	0.30	0.07	0.05	0.00	0.00	0.00	*1*
Luxembourg	0.51	0.00	0.00	0.00	0.00	0.01	0.17	0.01	0.01	0.00	0.32	0.01	0.00	0.00	*1*
Latvia	0.00	0.01	0.06	0.00	0.00	0.15	0.02	0.01	0.06	0.09	0.02	0.00	0.00	0.00	*0*
Mexico	4.13	1.84	0.42	0.06	1.94	0.37	3.00	6.91	0.56	0.03	7.35	0.12	0.00	0.00	*27*
Malta	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.06	0.00	0.00	0.02	0.00	0.00	0.00	*0*
The Netherlands	7.36	0.33	0.67	0.02	0.07	2.00	1.93	6.85	1.84	3.94	3.14	0.64	0.01	2.57	*31*
Norway	0.90	0.00	0.25	0.06	0.00	0.01	0.08	0.45	0.05	0.00	0.06	0.02	0.00	0.00	*2*
Poland	0.35	0.73	0.23	0.01	0.27	2.25	1.21	1.98	2.09	0.25	3.15	1.14	0.00	0.01	*14*
Portugal	0.49	0.08	0.82	0.01	0.06	0.39	0.08	0.43	0.15	0.02	0.58	0.00	0.00	0.00	*3*
Rumania	0.18	0.06	0.11	0.11	0.06	0.14	0.15	0.44	0.03	0.11	0.40	0.02	0.00	0.00	*2*
Russia	0.10	0.01	0.02	0.12	0.09	0.12	0.62	1.36	0.46	0.18	0.26	0.01	0.00	0.55	*4*
Saudi Arabia	0.00	0.01	0.24	0.09	0.01	0.01	0.02	0.31	0.06	0.00	0.36	0.04	0.00	0.00	*1*
Slovakia	0.30	0.05	0.26	0.00	0.05	0.11	0.79	0.64	0.32	0.47	0.20	0.10	0.00	0.00	*3*
Slovenia	0.21	0.02	0.00	0.28	0.50	0.01	0.31	0.28	0.55	0.00	0.83	0.00	0.00	0.00	*3*
Sweden	2.09	0.07	0.28	0.05	0.08	0.65	4.46	8.67	1.01	0.44	1.81	0.03	0.00	0.12	*20*
Turkey	0.03	0.12	1.55	0.02	0.03	1.19	0.36	0.63	0.47	0.09	1.31	0.16	0.00	0.00	*6*
USA	15.71	0.89	2.24	0.40	1.63	4.57	6.84	61.76	4.35	8.50	15.72	5.92	0.01	0.56	*129*
South Africa	0.62	0.01	0.43	0.01	0.37	0.06	0.08	0.15	0.05	0.69	0.28	0.08	0.00	0.04	*3*
Sum per technology	*262*	*11*	*55*	*10*	*11*	*56*	*85*	*263*	*37*	*39*	*203*	*15*	*0*	*9*	*1057*

Source: UN Comtrade.

1.2.2. Patents

Innovation activity is measured by the number of patents filed in a specific patent category inside of a country. Patents data stems from the PATSTAT database of the European Patent Office (EPO). To establish comparability, we only use patents filed at the EPO and those filed under the Patent

Cooperation Treaty (PCT) worldwide. Filling a patent under the PCT is a facilitated way to protect intellectual property in several jurisdictions and is typically used important and economically relevant patents. That choice, using all patents applied at the EPO and all worldwide PCT patents, is mainly done to ensure comparability as well as capturing only high-quality patents. We must admit though that the inclusion of EPO patents potentially leads to a skewed picture towards the EU.

To classify the patents into low-carbon technologies, we use the Cooperative Patent Classification (CPC) scheme as our classification tool as it is developed and maintained by the EPO and the United States Patent and Trademark Office (USPTO). The CPC not only has technology-based patent codes to classify patents, but also cross-technological codes (so-classed CPC-Y codes) which were especially introduced to identify low-carbon technologies. Our patent panel exists in total of 649 different technologies (non "Y"-codes) as well as the 14 specified low-carbon technologies. To avoid double counting, we do not include the CPC-Y codes our panel but indirectly via our 14 low-carbon technologies.

To avoid double counting of patents in general, we do not take all patents into account but only the earliest occurrence date of a patent family. Often, the same patent is filled at several patent offices however within the same patent family. Using patent family counts instead of patent counts rules out double counting of the exact patent filed at different offices.

The number of patents attributed to a country is based on the location of the inventor of the patent. The patent holder may be in a different country from the inventor. The earliest application of individual patent families is used and attributed in fractions to all inventor countries and technology codes. That means that a patent count of one gets distributed over multiple inventors and multiple categories, if applicable. The rational of fractional counting (regarding inventor countries and technology codes) is to avoid an artificial inflation of patent counts due to several inventors or multiple classifications. This is especially relevant in the context of an increasing internationalisation where several inventors from multiple countries work together on the same patent. However, we are aware that fractional counting, while eliminating the bias of patent count inflation, introduces a bias of unequal patent counting. Single technology and single inventor patents are favoured in a fractional counting regime.

As shown in Table 1-3, Germany, the US, Japan, and South Korea are dominating patenting in low-carbon technologies. In combination with Table 1-2, it seems that certain countries (like China) have comparably low patenting activity compared to their strong export profile, while other countries have comparably low export figures in relation to their patenting activity.

Table 1-3: Number of patents (2008-2012) of low-carbon technologies

	Solar PV	Solar thermal	Wind	Hydro	Energy management	Efficient lighting	Efficient heating and cooling	Efficient combustion	Residential insulation	Biofuels	Batteries	Electric cars	Efficient rail transport	Nuclear	*Sum per country*
Argentina	1	2	1	2	1	0	0	0	0	0	0	0	0	0	*6*
Australia	71	57	31	19	1	8	21	8	1	48	18	5	7	1	*296*
Austria	53	65	53	29	2	45	21	14	6	37	36	15	8	1	*386*
Belgium	57	26	45	9	3	17	32	7	6	19	17	0	2	2	*242*
Bulgaria	2	3	5	2	0	2	0	0	0	0	2	0	0	0	*16*
Brazil	3	4	19	8	1	3	5	3	0	57	3	4	0	0	*109*
Canada	81	32	66	24	6	41	25	22	4	121	62	10	7	19	*520*
Chile	154	78	39	16	4	42	32	63	2	21	45	9	2	3	*510*
China	322	144	298	51	7	262	148	20	20	121	271	48	16	17	*1746*
Cyprus	0	2	1	1	1	0	0	0	0	0	0	0	0	0	*4*
Czech Republic	5	6	2	6	0	1	4	3	1	6	6	0	1	2	*42*
Germany	1252	566	1008	108	32	264	256	251	54	492	948	291	49	89	*5661*
Denmark	17	16	892	5	1	6	34	8	3	73	7	2	0	0	*1065*
Spain	89	211	304	24	2	10	19	8	0	41	18	5	1	3	*734*
Estonia	1	0	1	0	0	0	3	0	0	3	0	0	0	0	*8*
Finland	32	5	35	5	1	17	20	25	0	72	17	9	0	0	*237*
France	261	119	110	56	8	36	127	89	11	159	321	73	26	92	*1488*
United Kingdom	173	47	248	94	9	60	70	35	11	113	67	37	2	5	*970*
Greece	6	8	8	1	0	1	0	0	1	7	1	0	1	0	*32*
Croatia	0	1	3	3	0	1	0	0	2	0	1	0	0	0	*11*
Hungary	3	5	6	3	0	25	4	1	0	6	1	1	1	0	*55*
Indonesia	0	0	1	0	0	0	0	1	0	2	0	0	0	0	*4*
India	28	23	69	14	4	7	16	19	0	49	17	7	1	0	*255*
Ireland	8	3	14	33	0	2	5	1	0	9	2	0	0	0	*77*
Iceland	0	0	0	0	0	0	0	0	0	1	0	0	0	0	*1*
Israel	76	108	31	11	1	8	7	6	0	25	15	5	1	0	*294*
Italy	159	162	108	26	4	33	91	51	7	90	58	20	7	10	*827*
Japan	2539	196	445	54	43	296	405	167	10	427	3137	793	29	142	*8682*
South Korea	974	81	179	63	21	148	159	43	15	126	729	56	5	31	*2629*
Lithuania	0	0	3	1	0	0	3	1	0	0	0	0	1	0	*9*
Luxembourg	2	3	4	0	0	0	3	0	0	2	3	0	0	0	*17*
Latvia	1	0	1	0	0	0	0	1	0	1	0	1	0	0	*5*
Mexico	1	11	8	1	1	7	3	2	0	6	1	0	0	0	*40*
Malta	0	2	0	0	0	0	1	0	0	0	2	0	0	0	*5*
The Netherlands	149	28	130	13	2	145	42	22	10	135	24	8	2	2	*713*
Norway	23	5	53	32	1	1	5	7	0	30	1	0	0	1	*161*
Poland	3	6	12	5	1	2	12	4	2	19	4	1	0	0	*71*
Portugal	13	8	7	4	0	0	6	0	0	4	2	1	1	0	*46*
Rumania	6	0	2	5	0	0	0	4	0	1	1	0	0	0	*18*
Russia	23	10	44	15	0	16	5	11	0	28	11	4	1	19	*188*
Saudi Arabia	2	2	0	1	0	0	1	4	0	1	0	0	0	0	*11*
Slovakia	3	4	2	3	0	2	1	0	0	1	0	0	2	1	*18*
Slovenia	5	4	1	2	0	1	3	0	1	3	4	0	0	0	*24*
Sweden	34	34	68	7	3	5	38	36	1	77	55	31	3	14	*406*
Turkey	7	15	11	5	0	2	5	0	1	4	3	2	0	0	*54*
USA	2117	472	785	100	57	410	188	370	41	1203	913	165	31	211	*7064*
South Africa	3	13	9	7	2	3	0	3	0	14	2	0	0	1	*57*
Sum per technology	*8762*	*2587*	*5162*	*866*	*220*	*1929*	*1819*	*1308*	*211*	*3654*	*6824*	*1599*	*204*	*666*	*35813*

Source: EPO Patstat.

1.3. Methodology

In the first part of this section, we describe in detail how to calculate a country's "revealed comparative advantage" (RCA) in trade or "revealed technological advantage" (RTA) in patents. The second part of this section is devoted to the explanation of the estimation of the "potential revealed comparative advantage" (pRCA) and "potential revealed technological advantage" (pRTA).

1.3.1. Current comparative and technological advantage

1.3.1.1. Revealed comparative advantage (RCA)

We base our assessment of the current competitive status of countries within the 14 defined technology groups on the revealed comparative advantage (RCA). We follow a common definition of a revealed comparative advantage (Balassa, 1965). A country's RCA in a certain product is defined by the product's share of exports on the country's total exports divided by that product's world export share.

Thus, the RCA can be written as:

$$RCA_{il} = \frac{x_{il}}{\sum_i x_{il}} \Big/ \frac{\sum_l x_{il}}{\sum_{il} x_{il}} \tag{1}$$

The index i indicates a product and the index l defines a country. For better readability, we have dropped the time index. x_{il} are the gross exports of country l in product of i. $\sum_i x_{il}$ is the sum of all gross exports of country l. The term $\sum_l x_{il}$ is the sum of exports of product i of all countries. The expression $\sum_{il} x_{il}$ is the sum of worldwide exports of all products of all countries.

We do not use the RCA as defined in (1), but a standardized version as shown in (2) so that values lie in an interval of 0 and 1, whereas 0 reflects no revealed comparative advantage at all, 0.5 neither advantage nor disadvantage, and 1 is a very strong revealed advantage. The standardized RCA has the advantage that possible values are bound between (including) 0 and 1, whereas the no-standardized RCA cannot be below zero but has no upper bound.

$$RCA_{standaridized} = \frac{\frac{RCA_{not\ standaridized} - 1}{RCA_{not\ standaridized} + 1} + 1}{2} \tag{2}$$

When the term RCA is mentioned subsequently, we refer always to the standardized values as defined above.

1.3.1.2. Revealed technological advantage (RTA)

Following the OECD (2018) definition of 'revealed technological advantage' (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 [...]. 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 definition of RTA follows the same logical as the definition of RCA: a country's revealed technological advantage is the share of patents of that technology on all the country's patents divided by the technology's world-wide share:

$$RTA_{il} = \frac{y_{il}}{\sum_i y_{il}} \Big/ \frac{\sum_l y_{il}}{\sum_{il} y_{il}} \tag{3}$$

y_{il} is the number of patents of technology i in country l. Like the RCA, the RTA will be used in its standardized form so that values are in an interval of 0 and 1, where 0 reflects no revealed comparative advantage at all, 0.5 neither advantage nor disadvantage, and 1 is a very strong revealed advantage.

$$RTA_{standaridized} = \frac{\frac{RTA_{not\ standaridized} - 1}{RTA_{not\ standaridized} + 1} + 1}{2} \quad (4)$$

When the term RTA is mentioned subsequently, we refer always to the standardized values as defined above.

1.3.2. Future potential comparative and technological advantage

To estimate potential competitiveness of a country in a low-carbon technology, we rely on export and patent data. Based on a methodology by Hausman et al. (2014), we can calculate the potential RCA (pRCA) and potential RTA (pRTA) of a country in a low-carbon technology.

The methodology by Hausman et al. (2014), developed to estimate pRCA, assumes a relationship between the comparative advantage of products. For instance, a country's comparative strength in one product can imply a potential strength of another product, given there is a link either between the products or countries. Hausman et al. (2014) construct a product- and country-density space to estimate the pRCA. These product density spaces are based on pairwise correlations of RCA values. In order that one product has a positive influence on another product's pRCA, two conditions have to be fulfilled. First, the product's RCA has to be strong and second there needs to be an existing link between the two products.

The structure to obtain pRCA values is the following. Using RCA values based on 2003-2007 trade data, we fit a model explaining 2008-2012 RCA values. The coefficients we obtain from that model are used to estimate pRCA values using 2008-2012 RCA values as an input.

1.3.2.1. Potential comparative advantage (pRCA)

In the following, we describe in detail the steps to obtain the pRCA values of country's low-carbon technologies.

1.3.2.1.1. Compute RCA values

In the first step, we use the UN Comtrade trade database to calculate RCA values for all available 5477 products (based on 6-digit HS codes) and the 14 low-carbon technologies. As the 14 low-carbon technologies consist of one or several HS codes, the RCA values are calculated in such a way that the RCA values of the 5477 products are not affected by the addition of the 14 low-carbon technologies.

Based on the formulas (1) and (2) as presented in the previous section, we calculate standardized RCA values for products on country level.

1.3.2.1.2. Correlation matrices

Using the matrix of country-product RCAs, we calculate two correlation matrices: the product-correlation matrix $\phi_{ii'}$ and the country correlation matrix $\phi_{ll'}$.

$$\phi_{ii'} = \frac{1 + corr\{RCA_i, RCA_{i'}\}}{2} \quad (5)$$

$$\phi_{ll'} = \frac{1 + corr\{RCA_l, RCA_{l'}\}}{2} \quad (6)$$

These correlations are defined in the way that they are non-negative. Positive correlations are expressed by values from 0.5 to 1, negative correlation by values between 0 and 0.5 and no correlation is expressed by 0.5. The product-correlation matrix $\phi_{ii'}$ measures the similarity between products by expressing how strong the RCA-pattern of a product are associated with any other product. Two products are regarded to be similar if several countries share similar RCA patterns in these two products. The country-correlation matrix $\phi_{ll'}$ measures the similarity between two countries by expressing how strong the RCA-patterns of these two countries are associated with each other. The two are regarded to be similar if they exhibit equivalent RCA patterns in comparable sizes, thus having similar-sized RCAs in similar products.

In order to only measure the influence by related technologies or countries, we set all own-correlations to zero, which are the diagonal of the correlation matrix. On top, we set the correlations of those technology-product pairs to zero, which constitute a joint technology. For instance, the technology "wind", as defined in Table 1-4 in the Annex, is comprised of the two HS codes 850231 and 730820. Hence, correlations between "wind" and 850231 and "wind" and 730820 are set to zero.

1.3.2.1.3. Top correlates

In order to improve the fit of our model, we apply filtering techniques on the number of product and country correlates that will be used for further calculation. We decided to use the following thresholds to calculate the pRCA and pRTA: only the top 10% (90% percentile) correlates of each product, and the top 50% correlates of each country are used subsequently.[3] In technical terms, the matrices $\phi_{ii'}$ and $\phi_{ll'}$ are scanned row-wise and all correlates that are smaller than the above quantile-thresholds are then set to 0.

1.3.2.1.4. Weighted sums

The remaining product and country correlates are row-wise weighted by dividing them by their corresponding row sums. We obtain two weight matrices which are both multiplied with the original country-product RCA matrix. Thus, we obtain two country-product RCA matrices of which one is adjusted by weighted product and the other by weighted country correlations.

In a subsequent step, we calculate the weighted product and country densities. For each country-product RCA value, there is one product and one country density value. Those values are the sum of all other RCA values, however, as explained above, weighted by the weighted and filtered correlations.

In terms of equations, the weighted product sums per RCA value per country are expressed as following.

$$w(u)_{il}^{PS} = \sum_{i' \in I_{iu}} \frac{\phi'_{ii}}{\sum_{i`` \in I_{iu}} \phi_{ii``}}, RCA_{il} \tag{7}$$

The intuition is the following: for each RCA_{il} (product i and country l), the weighted product density $w(u)_{il}^{PS}$ depends on the filter u and is defined as a sum of weighted values. Row-wise, every element of the product-correlation matrix ϕ'_{ii} is divided by sum of the corresponding row ($\sum_{i`` \in I_{iu}} \phi_{ii``}$). Please note, that u is our percentile filter by which we carry on only the top correlates and defines a set I_{iu} from which values are considered to be summed up. These weights are multiplied with the corresponding RCA value and then summed up per product ($\sum_{i' \in I_{iu}}$).

[3] Please note that Hausman et al. (2014) use a discrete threshold of the 50 closest regions and products. We use the 90% percentile to filter for the most strongly correlated regions, products, and technologies. Sensitivity tests have confirmed that the 90% percentile is a good compromise between under- and overfitting.

To calculate the weighted country density, we apply the same method but use the country correlation matrix as an input. Hence, the weighted country density is defined as following:

$$w(v)_{il}^{CS} = \sum_{l' \in L_{lv}} \frac{\phi'_{ll}}{\sum_{l`` \in I_{lu}} \phi_{ll'}} RCA_{i'l} \quad (8)$$

In a final step, both matrices that contain the weighted product and country densities are stacked vertically, so we obtain two column vectors with each of length of a product between all products and all countries. These vectors are used subsequently as regressors in the linear regression below.

1.3.2.1.5. Zero-inflated beta regression

To obtain the value of the potential revealed comparative advantage (pRCA) of every country-product combination, we fit a zero-inflated beta regression. The beta distribution can only take values in the range between zero and one. By using a zero-inflated beta distribution, zeros can also be modelled. The zero-inflated beta regression takes the following functional form.

$$\text{if y} = 0: \qquad f(y) = \upsilon$$

$$\text{if y} = (0,1): \qquad f(y|\mu,\sigma) = (1-\upsilon)\frac{\Gamma(\sigma)}{\Gamma(\mu\sigma)\Gamma\big((1-\mu)\sigma\big)} y^{\mu\sigma}(1-y)^{((1-\mu)\sigma)-1} \quad (9)$$

The parameter $\Gamma(\,.\,)$ describes a gamma function, the parameters satisfy the following conditions: $0 < \mu < 1, \sigma > 0$ and $0 < \upsilon < 1$. The parameters μ and σ define the shape of the beta distribution, while υ defines the likelihood of value to be exactly zero. The parameters of the model as well as the coefficients are obtained using a numerical algorithm. We rely on the R package *GAMLSS*[4] which implements that model with the function *BEZI()*[5].

As explaining regressors, we use the product density $w(u)_{il}^{PS}$, the country density $w(v)_{il}^{CS}$ and a constant to fit the model.

1.3.2.1.6. pRCA values

The potential comparative advantage values are obtained by calculating fitted values. In a first step, we calculate the RCA values and RCA correlations matrices based on 2003-2007 export data. With this data input, we undergo the steps as described above, and fit the model (9). Our regressors rely on 2003-2007 data, while our variable to be explained are RCA values based on 2008-2012 data. Using the obtained coefficients, we calculate the fitted values but using 2008-2012 trade data to calculate the RCA and correlation matrices.

With this approach, we aim to estimate the potential revealed comparative advantages of countries in products. We assume that the effect remains the same that explains RCAs based on 2008-2012 data with product and country densities based 2003-2007 data.

1.3.2.2. Potential technological advantage (pRTA)

To estimate a country's potential RTA in a low-carbon technology, we apply a similar method as explained above to estimate the pRCA. We rely on the different correlational patterns in patenting to measure the relatedness of two technologies. We use that measure to estimate the potential RTA based on the strength in related technologies.

[4] http://www.gamlss.com
[5] https://www.rdocumentation.org/packages/gamlss.dist/versions/5.0-6/topics/BEZI

The methodology is inspired by Hausman et al (2014) and thus alike to calculating pRCA as outlined in section 1.3.2.1. However, there are a few differences. Instead of calculating a related product and a country density to explain future RCA, we only use relatedness in technologies and do not factor in the country component. However, instead of relying only on one measure of technological relatedness (such as RTA correlation for pRCA), we use different methodologies to calculate 18 measures for closeness, called technological networks subsequently. However, we do not use all these 18 networks as explanatory variables but apply a principal component analysis (PCA) to filter out the most important information. The general structure of using 2003-2007 RTA values (based on patent data) to explain 2008-2012 RTA values and to make use of the obtained coefficients to calculate pRTA values using 2008-2012 RTA values stays the same.

1.3.2.2.1. Technological networks

As basis for the pRTA estimation, we calculate RTA values on 2003-2007 patenting data for all the all available patent classes and the 14 low-carbon technologies of all countries. We construct 18 different technological networks that are based on four different geographic levels of measurement (country, NUTS region[6], inventor, application) and different theoretical concepts. We borrow the definitions of the technological networks from several papers (Yan and Luo, 2015; Joo and Kim, 2009; Stellner, 2014).

The technological networks reflect different approaches on how to measure related patent classes and thus technologies. Some use correlations of RTA values (on different geographic levels) between different patent classes while others consider whether patent classes appear on the same patent filing. Table 1-5 in the annex of this paper provides a complete overview of all networks used and their definitions.

All technology networks, as in the case of the correlation matrices pro calculating the pRCA values, are weighted by dividing them by their corresponding sums. The weighted network matrices are then multiplied with the original country-technology RTA matrix, yielding network weighted RTA matrices that try to explain RTA patterns in a country using strength in related technologies

Please note that no filtering for top correlates is applied as in the case of the estimation of pRCA values.

In a final step, each matrix is stacked vertically, so we obtain 18 column vectors with each of length of a product between all technologies and all countries.

1.3.2.2.2. Principal component analysis

Before fitting the empirical model that enables us to estimate the potential RTA values of countries in low-carbon technologies, we reduce the number of technology networks used in the regression. As the 18 technology networks are very collinear, we apply a principal component analysis. By doing this, we can reduce the number of regressors from 18 to 2, still capturing over 90 percent of the variance, and avoiding co-linear regressors.

1.3.2.2.3. Zero-inflated beta regression

Similar to the calculation of the pRCA values, the potential revealed comparative advantage (pRTA) values are obtained by fitting a zero-inflated beta regression. The methodology follows section 1.3.2.1.5.

6 Please note that NUTS regions are only available for European countries therefore country level analysis is used for all remaining countries. Although patent origin should be reported on NUTS level in Europe, for some patents there is missing data which leads to patents being assigned to country level instead of NUTS even in Europe.

1.3.2.2.4. pRTA values

Similar to the procedure calculating the pRCA values, we obtain pRTA values with the following approach. Initially, we estimate the above stated zero-inflated beta model using a R-implantation by *GAMLSS*. Our explanatory variables are values we received from the PCA which themselves are based on RTA values and technology network values all based on 2003 – 2007 patent data. The RTA values to be explained are based from 2008 – 2012 patent data. From that model run, we obtain coefficients and parameters that are used to run the model using input data based on 2008 – 2012 patent data. The forecasted values out of that calculation constitute or pRTA values.

1.4. Results

1.4.1. General

Table 1-6 shows the export specialisation (RCA) values based on trade date from 2008 – 2012. Only four countries (Australia, Norway, Saudi Arabia and Malta) are not specialised in exporting any of the low-carbon product categories (RCA<0.5). For the first three countries, this is likely since they are strongly specialised in commodities exports rather than manufactured products (Russia does not feature here, as they are specialised in nuclear exports). Out of 48 countries, 26 countries do not export at all in at least one of the 14 product categories (at least an RCA value of zero in of the 14 low-carbon technologies). Again, larger countries are close to 0.5 in most of the categories, while smaller countries have more pronounced strength and weaknesses. Currently, the countries that have the most low-carbon products with export advantage (RCA > 0.5) are France (8 technologies), Germany (8), Bulgaria, Hungary, and Poland (all 7).

Certain low-carbon products show a pattern of strong concentration on few countries, such as nuclear power within Canada, Czech Republic, France, Germany, Japan, Netherlands, Russia, and Sweden have above average (RCA > 0.5) export specialization. Other products, such as efficient heating and cooling, efficient combustion technologies, and insulation products are much more widespread over many countries. That has most likely to do with the technological complexity involved in producing these products. While the production of products for nuclear power plants involves itself a lot of sophisticated technologies, thus the entry barrier for companies is high, other low-carbon technologies allow an easier access for newcomers and thus a wider spread over several countries.

The RCAs are correlated with the corresponding RTA values (r = 0.32) – but this correlation varies between technologies (negative for energy management and more than 0.5 for wind energy, efficient heating and cooling, batteries and nuclear energy).

Table 1-7 shows the potential export specialisation (pRCA) values based on our methodology. They are correlated with the RCA's – but less than for the RTAs – and one quarter of them deviates by more than 0.3 from the corresponding RCA – and 42% by more than 0.2. Especially for some small product categories such as energy management, the RCA and pRCA values can deviate substantially, indicating that those should be interpreted with extreme caution.

Table 1-8 shows the patenting specialisation (RTA values) of the 14 low-carbon technologies in the EU28, EEA, G20 countries and Israel. Of the total 47 countries, 31 mainly smaller countries have an RTA of exactly zero in at least one of the low-carbon technologies as no patent activity is recorded in that particular technology group for the covered time period. Overall, we see that large countries (for instance Germany, France, US, China, Japan) have an RTA close to 0.5 in most technology groups whereas many smaller countries specialise only in few technologies.

Table 1-9 shows the potential patenting specialisation (pRTA) values based on our methodology. They are highly correlated with the RTA's and only a quarter of them deviates by more than 0.2 from the corresponding RTA[7].

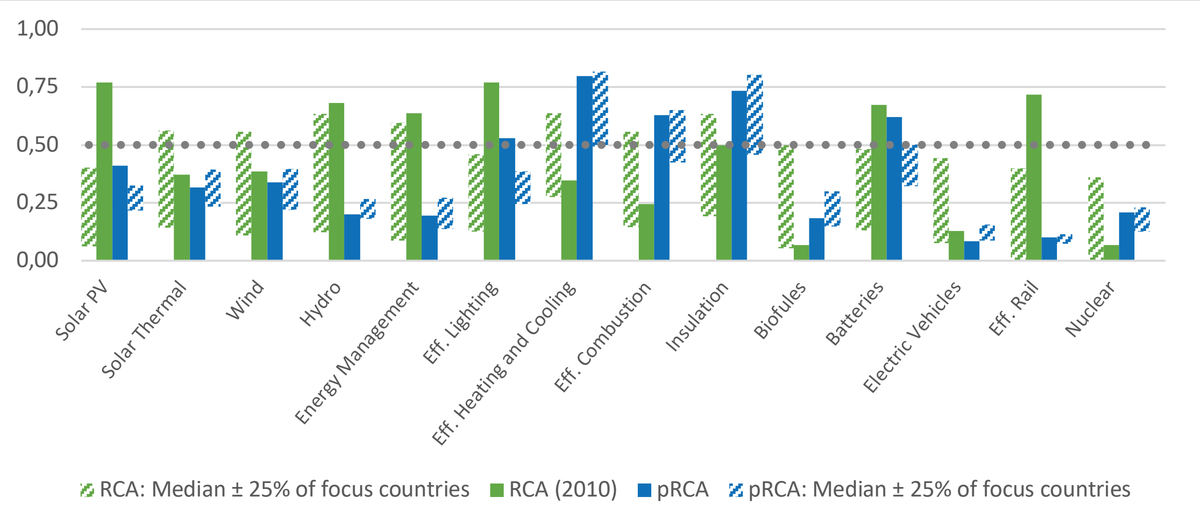
To illustrate the specific results, we provide below a discussion for the four countries, for which we have qualitative case studies (see chapters 3 to 7).

1.4.2. Case Study Countries

1.4.2.1. Brazil

In Figure 1-2 we see that Brazil has no exports (i.e., an RCA of 0) in PV, efficient rail and nuclear technologies in 2010; while it was specialised in the export of hydro energy technologies and biofuels.

Figure 1-2: Brazil, RCA (2008 - 2012) and pRCA



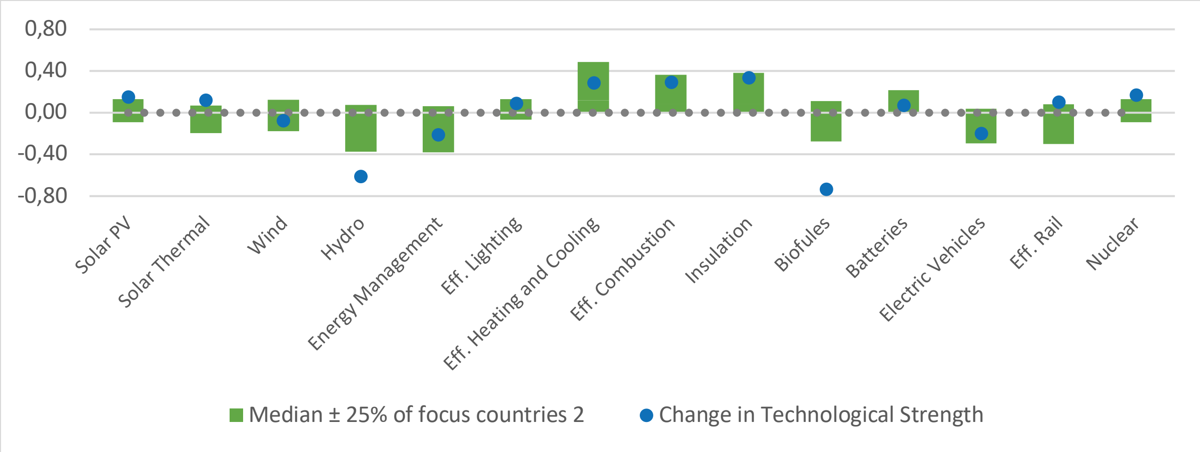
Source: Authors based on data from UN Comtrade.

Based on our methodology we would expect that Brazil has some potential to increase its specialisation in a number of low-carbon technologies – most notably "efficient heating and cooling" and "insulation" – where it could develop a comparative advantage (see Figure 1-3). But it might also strongly increase specialisation in efficient combustion and modestly in efficient lighting, solar PV and solar thermal.

In areas Brazil appears currently "over-specialised", or at least our methodology sees a lower potential than the current specialisation. This is mostly true for hydro energy and biofuels, which are already relatively well developed in Brazil. The lower pRCA values in these technologies could also be due to lack of strength in closely related technologies and therefore hint that Brazil might lose part of its comparative advantage in these areas.

[7] 25% (11%) of them are more than 0.1 (0.2) higher and 27% (14%) 0.1 (0.2) lower than the corresponding RTA.

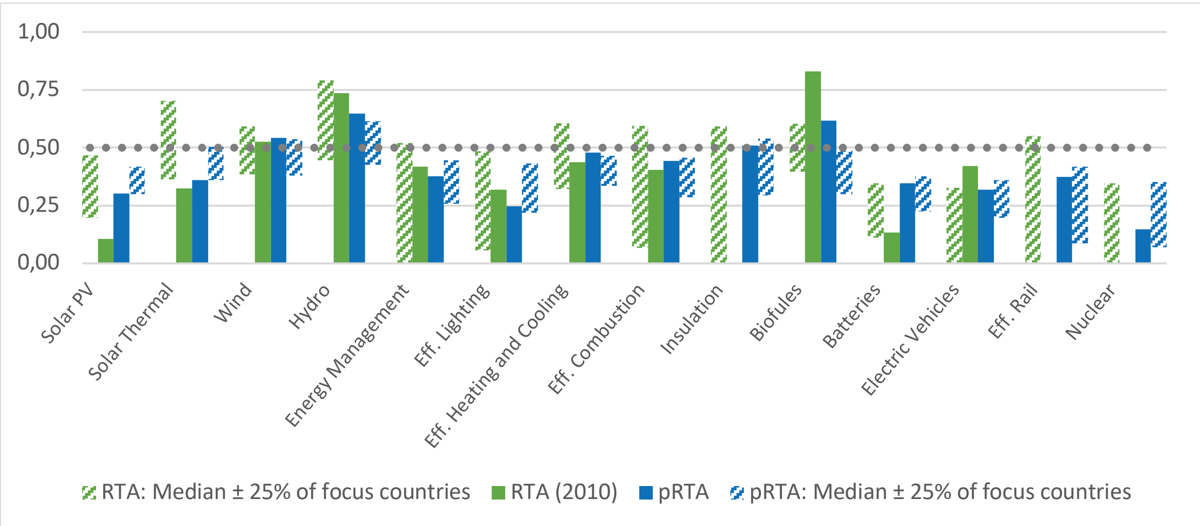
Figure 1-3: Brazil, change in export specialization



Source: Authors based on data from UN Comtrade.
Note: Change in export specialization is defined as pRCA minus RCA (2008 – 2012).

Interestingly, this picture is somewhat confirmed by patenting data (see Figure 1-4). We see the same current strength in hydro energy and biofuels patenting – and the same weakness in solar PV, efficient rail and nuclear.

Figure 1-4: Brazil, RTA (2008 - 2012) and pRTA

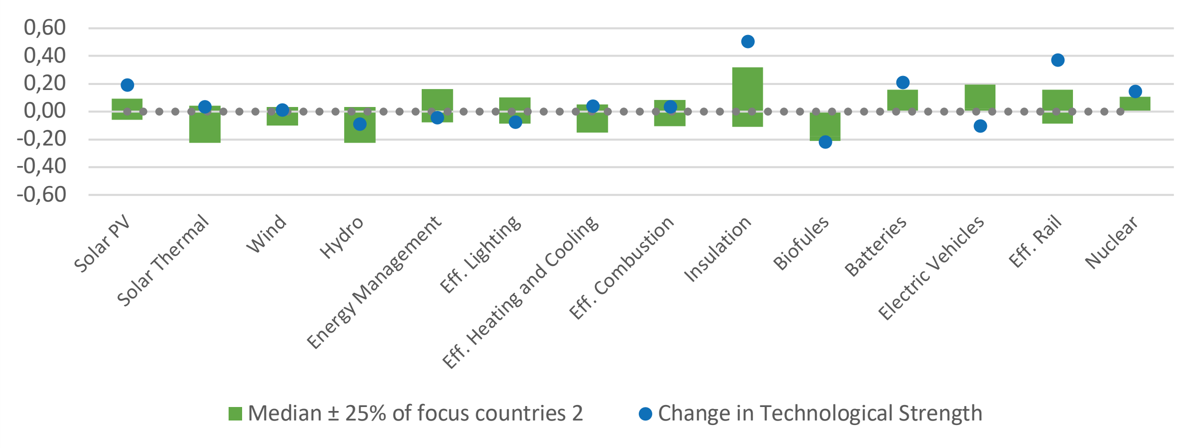


Source: Authors based on data from EPO Patstat.

In terms of technological growth potential (see Figure 1-5), we see – as with the export data - again insulation (very strong), efficient heating and cooling as well as batteries (moderate) featuring prominently. Our analysis for patent data also reconfirms the export data in that it also suggests declining specialisation in biofuels and hydro-energy (and electric vehicles).

One difference between export data and patent data for Brazil entails wind energy. Here exports are low and potential even lower while patenting and patenting potential are strong. The reason might be, that the domestic wind industry – albeit being innovative - tends to greatly produce for the large domestic market.

Figure 1-5: Brazil, change in technological specialization



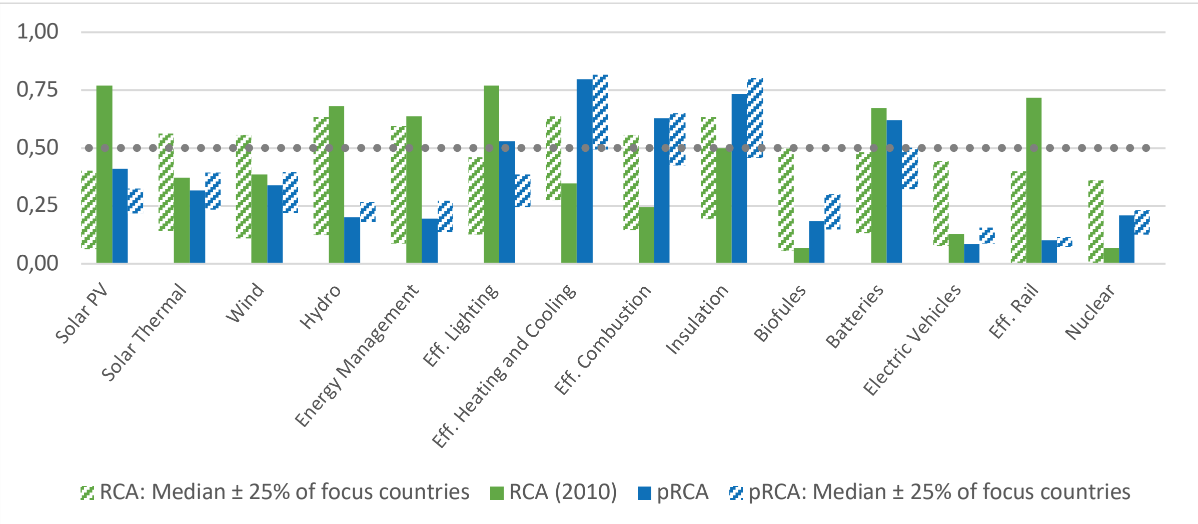
Source: Authors based on data from EPO Patstat.
Note: Change in technological specialization is defined as pRTA minus RTA (2008 – 2012).

Overall, the two quite different approaches based on completely different datasets render surprisingly similar results for most technologies for Brazil.

1.4.2.2. China

China has been somewhat specialised in exporting almost all of the analysed product categories – with the exemption of biofuels, electric vehicles and nuclear. The study revealed a strong comparative advantage in six categories (see Figure 1-6).

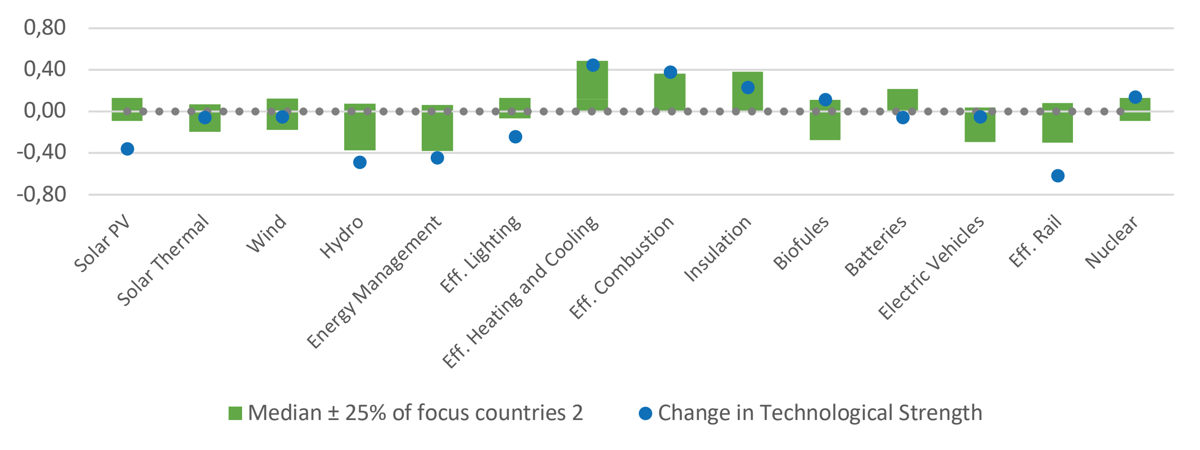
Figure 1-6: China, RCA (2008 - 2012) and pRCA



Source: Authors based on data from UN Comtrade.

Based on our analysis we would expect that China could increase its export specialisation in efficient heating and cooling, efficient combustion, insulation, nuclear and biofuels (see Figure 1-7). On the other hand, we would suspect that export specialisation in solar PV, hydro, efficient rail and energy management is currently higher than the potential and might decline.

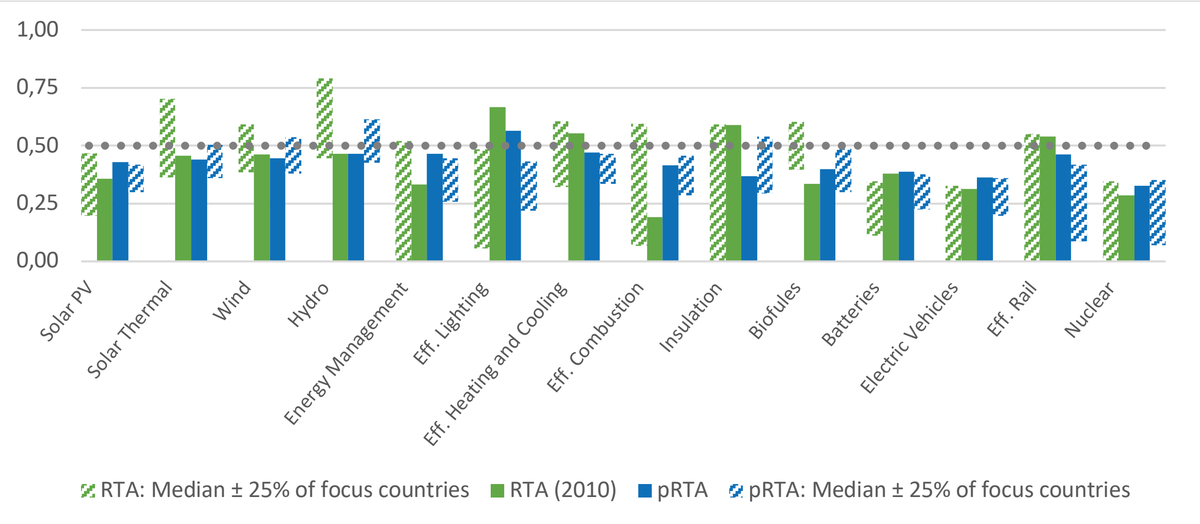
Figure 1-7: China, change in export specialization



Source: Authors based on data from UN Comtrade.
Note: Change in export specialization is defined as pRCA minus RCA (2008 – 2012).

In terms of low-carbon patent specialisation China shows almost no weaknesses –with the exemption of efficient combustion technology and biofuels. The country is particularly specialised in insulation, efficient lighting, heating and cooling, and rail (see Figure 1-8).

Figure 1-8: China, RTA (2008 - 2012) and pRTA



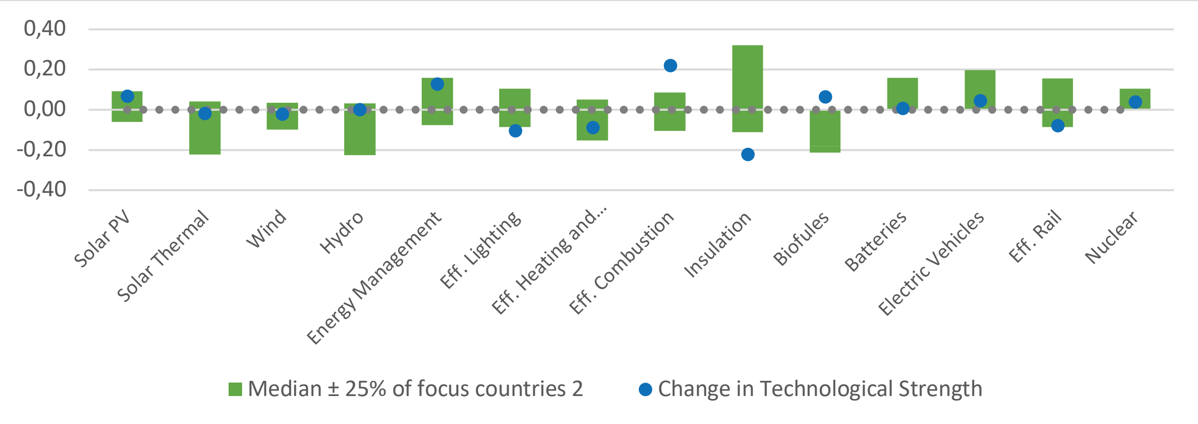
Source: Authors based on data from EPO Patstat.

The potential to increase specialisation in nuclear and biofuels is confirmed by patenting data (see An interesting observation is that neither export nor patent data suggest a massive potential for China dominating in electric vehicles. However, that might be explained by the quite old patent data we are relaying and that China's automotive sector is mainly supplying the domestic market Thus, China's productive capacity in (electric) cars are not visible in trade data.

Figure 1-9). In contrast to export data, "efficient heating and cooling" and "insulation" patenting specialisation is not expected to grow, while China might increase its surprisingly low specialisation in solar PV patenting. The later may be due to the fact that China's export specialisation in solar PV was not driven by innovation advantages, but other measures (arguable distorted factor costs).

An interesting observation is that neither export nor patent data suggest a massive potential for China dominating in electric vehicles. However, that might be explained by the quite old patent data we are relaying and that China's automotive sector is mainly supplying the domestic market Thus, China's productive capacity in (electric) cars are not visible in trade data.

Figure 1-9: China, change in technological specialization

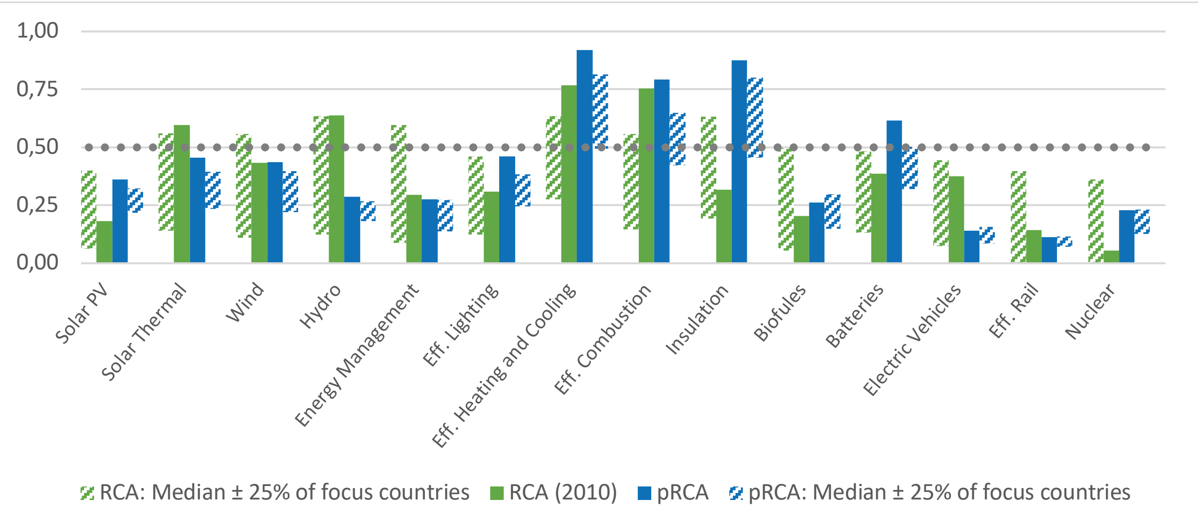


Source: Authors based on data from EPO Patstat.
Note: Change in technological specialization is defined as pRTA minus RTA (2008 – 2012).

1.4.2.3. Italy

Italy specializes in exporting solar thermal, hydro, efficient heating and cooling as well as efficient combustion products. It is almost absent in exporting PV, biofuels, efficient rail and nuclear products (see Figure 1-10).

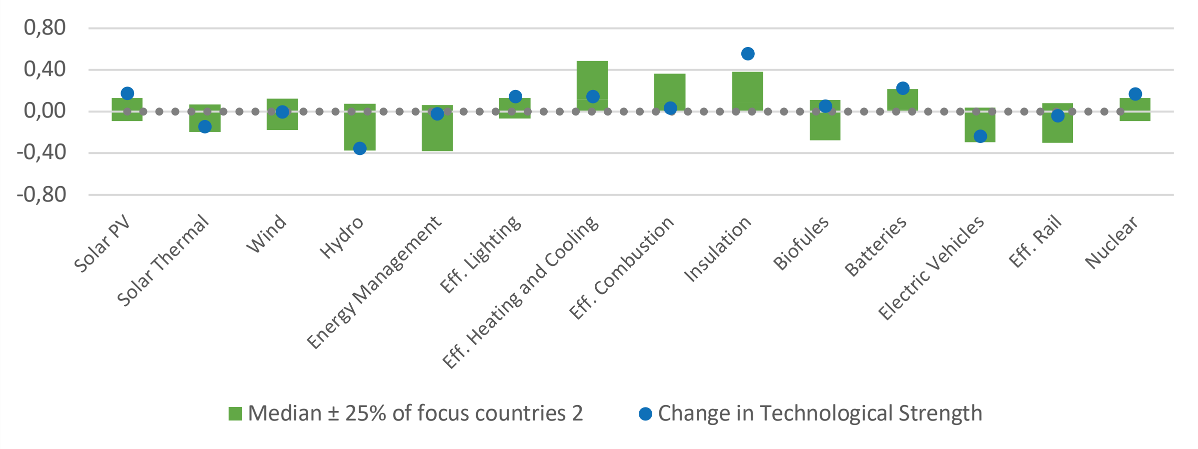
Figure 1-10: Italy, RCA (2008 – 2012) and pRCA



Source: Authors based on data from UN Comtrade.

We see potential for increasing export specialisation (i) in two of the currently relatively weak products: solar PV and insulation; and (ii) two of the currently relatively strong products: efficient heating and cooling as well as efficient combustion products. Furthermore, the current export profile suggests that the country could specialise in exporting batteries in the future (see Figure 1-11).

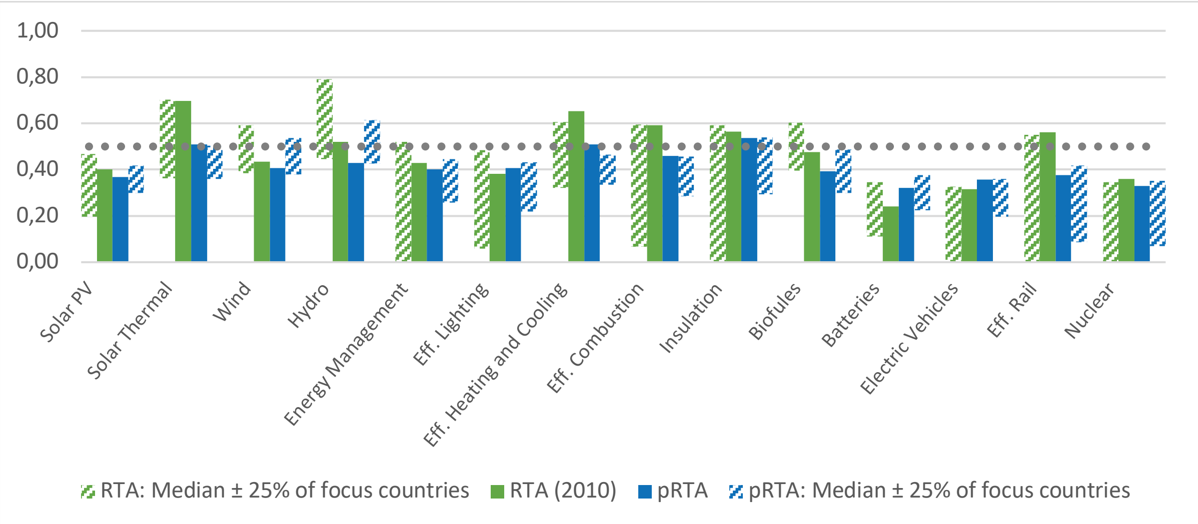
Figure 1-11: Italy, change in export specialization



Source: Authors based on data from UN Comtrade.
Note: Change in export specialization is defined as pRCA minus RCA (2008 – 2012).

Patenting specialisation reconfirms several of the findings from export specialisation (see Figure 1-12). Italy is specialised in exporting solar thermal, hydro, efficient heating and cooling as well as efficient combustion products. Beyond what was revealed by the export data – Italian patenting is also showing some specialisation in insulation and efficient rail technology.

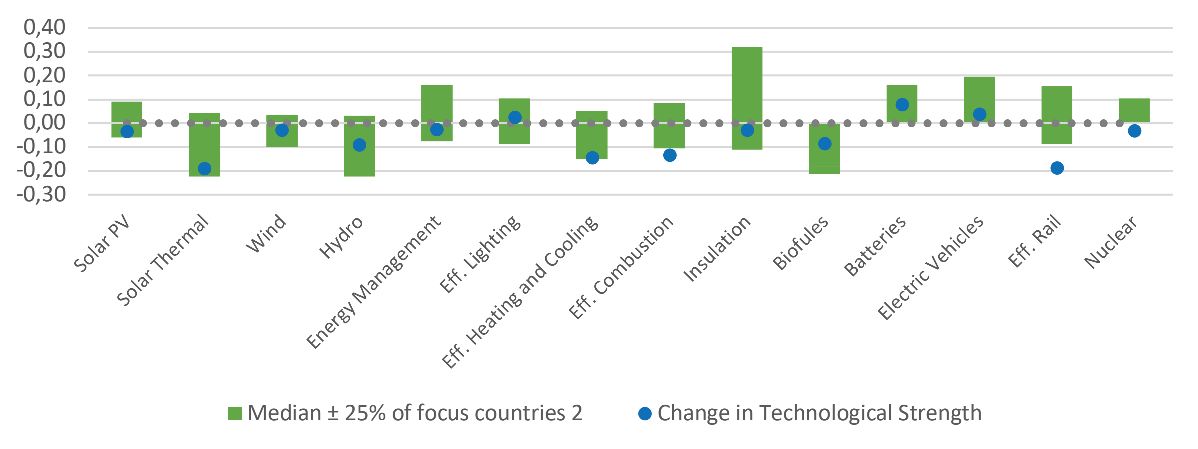
Figure 1-12: Italy, RTA (2008 - 2012) and pRTA



Source: Authors based on data from EPO Patstat.

Interestingly, there are no clear cases where our methodology predicts the potential of Italy to specialise much more in patenting in our low-carbon technologies than it already does – with batteries maybe the only exemption (see Figure 1-13).

Figure 1-13: Italy, change in technological specialization

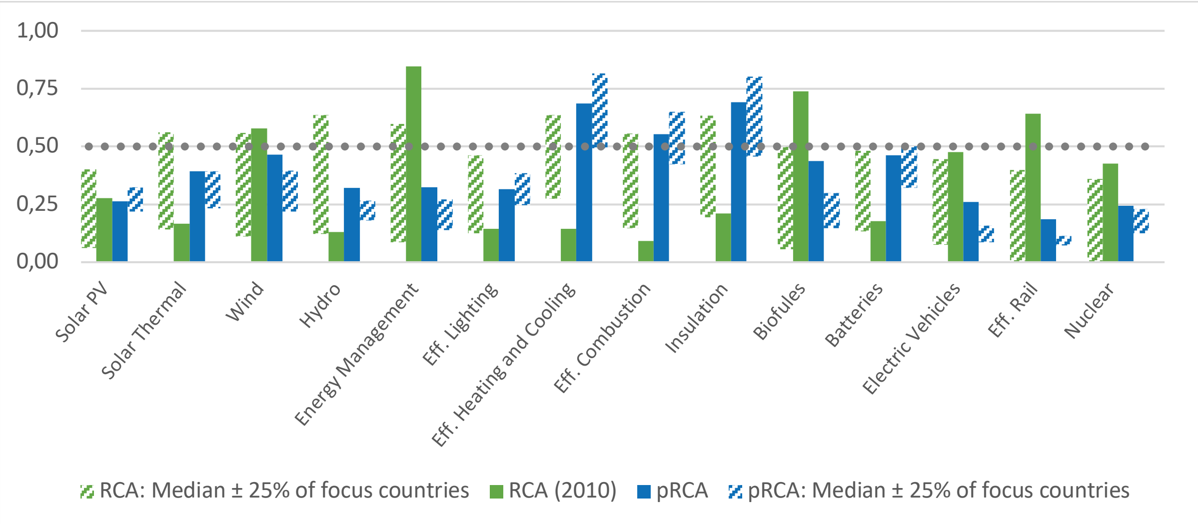


Source: Authors based on data from EPO Patstat.
Note: Change in technological specialization is defined as pRTA minus RTA (2008 – 2012).

1.4.2.4. South Africa

South Africa specializes in exporting products related to wind energy, biofuel and electric vehicles (as well as the small categories energy management and efficient rail). It has no specialisation in solar, hydro, efficient heating and cooling, combustion, insulation and batteries.

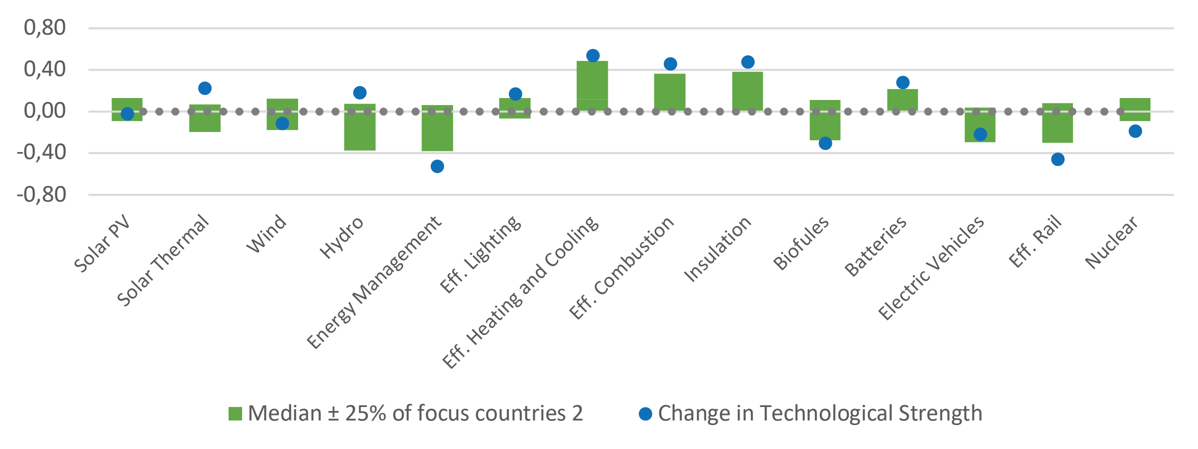
Figure 1-14: South Africa, RCA (2008 - 2012) and pRCA



Source: Authors based on data from UN Comtrade.

Based on our methodology we would see potential for increasing export specialisation in many of the product categories where South Africa is currently not specialised – most notably solar thermal, hydro, efficient heating and cooling, combustion, insulation and batteries (see Figure 1-15).

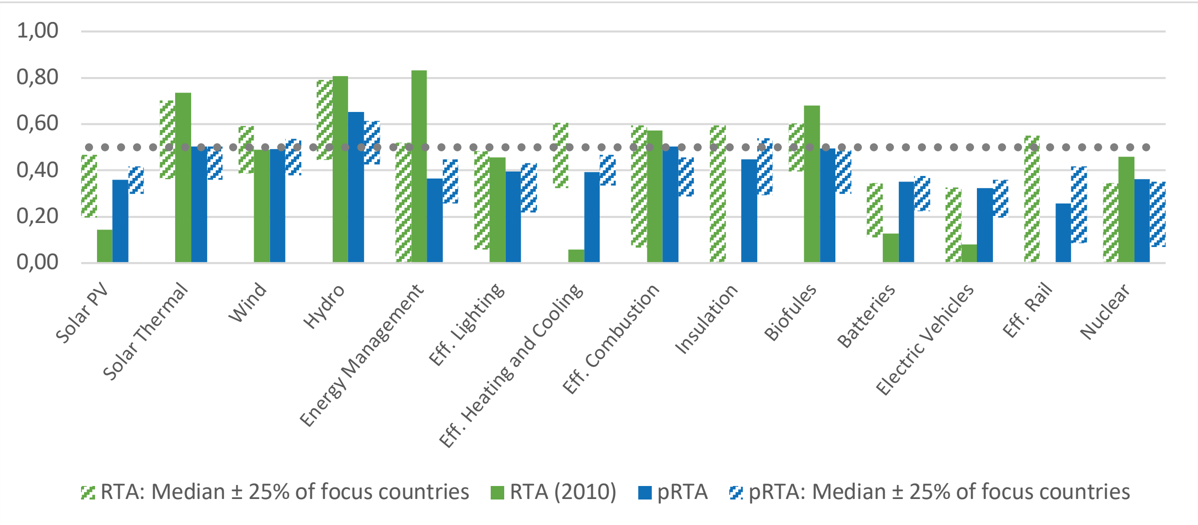
Figure 1-15: South Africa, change in export specialization



Source: Authors based on data from UN Comtrade.
Note: Change in export specialization is defined as pRCA minus RCA (2008 – 2012).

Patent specialisation in South Africa needs to be interpreted with caution – as the country has the smallest overall number of patents of all considered countries – so individual patents drive the results. In contrast to the specialisation revealed by export data, South Africa is specialised in solar thermal and hydro energy patents, but not in efficient rail and electric vehicle patents (see Figure 1-16). For biofuel, wind and to a lesser degree nuclear technology, both export and patent data indicate some specialisation.

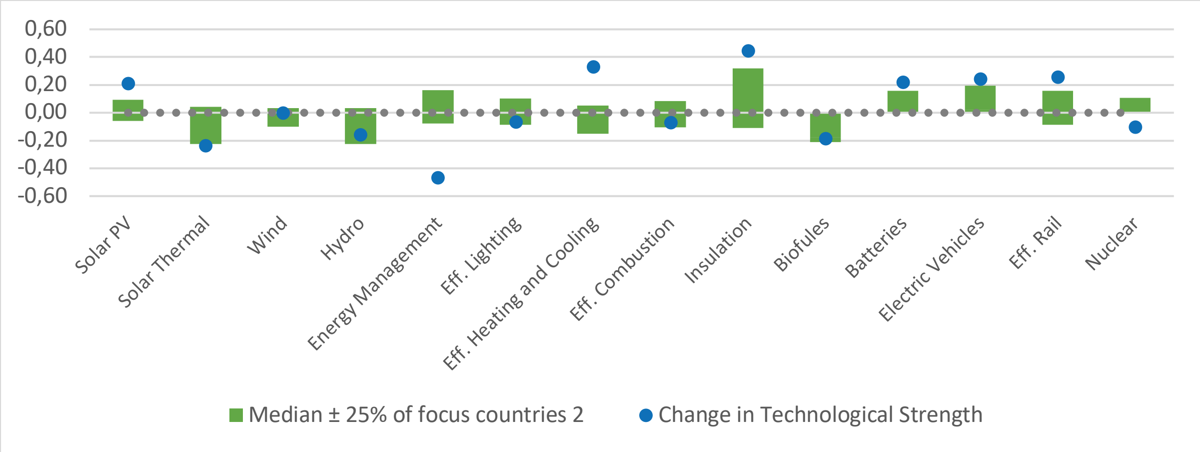
Figure 1-16: South Africa, RTA (2008 - 2012) and pRTA



Source: Author based on data from EPO PATSTAT.

As South African patent data are sparse, we would refrain from interpreting much into the results of our assessment of specialisation potential.

Figure 1-17: South Africa, change in technological specialization



Source: Authors based on data from EPO Patstat.
Note: Change in technological specialization is defined as pRTA minus RTA (2008 – 2012).

1.5. Conclusions

This chapter provides an overview about countries' competitiveness in 14 low-carbon technologies. We estimate the "revealed comparative advantage" (RCA), which measures a country's degree of export specialization, using gross export data, and the "revealed technological advantage" (RTA), which assess a country's specialization in innovation, using patent count data. Both RTA and RCA divide the within-country share of exports or patents of a low-carbon technology by the worldwide share of that same technology. For example, if 20% of a country's exports are of one specific technology, however the worldwide share of all exports in that technology is only 10%, we consider that county to have a strong RCA in that technology, thus an export specialisation. Using patent counts, the RTA is constructed in the same manner.

Relying on a method by Hausmann et al. (2014), we are also able to estimate the "potential revealed comparative advantage" (pRCA) and "potential revealed technological advantage" (pRTA) of a country per low-carbon technology. Strength in closely related technologies, measured with network metrics, increase the potential strength in a country's technology, both in terms of export and innovation. The metric pRCA is based on gross exports, while pRTA uses patent counts.

We find that larger countries sustain specializations in several technologies, while smaller countries specialize in a smaller number of technologies. Certain technologies, such as nuclear, remain exclusive for a small number of countries that are already strong in exporting or innovating nuclear technology. We do not find any potential for countries that are not already specialized in nuclear technology, neither in terms of trade or innovation. Other technologies, such as "efficient heating and cooling", "efficient combustion technologies" and "insulation" are promising for several countries in terms of export specialization. In terms of innovation specialization, certain energy technologies such as wind and hydro power appear to be promising for many countries.

All results presented have to be interpreted in a careful way, considering the limits of the data used to estimate these results. We rely only on gross exports and patent counts, thus any others factors, such as structural characters of a country like the geography or the economic situation, are not taken into account.

The results of this chapter should be seen as an indication of where export and innovation potentials exist and could be used. Yet, more between country-level analyses are needed to translate these results into recommendations and policy actions. The case studies in this report, chapters 3 - 7, give concrete examples of opportunities and challenges of specific low-carbon technologies in different countries and distinct policy options to foster competitiveness of low-carbon technologies.

1.6. References

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1.7. Annex

Table 1-4: Technologies and their corresponding CPC-Y and HS codes

Technology	CPC-Y codes (patents)	HS codes (exports)
Solar PV	Y02E1050, Y02E1052, Y02E1054, Y02E10541, Y02E10542, Y02E10543, Y02E10544, Y02E10545, Y02E10546, Y02E10547, Y02E10548, Y02E10549, Y02E1056, Y02E10563, Y02E10566, Y02E1058	854140
Solar Thermal	Y02E1040, Y02E1041, Y02E1042, Y02E1043, Y02E1044, Y02E1045, Y02E1046, Y02E10465, Y02E1047	841919
Wind	Y02E1070, Y02E1072, Y02E10721, Y02E10722, Y02E10723, Y02E10725, Y02E10726, Y02E10727, Y02E10728, Y02E1074, Y02E1076, Y02E10763, Y02E10766	850231, 730820
Hydro	Y02E1020, Y02E1022, Y02E10223, Y02E10226, Y02E1028	841011, 841012, 841013, 841090
Energy management	Y02B7030, Y02B7032, Y02B703208, Y02B703216, Y02B703225, Y02B703233, Y02B703241, Y02B70325, Y02B703258, Y02B703266, Y02B703275, Y02B703283, Y02B703291, Y02B7034, Y02B70343, Y02B70346	902830
Lighting	Y02B2010, Y02B2012, Y02B20125, Y02B2014, Y02B20142, Y02B20144, Y02B20146, Y02B20148, Y02B2016, Y02B2018, Y02B20181, Y02B20183, Y02B20185, Y02B20186, Y02B20188, Y02B2019, Y02B2020, Y02B20202, Y02B20204, Y02B20206, Y02B20208, Y02B2022, Y02B2030, Y02B2032, Y02B20325, Y02B2034, Y02B20341, Y02B20342, Y02B20343, Y02B20345, Y02B20346, Y02B20347, Y02B20348, Y02B2036, Y02B2038, Y02B20383, Y02B20386, Y02B2040, Y02B2042, Y02B2044, Y02B20445, Y02B2046, Y02B2048, Y02B2070, Y02B2072	853931, 853120
Heating and cooling	Y02B3008, Y02B3010, Y02B30102, Y02B30104, Y02B30106, Y02B30108, Y02B3012, Y02B30123, Y02B30126, Y02B3014, Y02B3016, Y02B3018, Y02B3020, Y02B3022, Y02B3024, Y02B3026, Y02B3028, Y02B3050, Y02B3052, Y02B3054, Y02B30542, Y02B30545, Y02B30547, Y02B3056, Y02B30563, Y02B30566, Y02B3060, Y02B3062, Y02B30625, Y02B3064, Y02B3066, Y02B3070, Y02B3072, Y02B3074, Y02B30741, Y02B30743, Y02B30745, Y02B30746, Y02B30748, Y02B3076, Y02B30762, Y02B30765, Y02B30767, Y02B3078, Y02B3080, Y02B3090, Y02B3092, Y02B3094	903210, 841861, 841950
Combustion	Y02B8010, Y02B8012, Y02B8014, Y02B8020, Y02B8022, Y02B8024, Y02B8026, Y02B8028, Y02B8030, Y02B8032, Y02B8034, Y02B8040, Y02B8050	841990, 841181, 841199, 841182, 841950, 840420
Residential insulation	Y02E2010, Y02E2012, Y02E2014, Y02E2016, Y02E2018, Y02E2030, Y02E2032, Y02E20322, Y02E20324, Y02E20326, Y02E20328, Y02E2034, Y02E20342, Y02E20346, Y02E20348, Y02E2036, Y02E20363, Y02E20366, Y02E20185, Y02E20344	680610, 680690, 700800, 701939
Biofuels	Y02E5010, Y02E5011, Y02E5012, Y02E5013, Y02E5014, Y02E5015, Y02E5016, Y02E5017, Y02E5018, Y02E5030, Y02E5032, Y02E5034, Y02E50343, Y02E50346	220710, 220720
Batteries	Y02E6012, Y02E60122, Y02E60124, Y02E60126, Y02E60128, Y02T1070, Y02T107005, Y02T107011, Y02T107016, Y02T107022, Y02T107027, Y02T107033, Y02T107038, Y02T107044, Y02T10705, Y02T107055, Y02T107061, Y02T107066, Y02T107072, Y02T107077, Y02T107083, Y02T107088, Y02T107094, Y02T1072, Y02T107208, Y02T107216, Y02T107225, Y02T107233, Y02T107241, Y02T10725, Y02T107258, Y02T107266, Y02T107275, Y02T107283, Y02T107291	850710, 850720, 850730, 850740, 850780, 850790, 853224
Electric cars	Y02T1064, Y02T10641, Y02T10642, Y02T10643, Y02T10644, Y02T10645, Y02T10646, Y02T10647, Y02T10648, Y02T10649, Y02T1062, Y02T106204, Y02T106208, Y02T106213, Y02T106217, Y02T106221, Y02T106226, Y02T10623, Y02T106234, Y02T106239, Y02T106243, Y02T106247, Y02T106252, Y02T106256, Y02T10626, Y02T106265, Y02T106269, Y02T106273, Y02T106278, Y02T106282, Y02T106286, Y02T106291, Y02T106295	870390
Rail transport	Y02T3000, Y02T3010, Y02T3012, Y02T3014, Y02T3016, Y02T3018, Y02T3030, Y02T3032, Y02T3034, Y02T3036, Y02T3038, Y02T3040, Y02T3042	860120
Nuclear	Y02E3030, Y02E3031, Y02E3032, Y02E3033, Y02E3034, Y02E3035, Y02E3037, Y02E3038, Y02E3039, Y02E3040	840110, 840120, 840140

Table 1-5: Technological Networks

<table>
<tr>
<td rowspan="2">RTA-based
We calculate the RTA (as defined above) on country, NUTS region, and inventor level as basis of our subsequent calculation.
Correlation between two RTAs (i and j) are defined as follows: (1+corr{RTA_i,RTA_j})/2.
Please note that own correlations are set to zero to avoid explaining a technological relatedness with the same technology.</td>
<td>Correlation
We calculate the correlation between RTAs and use that correlation matrix as a technology network to measure the relatedness of technology.</td>
<td rowspan="2">Calculations executed on
• Country level
• NUTS region level
• Inventor level</td>
</tr>
<tr>
<td>Minimum pairwise conditional probability (MPCP)
Minimum of the pairwise conditional probabilities of an entity having stronger than average patenting records (here measured as RTA>0.5) in one class, given that he also has stronger than average records in the other.</td>
</tr>
<tr>
<td rowspan="4">Co-occurrence
Based on the number of patents that are appearing together (co-occurrence) in different entities, we can draw conclusions of the relatedness of technologies.</td>
<td>Normalised
Normalised co-occurrence is defined as the number of shared patents of a pair of technology classes, normalized by the number of all unique patents in both classes. This measure is inspired by the “normalised co-classification” (explained below) and is calculated as the sum of minimums between patents of technology i and j over all entities, divided by the sum of all patents of both technologies over all entities.
Please note that calculations are only done on inventor and NUTS level, as the calculations on country do not make sense due to the high number of patents filled in different technology classes.</td>
<td rowspan="4">Calculations executed on
• NUTS region level
• Inventor level</td>
</tr>
<tr>
<td>Cosine similarity
The cosine of the angle of the two vectors representing two technology classes' distributions of shared patents with all other technology classes.</td>
</tr>
<tr>
<td>Expected co-occurrence frequency
The deviation of the number of entities of a pair of technology classes from the expected value under the hypothesis that diversification patterns are random.</td>
</tr>
<tr>
<td>Minimum pairwise conditional
Minimum of the pairwise conditional probabilities of an entity having stronger than average patenting records in one class, given that he also has stronger than average records in the other.</td>
</tr>
<tr>
<td rowspan="4">Co-classification</td>
<td>Normalised
The number of shared patents of a pair of technology classes, normalized by the number of all unique patents in both classes.</td>
<td rowspan="4">Calculations executed on
• Application level</td>
</tr>
<tr>
<td>Cosine similarity
The cosine of the angle of the two vectors representing two technology classes' distributions of shared patents with all other technology classes.</td>
</tr>
<tr>
<td>Expected Patent co-occurrence frequency
The deviation of the empirically observed number of patents occurring in a pair of technology classes from the value that would be expected when technology classes are randomly assigned to patents.</td>
</tr>
<tr>
<td>Minimum pairwise conditional
Minimum of the pairwise conditional probabilities of an entity having stronger than average patenting records in one class, given that he also has stronger than average records in the other.</td>
</tr>
</table>

Table 1-6: RCA (2008 - 2012 data)

	Solar PV	Solar Thermal	Wind Energy	Hydro Energy	Energy Management	Efficient Lighting	Eff. Heating & Cooling	Eff. Combust. Tech	Insulation	Biofuels	Batteries	Electric Vehicles	Eff. Rail Techs	Nuclear
Argentina	0.00	0.15	0.19	0.80	0.25	0.02	0.20	0.13	0.18	0.36	0.05	0.00	0.00	0.01
Australia	0.06	0.10	0.07	0.14	0.11	0.13	0.10	0.13	0.11	0.11	0.03	0.14	0.01	0.04
Austria	0.39	0.90	0.13	0.88	0.07	0.30	0.66	0.44	0.62	0.51	0.49	0.05	0.00	0.30
Belgium	0.38	0.34	0.14	0.21	0.07	0.29	0.36	0.29	0.68	0.60	0.25	0.64	0.12	0.22
Bulgaria	0.21	0.57	0.77	0.76	0.65	0.16	0.28	0.11	0.21	0.69	0.75	0.19	0.88	0.00
Brazil	0.00	0.05	0.27	0.81	0.31	0.10	0.19	0.09	0.12	0.94	0.21	0.27	0.00	0.00
Canada	0.08	0.17	0.30	0.42	0.25	0.32	0.34	0.51	0.47	0.30	0.11	0.30	0.26	0.55
Chile	0.12	0.54	0.02	0.76	0.65	0.17	0.45	0.76	0.41	0.01	0.16	0.09	0.17	0.02
China	0.77	0.37	0.39	0.68	0.64	0.77	0.35	0.24	0.50	0.07	0.67	0.13	0.72	0.07
Cyprus	0.92	0.01	0.03	0.06	0.12	0.09	0.09	0.26	0.00	0.08	0.03	0.10	0.00	0.00
Czech Republic	0.60	0.45	0.36	0.74	0.27	0.46	0.73	0.47	0.74	0.35	0.68	0.08	0.24	0.75
Germany	0.57	0.68	0.71	0.52	0.23	0.46	0.64	0.58	0.66	0.24	0.38	0.13	0.45	0.67
Denmark	0.10	0.69	0.98	0.35	0.33	0.18	0.77	0.56	0.48	0.13	0.15	0.20	0.00	0.01
Spain	0.46	0.49	0.87	0.75	0.10	0.16	0.45	0.26	0.46	0.61	0.49	0.49	0.94	0.19
Estonia	0.11	0.05	0.64	0.36	0.07	0.24	0.57	0.22	0.75	0.06	0.17	0.12	0.00	0.00
Finland	0.09	0.29	0.11	0.33	0.49	0.28	0.55	0.34	0.70	0.08	0.09	0.78	0.00	0.31
France	0.22	0.70	0.11	0.68	0.49	0.49	0.73	0.62	0.54	0.76	0.39	0.62	0.10	0.83
United Kingdom	0.32	0.40	0.09	0.30	0.59	0.28	0.41	0.71	0.61	0.36	0.30	0.63	0.13	0.47
Greece	0.28	0.90	0.62	0.01	0.91	0.14	0.28	0.22	0.58	0.05	0.54	0.02	0.40	0.00
Croatia	0.69	0.35	0.58	0.63	0.26	0.12	0.46	0.69	0.93	0.43	0.46	0.06	0.00	0.00
Hungary	0.56	0.35	0.02	0.18	0.77	0.69	0.64	0.66	0.62	0.74	0.43	0.06	0.00	0.00
Indonesia	0.06	0.10	0.54	0.02	0.57	0.58	0.09	0.14	0.10	0.33	0.48	0.10	0.00	0.01
India	0.31	0.25	0.74	0.55	0.62	0.12	0.34	0.34	0.14	0.41	0.18	0.35	0.01	0.05
Ireland	0.05	0.14	0.16	0.01	0.01	0.12	0.75	0.05	0.41	0.08	0.06	0.03	0.14	0.02
Iceland	0.00	0.00	0.01	0.05	0.03	0.01	0.13	0.03	0.53	0.00	0.01	0.02	0.00	0.13
Israel	0.02	0.80	0.28	0.33	0.02	0.04	0.63	0.61	0.09	0.00	0.27	0.23	0.00	0.00
Italy	0.18	0.60	0.43	0.64	0.29	0.31	0.77	0.75	0.32	0.20	0.39	0.38	0.14	0.06
Japan	0.71	0.04	0.28	0.35	0.01	0.18	0.56	0.56	0.47	0.01	0.77	0.77	0.28	0.68
South Korea	0.65	0.14	0.07	0.19	0.06	0.70	0.64	0.44	0.16	0.02	0.79	0.13	0.50	0.44
Lithuania	0.07	0.27	0.16	0.07	0.80	0.24	0.44	0.15	0.83	0.49	0.12	0.06	0.00	0.00
Luxembourg	0.65	0.22	0.03	0.04	0.02	0.16	0.67	0.03	0.21	0.03	0.59	0.41	0.00	0.00
Latvia	0.01	0.49	0.63	0.04	0.08	0.77	0.27	0.05	0.70	0.76	0.10	0.30	0.00	0.00
Mexico	0.40	0.89	0.27	0.24	0.88	0.21	0.62	0.55	0.42	0.04	0.60	0.28	0.00	0.01
Malta	0.04	0.00	0.01	0.02	0.12	0.10	0.43	0.44	0.01	0.02	0.20	0.02	0.00	0.00
The Netherlands	0.43	0.47	0.26	0.05	0.14	0.48	0.40	0.43	0.59	0.73	0.28	0.56	0.70	0.89
Norway	0.24	0.03	0.32	0.41	0.02	0.02	0.09	0.15	0.13	0.00	0.03	0.11	0.10	0.00
Poland	0.10	0.85	0.27	0.12	0.66	0.76	0.55	0.40	0.83	0.34	0.55	0.87	0.00	0.06
Portugal	0.32	0.66	0.80	0.23	0.59	0.62	0.20	0.31	0.54	0.10	0.41	0.03	0.00	0.11
Rumania	0.15	0.60	0.37	0.76	0.59	0.38	0.33	0.31	0.17	0.42	0.33	0.29	0.44	0.10
Russia	0.01	0.02	0.01	0.30	0.20	0.06	0.19	0.15	0.29	0.12	0.04	0.03	0.39	0.67
Saudi Arabia	0.00	0.06	0.17	0.31	0.03	0.01	0.01	0.05	0.07	0.00	0.07	0.11	0.00	0.00
Slovakia	0.18	0.49	0.50	0.09	0.45	0.27	0.66	0.33	0.65	0.70	0.16	0.59	0.83	0.00
Slovenia	0.33	0.48	0.05	0.95	0.96	0.13	0.71	0.42	0.91	0.00	0.71	0.01	0.00	0.13
Sweden	0.40	0.37	0.31	0.31	0.37	0.48	0.83	0.75	0.72	0.48	0.42	0.14	0.38	0.54
Turkey	0.01	0.55	0.76	0.20	0.20	0.68	0.33	0.22	0.60	0.20	0.40	0.55	0.49	0.00
USA	0.38	0.47	0.31	0.32	0.60	0.44	0.47	0.72	0.57	0.68	0.43	0.82	0.44	0.41
South Africa	0.28	0.17	0.58	0.13	0.85	0.14	0.14	0.09	0.21	0.74	0.18	0.48	0.64	0.43

Source: Authors based on data from UN Comtrade**.**

Note: To ease the understanding of the data, we added a colour scheme to the table. Green values are larger and closer to one, red values smaller and closer to zero.

Table 1-7: Estimated pRCA

	Solar PV	Solar Thermal	Wind Energy	Hydro Energy	Energy Management	Efficient Lighting	Eff. Heating & Cooling	Eff. Combust. Tech	Insulation	Biofuels	Batteries	Electric Vehicles	Eff. Rail Techs	Nuclear
Argentina	0.11	0.20	0.23	0.21	0.13	0.15	0.43	0.32	0.46	0.26	0.23	0.08	0.10	0.12
Australia	0.16	0.26	0.24	0.22	0.17	0.17	0.44	0.37	0.45	0.28	0.26	0.18	0.12	0.15
Austria	0.33	0.41	0.35	0.28	0.23	0.38	0.89	0.71	0.86	0.20	0.52	0.11	0.09	0.23
Belgium	0.32	0.34	0.34	0.20	0.19	0.35	0.81	0.65	0.81	0.23	0.44	0.10	0.11	0.27
Bulgaria	0.22	0.35	0.39	0.28	0.25	0.35	0.69	0.45	0.69	0.34	0.49	0.12	0.14	0.12
Brazil	0.16	0.17	0.20	0.20	0.11	0.19	0.48	0.38	0.46	0.22	0.29	0.07	0.11	0.18
Canada	0.22	0.30	0.27	0.24	0.18	0.25	0.70	0.58	0.70	0.21	0.35	0.12	0.12	0.26
Chile	0.29	0.27	0.15	0.17	0.12	0.24	0.68	0.62	0.57	0.07	0.33	0.07	0.04	0.15
China	0.41	0.32	0.34	0.20	0.19	0.53	0.80	0.63	0.73	0.18	0.62	0.08	0.10	0.21
Cyprus	0.22	0.33	0.31	0.22	0.27	0.21	0.42	0.36	0.40	0.28	0.27	0.19	0.07	0.08
Czech Republic	0.34	0.39	0.32	0.26	0.22	0.40	0.87	0.67	0.84	0.18	0.56	0.10	0.09	0.24
Germany	0.40	0.39	0.30	0.25	0.19	0.41	0.92	0.82	0.88	0.16	0.54	0.10	0.10	0.32
Denmark	0.30	0.45	0.42	0.26	0.29	0.39	0.83	0.65	0.81	0.31	0.49	0.18	0.08	0.16
Spain	0.33	0.44	0.49	0.33	0.30	0.43	0.87	0.71	0.85	0.38	0.58	0.18	0.16	0.23
Estonia	0.24	0.38	0.40	0.27	0.28	0.38	0.75	0.50	0.78	0.32	0.45	0.17	0.09	0.15
Finland	0.21	0.28	0.23	0.20	0.16	0.25	0.70	0.53	0.70	0.11	0.31	0.11	0.07	0.21
France	0.35	0.44	0.40	0.29	0.27	0.42	0.90	0.78	0.86	0.28	0.55	0.14	0.11	0.29
United Kingdom	0.38	0.40	0.33	0.24	0.26	0.39	0.85	0.76	0.79	0.21	0.50	0.16	0.09	0.28
Greece	0.24	0.39	0.44	0.26	0.30	0.35	0.63	0.45	0.65	0.40	0.47	0.18	0.13	0.10
Croatia	0.27	0.41	0.41	0.31	0.30	0.34	0.72	0.55	0.75	0.37	0.49	0.19	0.11	0.12
Hungary	0.27	0.34	0.30	0.21	0.23	0.36	0.75	0.53	0.73	0.20	0.45	0.09	0.07	0.13
Indonesia	0.17	0.10	0.21	0.05	0.07	0.33	0.28	0.23	0.25	0.12	0.34	0.05	0.03	0.05
India	0.23	0.14	0.27	0.12	0.09	0.29	0.47	0.43	0.38	0.17	0.35	0.05	0.08	0.14
Ireland	0.18	0.20	0.16	0.11	0.11	0.16	0.47	0.34	0.43	0.12	0.20	0.07	0.04	0.08
Iceland	0.03	0.06	0.06	0.04	0.04	0.04	0.16	0.12	0.17	0.03	0.04	0.06	0.03	0.05
Israel	0.24	0.26	0.19	0.12	0.15	0.22	0.51	0.46	0.37	0.14	0.30	0.09	0.05	0.11
Italy	0.36	0.46	0.44	0.29	0.28	0.46	0.92	0.79	0.88	0.26	0.62	0.14	0.11	0.23
Japan	0.39	0.16	0.10	0.11	0.07	0.31	0.70	0.65	0.52	0.05	0.44	0.05	0.05	0.28
South Korea	0.33	0.18	0.16	0.11	0.10	0.35	0.61	0.51	0.47	0.07	0.45	0.07	0.06	0.21
Lithuania	0.23	0.42	0.41	0.25	0.29	0.36	0.77	0.52	0.81	0.36	0.45	0.17	0.10	0.14
Luxembourg	0.25	0.31	0.27	0.19	0.20	0.25	0.62	0.41	0.58	0.19	0.37	0.13	0.07	0.13
Latvia	0.23	0.42	0.44	0.27	0.31	0.38	0.73	0.49	0.78	0.38	0.44	0.21	0.11	0.14
Mexico	0.30	0.36	0.34	0.23	0.28	0.34	0.68	0.53	0.62	0.26	0.50	0.11	0.12	0.15
Malta	0.16	0.21	0.13	0.11	0.15	0.16	0.31	0.27	0.26	0.09	0.21	0.10	0.04	0.05
The Netherlands	0.35	0.36	0.35	0.23	0.22	0.37	0.82	0.68	0.80	0.29	0.47	0.13	0.12	0.29
Norway	0.15	0.20	0.18	0.15	0.12	0.14	0.42	0.35	0.41	0.09	0.20	0.10	0.06	0.13
Poland	0.29	0.44	0.43	0.30	0.30	0.43	0.86	0.64	0.87	0.33	0.57	0.15	0.14	0.22
Portugal	0.28	0.45	0.51	0.29	0.33	0.45	0.75	0.54	0.77	0.41	0.56	0.22	0.10	0.13
Rumania	0.24	0.36	0.37	0.28	0.27	0.39	0.71	0.49	0.69	0.28	0.50	0.12	0.12	0.14
Russia	0.09	0.10	0.11	0.13	0.06	0.10	0.34	0.27	0.36	0.10	0.17	0.05	0.09	0.21
Saudi Arabia	0.06	0.08	0.14	0.06	0.06	0.06	0.17	0.16	0.19	0.11	0.10	0.08	0.04	0.07
Slovakia	0.25	0.35	0.35	0.24	0.24	0.36	0.75	0.51	0.74	0.23	0.45	0.10	0.12	0.16
Slovenia	0.28	0.37	0.32	0.26	0.25	0.34	0.81	0.59	0.80	0.19	0.52	0.10	0.09	0.16
Sweden	0.31	0.38	0.33	0.22	0.24	0.34	0.84	0.70	0.82	0.17	0.45	0.12	0.09	0.26
Turkey	0.23	0.37	0.46	0.26	0.25	0.41	0.74	0.51	0.74	0.34	0.54	0.11	0.13	0.13
USA	0.41	0.33	0.29	0.24	0.18	0.37	0.87	0.81	0.80	0.21	0.50	0.15	0.11	0.34
South Africa	0.26	0.39	0.47	0.32	0.33	0.32	0.68	0.55	0.69	0.44	0.46	0.26	0.19	0.24

Source: Authors based on data from UN Comtrade**.**

Note: To ease the understanding of the data, we added a colour scheme to the table. Green values are larger and closer to one, red values smaller and closer to zero.

Table 1-8: RTA (2008 - 2012 data)

	Solar PV	Solar Thermal	Wind	Hydro	Energy Management	Eff. Lighting	Eff. Heating and Cooling	Eff. Combustion	Insulation	Biofuels	Batteries	Electric Vehicles	Eff. Rail	Nuclear
Argentina	0.23	0.61	0.38	0.82	0.86	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00
Australia	0.47	0.70	0.39	0.70	0.30	0.31	0.56	0.39	0.37	0.58	0.22	0.26	0.79	0.08
Austria	0.36	0.70	0.49	0.75	0.48	0.68	0.52	0.51	0.73	0.49	0.34	0.47	0.78	0.13
Belgium	0.42	0.52	0.48	0.51	0.62	0.48	0.66	0.37	0.76	0.36	0.21	0.01	0.52	0.25
Bulgaria	0.52	0.84	0.83	0.92	0.00	0.85	0.00	0.00	0.00	0.00	0.64	0.00	0.00	0.00
Brazil	0.11	0.32	0.53	0.74	0.42	0.32	0.44	0.40	0.00	0.83	0.13	0.42	0.00	0.00
Canada	0.34	0.41	0.42	0.60	0.62	0.54	0.44	0.49	0.49	0.65	0.34	0.26	0.68	0.62
Chile	0.48	0.62	0.29	0.49	0.50	0.53	0.49	0.72	0.34	0.24	0.26	0.23	0.30	0.21
China	0.36	0.46	0.46	0.46	0.33	0.67	0.55	0.19	0.59	0.33	0.38	0.31	0.54	0.29
Cyprus	0.00	0.92	0.70	0.90	0.97	0.00	0.00	0.00	0.00	0.53	0.00	0.00	0.00	0.00
Czech Republic	0.29	0.62	0.17	0.82	0.00	0.26	0.60	0.60	0.77	0.53	0.37	0.01	0.77	0.66
Germany	0.50	0.60	0.57	0.45	0.51	0.48	0.50	0.57	0.64	0.48	0.49	0.56	0.62	0.49
Denmark	0.20	0.43	0.95	0.43	0.38	0.26	0.70	0.43	0.63	0.71	0.12	0.11	0.00	0.00
Spain	0.46	0.87	0.83	0.69	0.44	0.29	0.47	0.33	0.00	0.48	0.18	0.20	0.29	0.30
Estonia	0.29	0.00	0.49	0.00	0.00	0.00	0.86	0.00	0.00	0.74	0.00	0.00	0.00	0.00
Finland	0.28	0.16	0.41	0.37	0.29	0.47	0.53	0.66	0.17	0.67	0.21	0.36	0.00	0.00
France	0.36	0.46	0.29	0.54	0.40	0.26	0.57	0.56	0.50	0.45	0.47	0.47	0.71	0.73
United Kingdom	0.36	0.33	0.57	0.74	0.54	0.46	0.52	0.42	0.60	0.46	0.22	0.39	0.19	0.18
Greece	0.47	0.81	0.68	0.61	0.00	0.26	0.16	0.00	0.89	0.72	0.09	0.00	0.87	0.00
Croatia	0.13	0.57	0.70	0.92	0.00	0.49	0.00	0.00	0.97	0.00	0.36	0.00	0.00	0.00
Hungary	0.20	0.58	0.43	0.65	0.00	0.90	0.57	0.30	0.00	0.54	0.07	0.27	0.63	0.00
Indonesia	0.00	0.00	0.64	0.00	0.00	0.00	0.00	0.88	0.00	0.85	0.00	0.00	0.00	0.00
India	0.26	0.49	0.59	0.63	0.64	0.27	0.49	0.60	0.00	0.59	0.21	0.34	0.37	0.00
Ireland	0.27	0.30	0.53	0.94	0.41	0.32	0.53	0.14	0.00	0.50	0.10	0.00	0.00	0.00
Iceland	0.00	0.00	0.06	0.00	0.83	0.00	0.00	0.20	0.00	0.51	0.00	0.00	0.00	0.00
Israel	0.47	0.81	0.37	0.56	0.32	0.30	0.27	0.33	0.00	0.41	0.18	0.25	0.34	0.00
Italy	0.40	0.70	0.43	0.52	0.43	0.38	0.65	0.59	0.56	0.48	0.24	0.32	0.56	0.36
Japan	0.61	0.29	0.31	0.24	0.52	0.44	0.55	0.41	0.21	0.39	0.71	0.73	0.43	0.54
South Korea	0.67	0.36	0.38	0.56	0.64	0.58	0.62	0.37	0.57	0.38	0.66	0.39	0.31	0.46
Lithuania	0.00	0.54	0.79	0.84	0.00	0.00	0.92	0.84	0.00	0.41	0.00	0.00	0.97	0.00
Luxembourg	0.35	0.71	0.60	0.00	0.00	0.00	0.79	0.00	0.00	0.58	0.50	0.00	0.00	0.00
Latvia	0.39	0.00	0.51	0.00	0.00	0.00	0.00	0.81	0.00	0.43	0.21	0.70	0.00	0.00
Mexico	0.06	0.79	0.56	0.49	0.80	0.74	0.59	0.50	0.00	0.61	0.16	0.00	0.00	0.00
Malta	0.00	0.95	0.00	0.00	0.00	0.00	0.93	0.00	0.00	0.00	0.84	0.00	0.00	0.00
The Netherlands	0.47	0.36	0.57	0.43	0.37	0.79	0.55	0.47	0.72	0.66	0.16	0.20	0.34	0.14
Norway	0.40	0.33	0.72	0.90	0.52	0.11	0.43	0.58	0.24	0.68	0.05	0.00	0.00	0.33
Poland	0.14	0.52	0.51	0.73	0.64	0.32	0.76	0.60	0.80	0.71	0.21	0.14	0.37	0.00
Portugal	0.64	0.79	0.62	0.84	0.00	0.00	0.78	0.00	0.00	0.58	0.21	0.43	0.85	0.00
Rumania	0.66	0.28	0.54	0.94	0.00	0.00	0.00	0.89	0.00	0.38	0.34	0.24	0.00	0.00
Russia	0.35	0.44	0.63	0.77	0.29	0.61	0.37	0.63	0.00	0.60	0.25	0.31	0.45	0.85
Saudi Arabia	0.26	0.56	0.00	0.47	0.00	0.00	0.35	0.83	0.00	0.38	0.00	0.00	0.00	0.00
Slovakia	0.56	0.82	0.57	0.90	0.00	0.76	0.68	0.00	0.00	0.47	0.05	0.09	0.96	0.71
Slovenia	0.42	0.66	0.23	0.76	0.00	0.38	0.65	0.00	0.85	0.45	0.39	0.07	0.00	0.00
Sweden	0.18	0.42	0.42	0.30	0.47	0.12	0.54	0.61	0.25	0.54	0.32	0.52	0.41	0.55
Turkey	0.23	0.67	0.42	0.65	0.00	0.26	0.47	0.00	0.62	0.27	0.14	0.26	0.00	0.00
USA	0.49	0.42	0.37	0.30	0.51	0.45	0.29	0.53	0.44	0.57	0.35	0.29	0.38	0.56
South Africa	0.14	0.74	0.49	0.81	0.83	0.46	0.06	0.57	0.00	0.68	0.13	0.08	0.00	0.46

Source: Authors based on data from PATSTAT.

Note: To ease the understanding of the data, we added a colour scheme to the table. Green values are larger and closer to one, red values smaller and closer to zero.

Table 1-9: Estimated pRTA

	Solar PV	Solar Thermal	Wind	Hydro	Energy Management	Eff. Lighting	Eff. Heating and Cooling	Eff. Combustion	Insulation	Biofuels	Batteries	Electric Vehicles	Eff. Rail	Nuclear
Argentina	0.22	0.33	0.30	0.50	0.19	0.10	0.18	0.12	0.28	0.20	0.16	0.15	0.06	0.06
Australia	0.38	0.51	0.43	0.55	0.37	0.35	0.45	0.39	0.58	0.46	0.34	0.31	0.43	0.21
Austria	0.44	0.52	0.46	0.50	0.46	0.52	0.48	0.48	0.58	0.42	0.43	0.45	0.71	0.22
Belgium	0.49	0.46	0.42	0.43	0.37	0.43	0.49	0.37	0.60	0.44	0.30	0.28	0.32	0.30
Bulgaria	0.22	0.41	0.63	0.63	0.24	0.15	0.18	0.22	0.15	0.11	0.28	0.38	0.06	0.06
Brazil	0.30	0.36	0.54	0.65	0.38	0.25	0.48	0.44	0.51	0.62	0.35	0.32	0.37	0.15
Canada	0.38	0.44	0.43	0.50	0.45	0.43	0.40	0.46	0.46	0.50	0.39	0.38	0.41	0.50
Chile	0.45	0.49	0.37	0.40	0.47	0.39	0.43	0.51	0.51	0.35	0.34	0.34	0.49	0.35
China	0.43	0.44	0.45	0.47	0.47	0.57	0.47	0.42	0.37	0.40	0.39	0.36	0.46	0.33
Cyprus	0.08	0.19	0.30	0.40	0.09	0.03	0.03	0.04	0.03	0.05	0.04	0.04	0.02	0.03
Czech Republic	0.42	0.58	0.40	0.60	0.52	0.50	0.56	0.53	0.63	0.46	0.37	0.44	0.54	0.45
Germany	0.41	0.47	0.46	0.40	0.45	0.43	0.46	0.47	0.47	0.39	0.45	0.48	0.55	0.40
Denmark	0.34	0.45	0.72	0.64	0.45	0.37	0.60	0.50	0.63	0.51	0.30	0.29	0.23	0.13
Spain	0.44	0.60	0.61	0.65	0.44	0.43	0.46	0.40	0.56	0.43	0.34	0.34	0.47	0.32
Estonia	0.14	0.12	0.22	0.40	0.13	0.08	0.25	0.10	0.20	0.27	0.11	0.06	0.04	0.04
Finland	0.33	0.35	0.42	0.51	0.46	0.35	0.43	0.57	0.54	0.54	0.39	0.36	0.21	0.14
France	0.42	0.44	0.37	0.42	0.44	0.37	0.45	0.45	0.51	0.42	0.44	0.48	0.58	0.60
United Kingdom	0.38	0.38	0.51	0.58	0.43	0.38	0.45	0.44	0.47	0.41	0.35	0.35	0.30	0.28
Greece	0.42	0.65	0.59	0.69	0.28	0.23	0.39	0.30	0.62	0.38	0.27	0.24	0.17	0.09
Croatia	0.13	0.13	0.54	0.62	0.17	0.19	0.13	0.26	0.28	0.24	0.17	0.18	0.06	0.05
Hungary	0.34	0.48	0.48	0.43	0.35	0.57	0.41	0.32	0.44	0.44	0.27	0.27	0.35	0.26
Indonesia	0.09	0.06	0.27	0.09	0.15	0.14	0.09	0.15	0.06	0.30	0.07	0.05	0.04	0.03
India	0.36	0.38	0.54	0.58	0.43	0.26	0.33	0.47	0.25	0.57	0.38	0.34	0.32	0.17
Ireland	0.44	0.42	0.57	0.68	0.43	0.38	0.42	0.38	0.54	0.37	0.23	0.20	0.15	0.09
Iceland	0.05	0.04	0.04	0.04	0.08	0.07	0.05	0.05	0.05	0.12	0.05	0.04	0.03	0.03
Israel	0.42	0.56	0.40	0.47	0.41	0.33	0.39	0.29	0.33	0.35	0.32	0.27	0.27	0.13
Italy	0.37	0.51	0.41	0.43	0.40	0.41	0.51	0.46	0.54	0.39	0.32	0.36	0.38	0.33
Japan	0.51	0.37	0.36	0.28	0.48	0.47	0.44	0.40	0.31	0.42	0.59	0.59	0.39	0.49
South Korea	0.50	0.44	0.43	0.50	0.49	0.53	0.54	0.36	0.43	0.38	0.49	0.43	0.27	0.45
Lithuania	0.15	0.16	0.51	0.60	0.17	0.20	0.37	0.29	0.27	0.14	0.07	0.06	0.09	0.05
Luxembourg	0.31	0.49	0.40	0.26	0.15	0.13	0.36	0.17	0.31	0.18	0.19	0.19	0.07	0.06
Latvia	0.17	0.16	0.28	0.55	0.10	0.08	0.11	0.12	0.15	0.12	0.16	0.13	0.05	0.04
Mexico	0.38	0.50	0.52	0.58	0.41	0.45	0.47	0.33	0.58	0.54	0.27	0.28	0.27	0.11
Malta	0.08	0.13	0.03	0.03	0.03	0.03	0.05	0.03	0.05	0.03	0.06	0.05	0.02	0.02
The Netherlands	0.41	0.42	0.45	0.43	0.41	0.58	0.45	0.44	0.54	0.51	0.32	0.30	0.32	0.23
Norway	0.34	0.40	0.65	0.75	0.45	0.26	0.41	0.51	0.51	0.50	0.25	0.24	0.18	0.35
Poland	0.41	0.54	0.54	0.58	0.45	0.37	0.59	0.58	0.67	0.53	0.35	0.36	0.54	0.17
Portugal	0.44	0.60	0.61	0.68	0.37	0.24	0.49	0.40	0.59	0.52	0.36	0.25	0.24	0.19
Rumania	0.29	0.36	0.60	0.67	0.46	0.36	0.18	0.39	0.40	0.33	0.33	0.43	0.30	0.08
Russia	0.40	0.50	0.58	0.63	0.43	0.47	0.47	0.54	0.54	0.53	0.38	0.35	0.62	0.70
Saudi Arabia	0.23	0.35	0.09	0.20	0.10	0.09	0.14	0.34	0.10	0.35	0.12	0.06	0.04	0.06
Slovakia	0.40	0.53	0.52	0.61	0.41	0.52	0.45	0.33	0.42	0.33	0.27	0.27	0.71	0.46
Slovenia	0.32	0.43	0.33	0.51	0.28	0.36	0.44	0.23	0.40	0.30	0.22	0.20	0.09	0.08
Sweden	0.33	0.39	0.44	0.44	0.48	0.29	0.46	0.45	0.45	0.41	0.44	0.51	0.43	0.48
Turkey	0.32	0.52	0.48	0.55	0.35	0.40	0.57	0.36	0.53	0.28	0.29	0.28	0.25	0.10
USA	0.46	0.43	0.39	0.36	0.43	0.43	0.35	0.46	0.39	0.48	0.38	0.36	0.29	0.53
South Africa	0.36	0.50	0.49	0.65	0.37	0.40	0.39	0.50	0.45	0.50	0.35	0.33	0.26	0.36

Source: Authors based on data from PATSTAT.

Note: To ease the understanding of the data, we added a colour scheme to the table. Green values are larger and closer to one, red values smaller and closer to zero.

2. Forecasting with experience curves, applications in the energy sector and technology portfolios

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Abstract

This chapter forecasts experience curves of technologies in the energy sector and implications for technology portfolios. One of the most important variables in addressing climate change is how much quicker clean technologies will become cheaper than dirty technologies. Therefore, understanding the rate of technological progress in clean (and dirty) energy is of utmost importance, as is understanding how we can accelerate the cost reductions. The distributional experience forecasting method shows that it is likely wind, solar and storage technologies will become much cheaper in the near future, and this progress can be accelerated by increasing near-term investments. In contrast, fossil fuel and nuclear based technologies, which have accumulated a vast amount of experience globally since their inception, have seen very little progress in the recent past. This, in combination with the vast resources they have had at their disposal during this time, shows that the corresponding experience curve analysis predicts a low chance of significant future progress. Hence, a global technology portfolio formed largely of currently immature but fast progressing technologies will have a good chance of being cheaper in the long run.

2.1. Introduction

One of the most important variables in addressing climate change is how quickly clean technologies will become cheaper than dirty technologies. Once clean technologies are cheaper, the politics of the climate problem become much easier, and greater reliance can be placed on markets to solve the problem. Therefore, understanding the rate of technological progress in clean (and dirty) energy is of first order importance, as is understanding how we can accelerate the cost reductions. The political and economic appetite to spend money on subsidies for green technological progress is limited, so we need to allocate our investments wisely and show why they make economic sense. Our work is helping provide the scientific basis that can underpin and accelerate the green energy transition and help steer an efficient path. We believe it is also likely to demonstrate that costs will be lower than generally anticipated. Highlighting the trend of decreasing technology costs in the near term, plus an understanding that future costs will likely be lower still, could help accelerate the green technologies that are capable of rapid progress, and thereby displace existing fossils fuels more quickly.

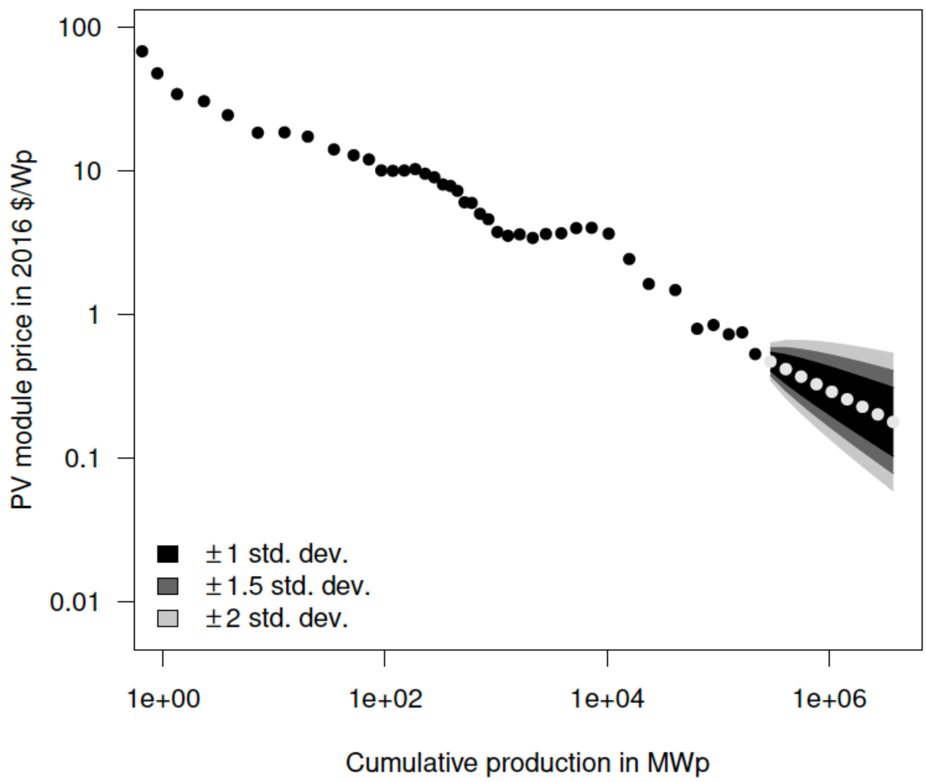
Good decisions depend on our ability to predict the future. Given a range of possible actions, which will yield the best outcomes? The detailed ways in which innovations happen are very difficult to predict. It is important to distinguish between forecasting under business-as-usual scenarios, which only requires careful extrapolation, and predicting what would happen if we implemented radical changes in the drivers of technological progress – which is what we want to do to accelerate the clean energy transition. We briefly summarise our overall workflow, then expand on each point below that.

In past and present work, we have determined that historically there are laws of technological progress (Nagy et al. 2013). Wright's law – the experience curve – states that the rate of increase of cumulative production determines the rate of technological progress, with some uncertainty (which we try to measure as carefully as possible). But for most technologies the rate of growth of experience has been constant, so it is impossible to say with much certainty what would happen under a sudden massive increase in production. To understand this better we have used historical data from World War II, where military demand was massively scaled up and then down, and was independent of demand. Then, with this improved understanding of the validity of experience curves under "accelerated" scenarios such as this, we can use them to evaluate different scenarios and determine potential overall costs (possibly negative) of the clean energy transition. This involves evaluating how different portfolios of technologies perform in terms of delivering a cheap energy system with the least possible risk.

2.2. If we keep investing in renewable energy technologies at the same rate as before, will they become cheaper?

In previous work (Farmer & Lafond 2016) we have shown that rates of improvement vary dramatically across technologies, and are remarkably persistent and predictable. Part of the reason why this is the case is that for some technologies deployment is very fast, so costs decrease faster. In order to capture this effect, instead of the generalized Moore's law model used previously (in which the independent variable is time), a Wright's law (experience curve) model may be used (in which the independent variable is cumulative experience) to make distributional forecasts, showing a range of cost improvements to expect given a certain rate of growth of experience. We have now completed this methodological extension of our previous work, and the results have been published in a peer-reviewed journal (Lafond et al. 2018). Figure 2-1 shows the forecast ranges for photovoltaic module prices, assuming a constant growth rate of 32%.

Figure 2-1: Forecast ranges for photovoltaic module prices assuming a 32% growth rate



Source: Lafond et al. (2018).

Our experience curve forecasting method involves supposing that from year to year each technology follows a persistent, technology-specific Wright's law trend, and is also subject to an exogenous shock (i.e. it is a first-difference stochastic Wright's law model with Gaussian noise). We assume the experience exponent and the noise distribution are constant and technology-specific, and then use historical data to estimate these parameters. This yields historically consistent distributional forecasts, conditional upon future production. We can then vary the future growth rate of experience and compare the resulting forecasts (see Lafond et al. 2018 for further details).

A feature of the method is that forecast uncertainty arises due to both our error in measuring the experience exponent (due to limited historical data) *and* periodic exogenous shocks (due to unforeseeable events within the wider economy and the innovation process itself). This leads to wide forecasts error bars (which is reasonable since this prediction problem is inherently difficult).

While this work shows that the forecast errors predicted by the method are consistent with observed historical data for a wide range of technologies, the rate of growth of experience for most technologies has been approximately constant. Hence it is still important to understand the extent to which Wright's law forecasts are valid under alternative scenarios.

2.3. If we accelerate our investments, will they become cheaper even faster?

A key critique of the experience curve concept is that perhaps it only works because technology diffusion in future will be similar to how it was in the past, so we cannot know for sure whether or not the model will remain valid under alternative future scenarios. Fortunately, we know of a specific context in which a massive government intervention created a radical and sudden change in production rates, in a sense similar to what might happen if we decided to accelerate the energy transition. The context is military production during World War II, and our analysis of the phenomenon required a tremendous effort in collecting and cleaning data.

Our record of product-level cost and production currently stands at around 450 different military products, including airplanes, ships, jeeps, rifles, ammunition etc. We have also used a sector-level monthly dataset that is extremely useful for conducting robust time series analysis, and a plant-level dataset on labour productivity in airframe production that has allowed us to compare our results with the existing literature to establish their novelty and comprehensiveness.

We have obtained two important results. First, in the early months of the war where production increased, costs dropped substantially. After a production peak was reached around 1943, costs kept decreasing at a rate determined by the growth of experience, validating the idea that technological progress is driven by accumulated experience (cumulative production), not by the scale of production itself. This is an important result that cannot be established with more modern data where both production and experience are always increasing. This means that even when the market for renewable energy technologies becomes saturated, and production growth slows down and eventually becomes negative, we should expect the continued growth of experience to keep driving costs down.

The second important result is meant to settle a controversy in the scientific literature. Some prominent economists have argued that using modern data it is impossible to say whether costs are dropping due to experience effects, or if they would drop anyway if no experience was gained (Nordhaus 2014, Magee et al. 2016). The argument is at least in part plausible – if we don't produce solar panels for 10 years, then 10 years from now new materials will have been discovered, new manufacturing techniques will exist, etc., so we may expect solar panels to be easier/cheaper to produce, despite the hiatus in effort on solar itself. This argument is used by some to assert that we should not tackle climate change now, because it is cheaper to wait for so-called "backstop" technologies that will emerge in future. In contrast, our main argument is that we should invest now, because this will make progress faster. Using modern-day data, we simply cannot tell who is right, because production tends to always grow: production, experience and "time" are so similar (they *all* grow) that it is impossible to distinguish their respective effects on costs. During WWII though, production was initially very low, then accelerated very fast, reached a plateau and a peak, and then decreased back to a very low level. Our preliminary estimate indicates that 40-70% of technological progress was due to specific investment in the technology, which clearly shows that investing now will accelerate progress. Having said that, it is also true that *some* technological progress was due to external factors – most likely institutional and organizational innovation (e.g. logistics progressed a lot during WWII), and technological progress in supporting technologies. This work has now been presented at a conference (Farmer, Greenwald & Lafond, 2018), but the final results are still a work in progress.

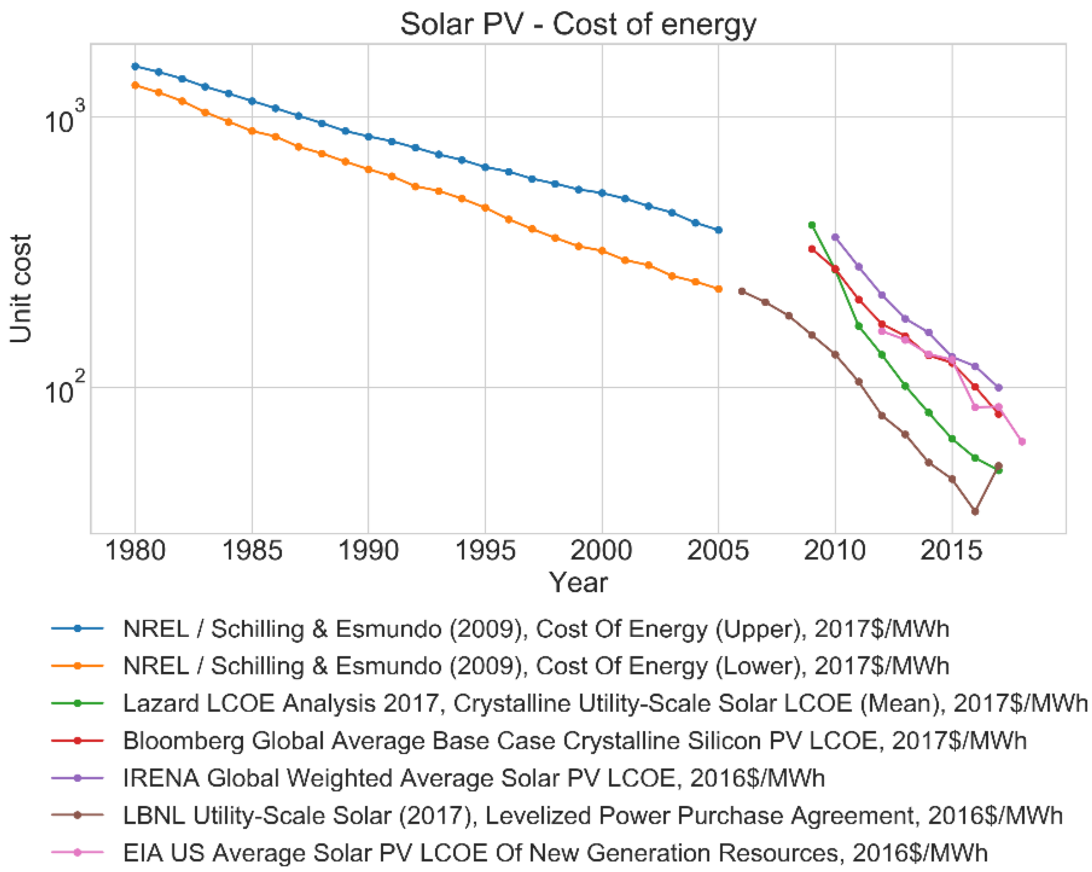
2.4. Application of the forecasting method to energy generation technologies

The experience curve framework is an approximate, empirical concept. There is no single formulation that is "true" or "correct" or that can capture the vast complexity of the innovation process. Hence a judicious, domain-appropriate choice of metric for unit cost and experience is always required, and ideally several different combinations should eventually be compared in order to verify the consistency of results.

Energy technologies have many diverse characteristics, which interact in complicated ways to influence investment decisions, so any particular measures of unit cost and experience will only convey part of the picture of how a technology is developing. Furthermore, forecasts should be interpreted with consideration of the technology's position within the wider energy system, and in particular any relevant engineering constraints (for example interdependencies between intermittent generators and backup generators or energy storage facilities). One of the most important characteristics of energy generation technologies is the dispatchability of energy; others include maximum power rating, capacity factor, local environmental conditions, ancillary grid services, ramp rate, black start capability, failure rates, pollution rates, fuel security, waste disposal, unit lifetime, and the prevailing investment and policy conditions.

Despite the wide array of technology characteristics, it is possible to identify a few key metrics and produce meaningful forecasts. Common cost metrics used in the literature include capacity investment cost and levelized cost of electricity (LCOE) (see e.g. Neij 2008). However, due to the diversity of data collection and calculation methodologies, data from different sources describing the same characteristic is often quite varied. For example, Figure 2-2 below shows LCOE data for solar PV from 1980-2017 from several sources. There is a lot of variation in the data for many reasons, such as location/region, calculation methodology and cost of capital (Ondraczek et al. 2015).

Figure 2-2: Levelized cost of energy for solar PV from various data sources 1980-2018



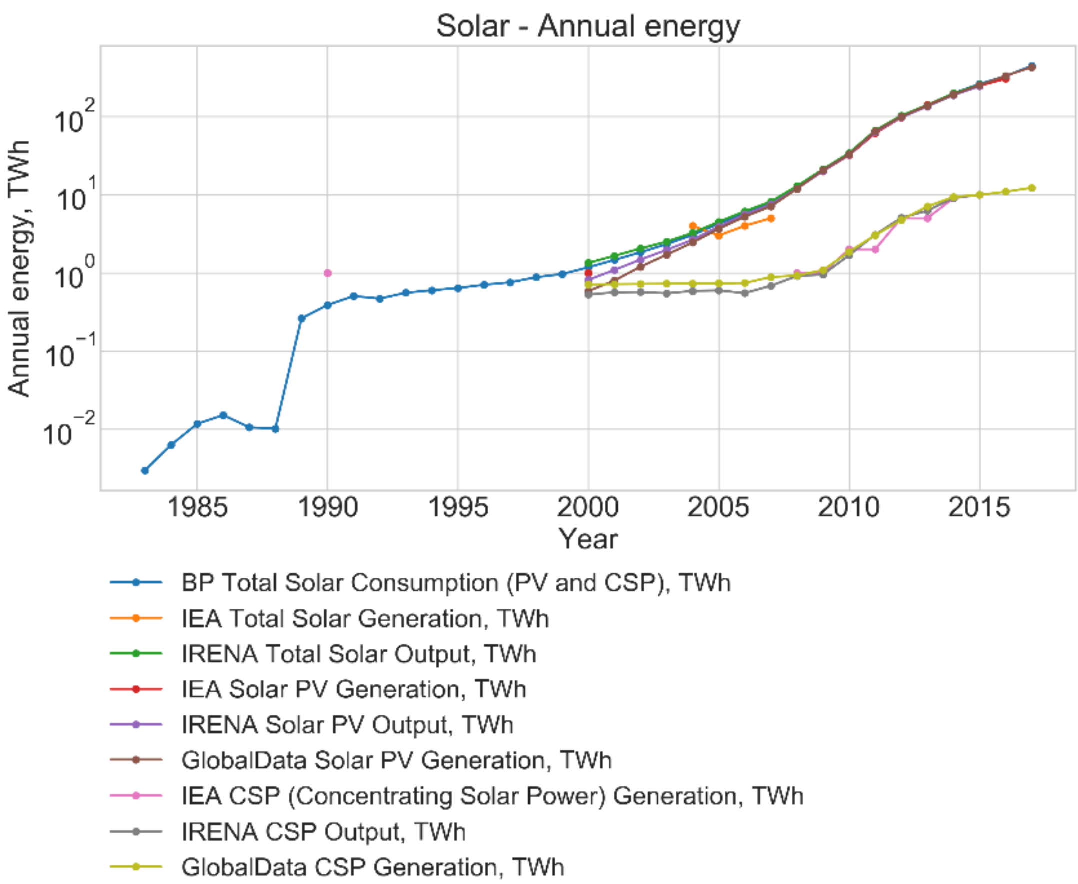
Source: Authors.

Here we use LCOE as our cost metric, as this represents an all-in estimate of the total cost of technically producing electricity from a given source (although as mentioned above, system costs and constraints must be borne in mind when considering the compatibility of various energy technologies).

Regarding the choice of metric for experience, the most common is cumulative installed capacity. However, it is also possible to use cumulative energy generated, and in fact we believe this is better when paired in an experience curve with LCOE, as it encompasses learning that takes place throughout the entire technology ecosystem, from basic science and innovation to process engineering, manufacturing, financing, installation, operation and decommissioning. It is a proxy for the total operating experience of the entire chain of technology responsible for the provision of electricity from a given source, taking account of its position within the evolving and adapting energy system. For example, this metric captures increases in solar PV generation due to learning in the installation of fixed PV panels but also captures increases due to innovation in solar tracking technology. These would not both be captured by a single cumulative installations metric.

Much like cost data, this data is highly inhomogeneous, with different sources providing information on different aspects of the system, and data representing the same feature often not being consistent across sources. Figure 2-3 shows annual solar energy output data from several sources. Sometimes total solar energy is reported, but sometimes a more detailed breakdown in to separate PV and CSP technologies is available. This ambiguity is typical for many energy technologies, due to the wide variety of technology characteristics. For example, the same problem is encountered when considering offshore and onshore wind, or CCGT and OCGT (closed/open-cycle gas turbines). Furthermore, here some data relates to energy generated/output, and some to energy consumption.

Figure 2-3: Annual energy production from solar energy (PV and CSP) from various data sources 1983-2017



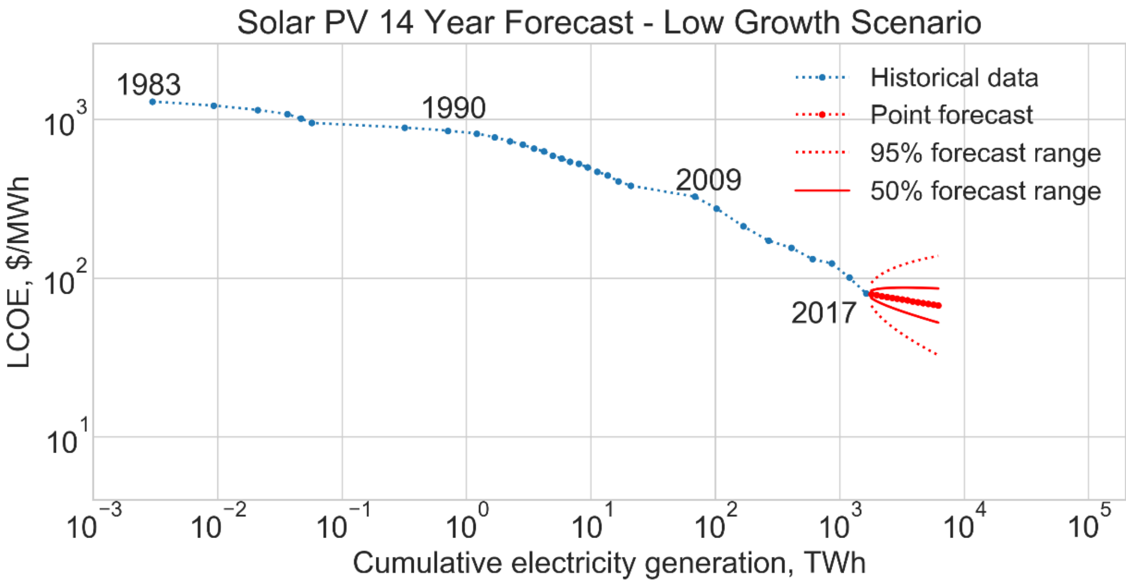
Source: Authors.

Having discussed the many unavoidable caveats regarding data sources, quality and definitions, Figures 8.4 and 8.5 show two 14-year forecasts for solar PV under low and high growth scenarios. This time period was chosen because it allows for a significant growth of experience, but not so much as to be unrealistic. It must be emphasised that these are very conservative forecasts – any other choice of historical data for experience curve calibration yields much faster, larger cost reductions. The forecasts are made by applying a slightly modified version of the method described in Lafond et al. (2018), using LCOE and cumulative generation data for solar PV. (An autocorrelation parameter value of 0.19 is used here, as this was found to be the average value over all technologies studied in that paper.) The low growth scenario shown corresponds to an annual growth in cumulative energy generation of 10%, while the figure for the high growth scenario is 30%.

For LCOE data we use the "NREL Upper Cost Of Energy" data chained together with the Bloomberg LCOE data (the blue and red curves in Figure 2-3). These provide very conservative, global estimates of the LCOE of solar PV for most years 1980-2017. Since the forecasting method relies on *differences* in data series, the lack of data for the years 2006-08 is not a serious problem – we simply omit the four first-differences where data is missing and perform a regression through the origin as usual on the remaining data. However, the original technique was designed and validated on series with no missing data, so strictly this ad-hoc implementation is not guaranteed to have the same analytically provable properties. The forecasts are still meaningful though: as a further test we inserted three plausible fabricated data values in the missing years, and recomputed the forecasts, which were virtually identical.

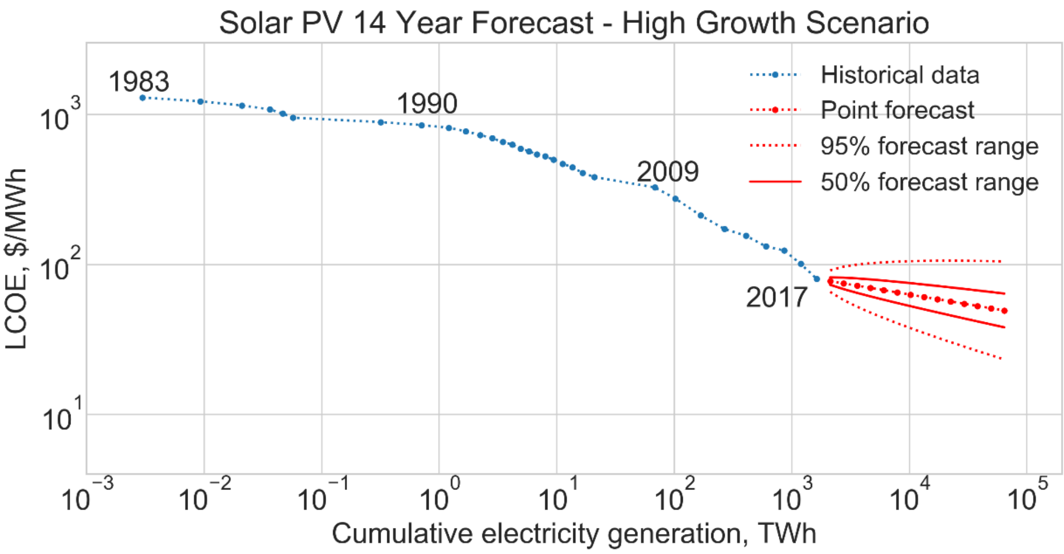
For energy generation data we use the BP total solar consumption data for 1983-2017. It is unfortunate that no data exists for PV generation alone, without CSP, before 2000 (see Figure 2-3), since the volatile behaviour before 1990 has a significant impact on the overall results. Including the pre-1990 data gives an experience exponent of around -0.13, while excluding this data gives a value of around -0.3. This discrepancy has a large impact on the results, and it would be very useful to know the precise breakdown between PV and CSP generation before 1990, in order to know whether or not this data is representative of PV experience in the period. However, this is impossible, and so by using the whole dataset, despite the known potential inaccuracies pre-1990, the forecasts produced are very conservative (but at least this avoids the potential pitfall of unconsciously cherry-picking data).

Figure 2-4: Forecast ranges for the LCOE of solar PV, assuming a 10% growth rate of experience (calibrated using historical energy dataset including early combined PV and CSP data)



Source: Authors.

Figure 2-5: Forecast ranges for the LCOE of solar PV assuming a 30% growth rate of experience (calibrated using historical energy dataset including early combined PV and CSP data)

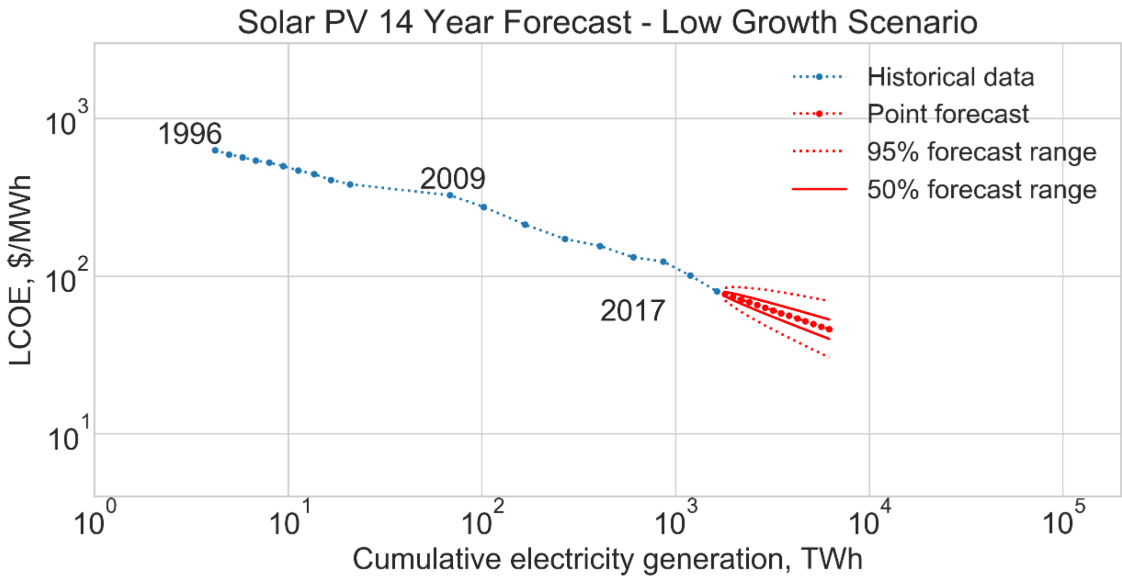


Source: Authors.

Under the high growth scenario, the mean forecast LCOE after 14 years is around $49/MWh, while under the low growth scenario it is around $67/MWh. The 50% range of costs are 38-64$/MWh and 52-86$/MWh respectively. For comparison, the current cumulative generation for gas-fired electricity is around 120000TWh (i.e. $1.2x10^5$TWh), and the average LCOE figure is around $56. So, after 14 years of the high growth scenario the global average LCOE of solar PV is predicted to be lower than the current cost of gas-fired electricity, while the cumulative generation would still be lower. Again, note that the data and inputs used here for calibration are all highly conservative choices. This shows the significant potential for solar to contribute to the global energy supply.

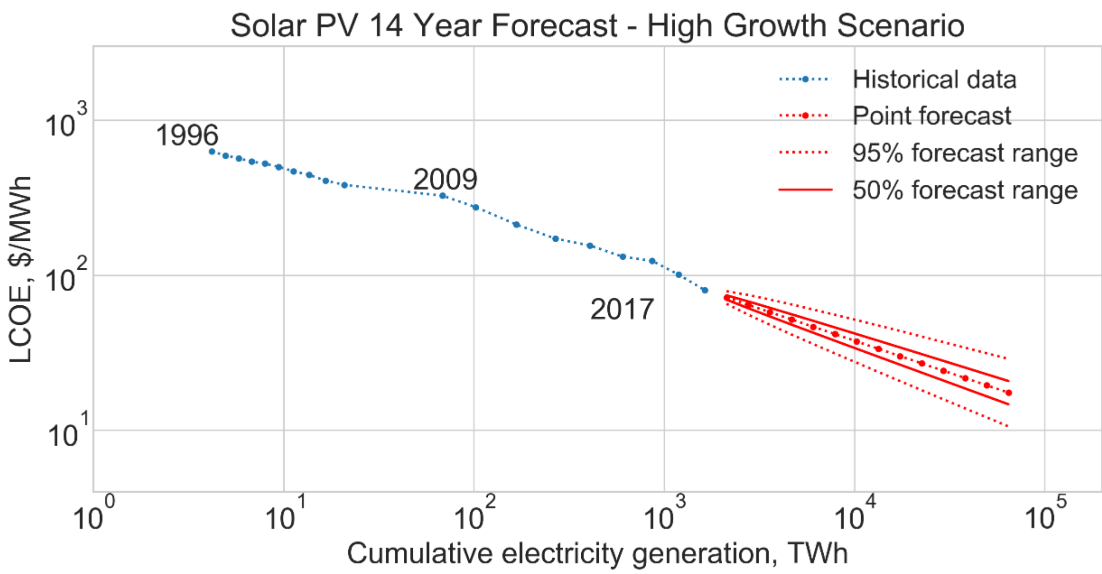
For comparison, we briefly present the corresponding forecasts if the earliest BP consumption data (explicitly covering both PV and CSP) is *excluded*. Using the BP consumption data from only 1996-2017, and the same LCOE data as before gives the forecasts shown in Figure 2-6 and Figure 2-7).

Figure 2-6: Forecast ranges for the LCOE of solar PV, assuming a 10% growth rate of experience (calibrated using historical energy dataset excluding early combined PV and CSP data)



Source: Authors.

Figure 2-7: Forecast ranges for the LCOE of solar PV, assuming a 30% growth rate of experience (calibrated using historical energy dataset excluding early combined PV and CSP data)



Source: Authors.

Under the high growth scenario, the mean forecast LCOE after 14 years is around \$17/MWh, while under the low growth scenario it is around \$46/MWh. The 50% range of costs are 15-21\$/MWh and 40-53\$/MWh respectively. These are much lower than the previous forecasts, and highlight the fact that cost reductions in the recent past have been so significant, and consistent, that we should expect such cost declines to persist in to the near future, in line with how technological progress has been empirically observed to occur in many other technologies over the last few centuries.

We have conducted similar analyses for wind and battery storage technologies and observed similar experience curve parameters, showing that accelerating production of all these technologies is likely to lead to faster cost declines.

2.5. Which technologies should we invest in, and in which proportions?

The work described so far has shown that for any single technology we are justified in using the experience curve model to make probabilistic forecasts of future costs, conditional upon some specified level of future production, which we are free to vary to model different scenarios. However, since the global energy system is made up of many technologies, what we really care about is how a whole suite of technologies progresses along their experience curves *simultaneously* under different full system scenarios. Some technologies will progress at a high average rate, but with high uncertainty, while others will progress at a lower average rate but with higher certainty. A mix of different technology types may therefore be advantageous when considering the system as a whole.

We have developed a framework for modelling this process using portfolio theory. Similar to an investor selecting a portfolio of assets with various returns and volatilities, the energy system can be thought of as a portfolio of technologies with various progress rates and volatilities. Our method assigns to each global energy scenario a probability distribution representing the present discounted cost of the whole system, based on how we expect all the experience curves to evolve simultaneously. Scenarios can then be compared to determine which are preferred, based on a range of criteria. In theory this method allows us to compute the “optimal” investment portfolio for fast yet certain cost reductions in low-carbon technologies. However, the multi-technology, multi-period problem is highly complex and becomes computationally intractable very quickly as the time-horizon increases beyond just a few periods. Hence, in order to understand the essential characteristics of the model we have studied the simplest case in detail: just two technologies and one or two production periods, i.e. we consider how to split our investments between two uncertain technologies in order to have the best chance of the lowest cost system at the end of the time horizon. We outline the method briefly now for these low dimensional cases.

Suppose there are two pure substitute electricity generation technologies, A and B, with current LCOE values of C(A,0) and C(B,0). (The case of non-substitutes requires extra constraints, such as the inclusion of extra energy storage technologies, so we just consider substitutes here.) Over the course of one period, let there be a fixed exogenous demand for electricity K(1), which must be met by some combination of the two technologies’ production, Q(A,1) and Q(B,1). During the period each technology makes progress (probabilistically) along its experience curve, and the average within-period costs are C(A,1) and C(B,1). These costs are random variables depending on the production levels during the period, the initial cost and cumulative production, the technology-specific experience exponents (inferred from historical data) and the technology-specific noise shocks (also inferred from historical data). The total cost of production for the period is then just the sum over both technologies of the unit cost times the number of units produced:

$$V(1) = C(A,1)Q(A,1) + C(B,1)Q(B,1)$$

To obtain the total system cost over two periods instead, with second period electricity demand K(2) and discount factor D, we simply add to V(1) the discounted second period cost (which depends on *cumulative* production levels, since costs follow experience curves):

$$V(2) = C(A,1)Q(A,1) + C(B,1)Q(B,1) + D[C(A,2)Q(A,2) + C(B,2)Q(B,2)]$$

In both cases the present discounted total system cost, V, is a stochastic quantity, so must be assessed in terms of the entire distribution of outcomes, not just a single central value. Because it is simple and intuitive, we use a mean-variance objective function f, with risk aversion R, to compare the risk-adjusted cost of different production combinations:

$$f = E[V] + R\,\mathrm{Var}(V)$$

Minimising this quantity, subject to the first and second period demand constraints (K(1), K(2)), gives the optimal way of splitting electricity production between the two technologies – the optimal production portfolio. This allows us observe the effect of the various model parameters on the optimal solution: risk aversion, discount rate, total production per period, initial costs, initial cumulative experience, experience exponents and volatilities. If the dimension of the problem is low enough then brute force minimisation may be used successfully. However, due to the feedback inherent in the experience curve model, the problem is non-convex, so efficient local optimisation routines are not guaranteed to find the global optimum and finding good solutions may be difficult.

In summary, the method combines the distributional experience curve forecasting method – which has already been shown to be logically consistent and historically validated (up to an exogenous progress factor, as discussed above) – with well-known tools from financial portfolio optimisation, in order to understand how to assign electricity production between a range of energy technologies, over a number of periods, and take advantage of high progress rates while also avoiding high uncertainty. The full details of the technique and some results have been published in a working paper (Way et al. 2018), which is currently under review at a journal. This is the first time the model has appeared in the literature.

There are two main insights from the work. First, while deterministic experience curve models typically exhibit extreme parameter sensitivity (i.e. changing the experience exponent little changes the results of the model a lot), moving to a probabilistic setting generates results that are more robust to parameter changes. There are still some regions of parameter space in which results are extremely sensitive to parameter changes, so it is still important to have accurate parameter estimates and conduct sensitivity analyses, but generally, by valuing both a central value and a dispersion measure of distributional outcomes, we find that results are more robust than in the deterministic case. Second, the work establishes a theoretical link between technology portfolios and financial portfolios. This is useful because it helps explain precisely when and why investments in dynamic, new technologies can be justified, as an ageing competitor technology's capacity for learning diminishes.

We have extended the model to cover the full multi-technology, long-time-horizon case, though this work is still being finalised. This application of the technique involves modelling the practicalities of the energy system, and producing policy-relevant outputs. In particular, energy storage and transmission technologies are included, and constraints regarding availability of different types of technology (e.g. availability of renewable energy sources and energy storage) must be respected when designing energy system scenarios. Preliminary results indicate that scenarios involving very large shares of solar, wind and batteries will be much more favourable in terms of cost and predictability than those with lower shares.

2.6. Conclusions

The distributional experience forecasting method shows that it is likely that wind, solar and storage technologies will become much cheaper in the near future, and that this progress can be accelerated by increasing near-term investments. In contrast, fossil fuel and nuclear based technologies, which have accumulated a vast amount of experience globally since their inception, have seen very little progress in the recent past. This, in combination with the vast resources they have had at their disposal during this time, mean that the corresponding experience curve analysis predicts a low chance of significant future progress. Hence a global technology portfolio formed largely of currently immature but fast progressing technologies will have a good chance of being cheaper in the long run. We are still working on the final detailed results.

2.7. References

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3. CASE STUDY: Local content requirements and financial incentives in emerging wind energy markets in Brazil and South Africa

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Abstract

This chapter analyses Local Content Requirements (LCR) in the Brazilian and South African wind energy programs. Local content policies are contested incentives that aim at enhancing technological and industrial development, while simultaneously posing trade barriers. The Brazilian renewable energy program has been running seven years longer than the South African program and provides insightful experiences for both South Africa and other emerging markets. The Brazilian program has created jobs in manufacturing, installation, operation and maintenance while achieving highly competitive energy prices through a competitive auction system. The South African government has attracted significant investment in the wind sector but must stabilize the renewable energy program to create a reliable investment climate.

3.1. Introduction

Over the past decade, wind power has played a major role in diversifying the electricity mix internationally. The incentive measures and local content requirements policies (LCR) have become an integral part of renewable energy industrial policy making in several emerging markets.

This article discusses the development of the wind power industry in Brazil and South Africa, with a special focus on LCR and technological development. A qualitative content analysis of wind industry data grounds on 43 interviews with stakeholders in the Brazilian and South African wind energy sectors (government and international OEMs representatives, developers and local manufacturing firms). Interviews took place during events such as the Wind Power Brazil Conferences, AfriWEA, and Windaba Conferences in South Africa, as well as individual visits. Secondary data from media articles and policy documents supplemented the interview data.

The cases of Brazil and South Africa were chosen in the logic of a most similar case study design, while having different incentive policies for renewable energy developing. Both countries experienced severe power cuts in 2001 and 2008, respectively. Power sectors have been continuously strained, because of persistent draught in Brazil (where hydropower dominates) and lack of maintenance of the South African coal fire plants (where electricity supply depends mostly on coal and nuclear power). Blackouts led to a debate on the need to diversify sources for power generation in both countries.

Public policy and market factors determined the impacts of renewable energy programs. Both countries changed their incentive systems from feed-in tariffs to competitive bidding programs, with LCR policies becoming key element in both wind energy incentive systems.

3.2. Factors, actors and impacts of local content policies

Local content requirements are rules, set by the government, which determine the way foreign investors have to allocate their resources. Usually governments require that a certain amount of technological equipment be manufactured locally. There are different ways of determining local content, which can be calculated as the percentage of the project value, the value of the technological equipment, designation of specific technological components or a percentage of their weight [1].

Specifying local content is a balancing act, because setting the requirements too high may deter investors and push technology prices up. Setting the requirements too low may exempt the desired technology upgrade and employment benefits. If content requirements target production from sophisticated industrial processes, the requirements usually target a percentage of the value added rather than physical units [1].

The rationale of local content requirements is the attempt to extract the full benefits of technology transfer and job creation. LCR can narrow the gap in technological capability and market opportunities between developed and developing countries. Typically, firms in developed countries have mature technologies, but struggle to sell them on saturated markets, whereas the developing countries have immature technologies and offer new market opportunities. The logic is that the protection schemes increase the production of domestic content in the receiving countries and reduces the output of the foreign country in its home country [8]. Another argument for local content requirements is that governments intent to correct a perceived gap between the private and social costs and benefits of the investment [9].

Domestic content policies create winners and losers. Obliging firms to manufacture locally through compulsory requirements directs foreign investment towards local firms and local jobs in the receiving country, reducing the profit of the investing firm. Therefore, content policies are a popular and controversial policy instrument, which mostly appeals to governments in developing countries.

Several authors identified benefits of local content requirements. The main benefits are i) technological upgrade, which refers to increasing the locally manufactured technology content and firm technological capability [10]; ii) the creation of “national champions”, which refers to companies that manufacture locally and eventually produce for export [11] and iii) creation of local jobs [9],[12].

The research literature reflects the controversy around the benefits and harm of local content requirement. The literature on industrial policy, which produces mostly individual country analyses, identifies three main indicators for successful implementation of local content requirements:

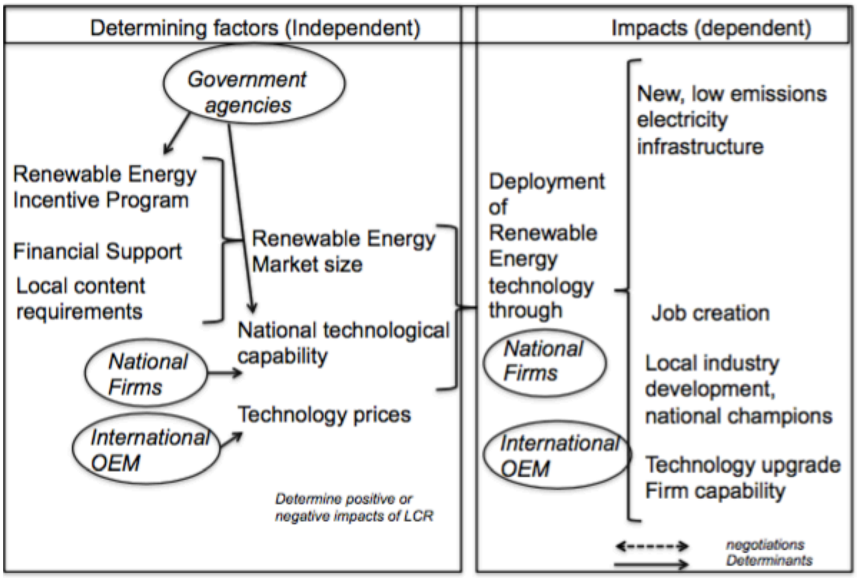
- Technological upgrade refers to adding value in the technology content, which is manufactured locally, and increasing firm technological capability [10].
- Creation of national champions, which can be quantified in the number of firms which manufacture locally and eventually produce for export [11].
- Creation of local jobs, which are usually quantified as jobs per MW installed [12, 9]

These positive impacts of local content requirements depend on the size of the market, the existent technological capability to absorb transferred technologies, and the technology prices. If technology prices in the world market exceed domestic prices, LCR are more likely to fail [1, 9]. The literature on local content requirements applied in the wind energy sectors reflects the mixed impacts of LCR found in the older theoretical literature. Lewis and Wiser (2007) analyse LCR in the wind energy sectors in twelve countries. The authors find that the successful implementation of local content policies depends on the size and stability of demand in the home market, which is an important “testing ground” for new technologies and market strategies [12]. Local content requirements can backfire, as Rivers and Wigle (2011) find in their partial equilibrium analysis of the Canadian case, if they increase the cost of renewable energy equipment and reduce the amount of renewable energy production and green job creation. This effect occurs if capital between sectors is not mobile and cannot easily be transferred across national borders due to regulatory restrictions. On the other hand, content requirements can have positive effects on employment and technology prices if capital is mobile and if there are economies of scale or economies of learning in equipment manufacturing. In this case content protection, combined with a renewable energy subsidy, can provide a local manufacturing sector with the capacity to become a dominant global supplier [14].

The literature in trade economics generally argues against local content requirements. The main argument states that local content requirements are barriers that distort the free trade flow and cause overall welfare losses. This conclusion rests on the assumption that welfare derived from the self-clearing markets under the principle of non-intervention, might not necessarily hold for the case of highly regulated electricity markets. Early macroeconomic writing on content requirements in the 1980s identifies possible negative effects, because the extent of the requirements is not predictable [1]. Hollander (1987) and Vousden (1987) confirm the possibility of harmful effects of content requirements on final good producers. Nakanishi and Masayuki (1997) show that the wage differential between the countries is crucial in determining the direction of how benefits and losses are allocated. Rodrik (2004) makes strong arguments for industrial policy intervention in developing countries. In their view, non-traditional sectors generally need support in new technologies, training and information as production diversifies with economic development [2]. Local content requirements fall under these ‘unorthodox’ policy measures. These measures can be found in the early trade disputes in European industrial development already, continuously in industrializing industries in the tobacco and in the automotive industries, and now the renewable energy industries recently [51].

Figure 3-1 summarises the factors and actors who can impact on success and failure in implementing local content requirements, based on the literature review above. This summary will serve as a framework for the analysis of the LCR policies in Brazil and South Africa in the following section.

Figure 3-1: Actors, factors and impacts of local policies in renewable energy programs



Source: Authors.

3.3. Factors, actors and impacts of local content policies in Brazil and South Africa's wind energy market

Trial and error mark the evolution of the wind energy incentive systems in Brazil and South Africa. Both countries experienced slow starts into renewable energy, because electricity supplies largely rely on dominant energy sources: hydropower in Brazil and coal in South Africa. The power shortages in 2001 in Brazil and 2008 in South Africa pushed governments into diversifying their energy sources and supporting wind energy systematically. The main differences between feed-in tariffs and competitive auctions are flexibility in pricing vs. market size. Feed-in tariffs set a fixed value and leave the allocated quantity flexible, whereas competitive auctions operate under a determined market size, and bidders compete in price.

3.3.1. Wind energy programs in Brazil

The Brazilian governments started to support renewable energy in the early 2000s with a feed-in tariff. Initial incentives created the conditions for establishing a market for wind energy at a slow pace and a high price, with high levels compulsory local content and slow-moving bureaucracies. Only very few companies could succeed in this policy environment. The incentive program was changed to a wind specific auction program in 2009, which coincided with the world economic crisis and opened the market for a dozen international OEMs. Local content requirements were a substantial ingredient of the Brazilian renewable energy program since its early beginnings but were then made optional. The administration of the program moved to the national development bank (BNDES).

3.3.1.1. Compulsory local content requirements in the feed in tariff

After some failed attempts to promote wind energy in Brazil (eg. Proeólica Program, from 2001 to 2003), the Incentive Program for Alternative Energies (PROINFA, law n. 10.438, of 26 April 2002[8]) came into place to support renewable energy deployment in Brazil in the form of a feed-in tariff, which set 60% of required local components in the new wind installations[9], targeting local industry development. The localization index was calculated over the total value of the park, considering services and equipment. The main goal of such localization rate was *"to strengthen the Brazilian industry of electric power generation, developing the field of supply chain […]"* [22].

PROINFA aimed at promoting 3,300 MW of generation capacity (consisting of 36% of small hydropower plants, 43% of wind and 21% of thermal biomass). The central utility Eletrobras committed at buying electricity from wind power producers over 20 years at an offered tariff of 300 R$ (128 US$) per MWh, conditional on LCR.

However, at the time, only one wind energy manufacturer had the technological capability to produce local equipment in Brazil, operating since 1996. Wobben, a Brazilian subsidiary of Germany's Enercon, had already installed the first wind farms in Brazil, independently from any incentive policy.

According to some interviewed experts, their motivation was to demonstrate that wind energy was a viable option for Brazil[10]. The firm managed to install most of the parks commissioned through PROINFA, while other firms struggled to fulfill the content requirements[11]. Yet, the newly created demand for locally produced wind turbines was higher than a single manufacturer could meet[12], which led to significant delays in installation and high market prices.

In 2006, only six of the initially planned 75 wind turbines were up and running, which still increased the capacity dramatically. The Spanish OEM Gamesa left the market temporarily[13]. According to one of the company's expert, the market was too small and too instable for other international competitors to invest[14]. GAMESA established its first manufacturing facility only by 2010.

Other factors contributed to the delay in the implementation of the local content requirements. Additional delay factors were the sluggish bureaucracy of the Environmental Agency (IBAMA), delays in the environmental assessments (licensing process) and grid connection expansion (at the time, there were not combined biddings for transmission lines projects with wind power plants)[15]. Between 2006 and 2009, a temporary suppression of import tariffs for wind turbines components was set, aiming to catch up on delays and reduce associated costs. In spite of delays, PROINFA contributed to installing 1.4 GW of wind capacity in Brazil between 2008 and 2013 [23].

3.3.1.2. Optional LCR linked with renewable energy finance

These above-described delays in the implementation of PROINFA deterred some international investors and privileged those who already had built up technological capability in Brazil.[16] The delays pushed the government to a policy change in regulation, shifting to a competitive bidding process.

The Ministry of Mines and Energy introduced its competitive bidding program in the form of a so-called reserve energy auction (Brazilian Decree 6 353/08) and other types of auctions.

8 The Proinfa's law was revised and adjusted by the Law n. 10.762, of 11 nov. 2003 and regulated by Brazilian decrees n. 4.541, of 2002 e n. 5.025, of 2004.
9 BNDES released 5.5 billion R$ for PROINFA for direct and indirect transfers.
10 Interviews No. 1, 2, 37
11 Interviews No. 12,13, 21
12 Interview No.1, 13
13 Interview No.13
14 Interviews No. 13, 4
15 Interviews No. 31, 35, 36
16 Interview No. 13, No.2

Local content requirements were formally abolished, remaining compulsory exclusively for developers who required financial support from the BNDES, the Brazilian National Development Bank. BNDES is the designated implementation agency, a public enterprise under the Department of Industrial Development and External Commerce. BNDES has received a powerful mandate for the implementation of local content requirements: The bank is responsible for the selection of bidders, financial support and enforcement of compliance with requirements.

BNDES can finance up to 80% of renewable energy projects, at approximately a 10% annual interest rate[17] (or 0.97% monthly), through its subsidiary Special Agency for Industrial Financing (FINAME). After 2016, the alternative energy line finances projects worth over BRL 20 million (USD 6.3 million) with a payback rate of 16 years.

BNDES's financial support mechanisms create a clear incentive for the use of wind energy, despite the obligation to fulfil local content requirements. In practice however, domestic content requirements remained, given no firm managed to developed a wind farm project without the bank´s support[18].

In the initial rule for the project funding, manufacturers must meet at least three of four criteria [26]: i) manufacture of towers in Brazil, with at least 70% of steel plates produced in the country or reinforced concrete of national origin; ii) manufacture of blades in Brazil in own or third-party unit; iii) assembly of the nacelle (main part of the wind turbine) in Brazil, in its own unit; iv) assembly of the cube (piece that involves the nacelle) in Brazil, with melted material of national origin.

Before these rules were set, firms needed to prove the origin, value and weight of each component (machines and equipment). The main parts produced under those requirements are the nacelle, the towers, the blades and the hubs. Therefore, a tower (usually made of concrete or steel), which is 100% locally produced, could meet 40% of localization of the whole turbine[19].

After 2012, BNDES created a new methodology to assess local contents to wind turbines aiming to improve the accreditation process. BNDES also started offering an Accreditation of Computerized Manufacturers (CFI), where producers can consult the national products that are listed in the system and obtain nationalization index certification, which enables firms to sell their products as domestic content. BNDES's focuses on the firm's production process and takes no responsibility on quality; it only certifies the local origin[20].

Staggered increases in requirements include high technology content and intensive labour deployment, targeting job creation. International investors gained trust in the Brazilian wind energy market once the government started sending clear market signals on the future demand and prospects later in the auction programs. In 2013, BNDES withdrew the accreditation of five international OEMs temporarily who struggled to show their compliance with the local content requirements. This was a -signal to the industry that the government was taking the issue seriously.

3.3.2. Wind energy support programs in South Africa

The South African government also experimented with renewable energy programs. Its Energy White paper announced the use of renewable energy already in the 1990s without creating specific incentive policies. A renewable white paper announced ambitious targets in 2003, but again, did not translate into policy that would reform the coal- based electricity sector. The electricity shortages and

17 Long-term interest rate (this varies from 5 to 7.5%)+bank's remuneration (it varies from 0.9 to 3.5%. Currently it is 1.2%)+risk rate (until 2.87%), per annum.
18 Correspondence No 33, 34, 31
19 Interviews No. 3, 6
20 Correspondence No. 33, 34

subsequent power cuts in 2008 eventually gave momentum for a policy process towards a feed-in tariff.

3.3.2.1. Wind energy under a feed in tariff proposal

In 2009, the National Energy Regulator (NERSA) announced guidelines for a Renewable Energy Feed-in Tariff (REFIT), which is supposed to guarantee the payment of a fix price per kwh produced through seven renewable energy technologies, including wind.

The REFIT also made provisions for local content requirements as part of the Accelerated Shared Growth Initiative (ASGI-SA). ASGI-SA is an economic development program, which identified public expenditure on infrastructure. New electric energy power stations were one of the focus areas. ASGI-SA requires local content, black economic empowerment and skills development targets as additional evaluation criteria for public procurement, besides price.

The ASGI-SA requirements identify five areas on a scorecard[21]:

- percentages of local content;
- percentage of local content established through “large black suppliers” (LBS), a firm with an annual turnover of more than R35 million and a Black Economic Empowerment Contributor;
- a percentage of procurement from “Black Woman Owned Enterprise” (BWO) defined as business owned more than 50% by black women;
- the percentage of procurement from “Small Black Enterprises” (SBE), must add up to at least 50% black owned with a turnover below R35 million;
- skills development as a commitment of the “tenderer to train certain individuals in specific trades” … “and qualify[ing] as an artisan, or the equivalent for any other required skill”.

Local content is defined as “value added in South Africa by South African resources. […] Local content is total spending minus the imported component. This [value] is calculated by subtracting the cost of imported goods and services in respect of the Works from the total Contract Amount”. The REFIT made provisions for sellers and buyers to procure through the obligations of the ASGI-SA program.

The REFIT was never implemented in its original format that NERSA had proposed. A number of political and regulatory problems stalled its implementation, which resulted from lack of political backing for the program. NERSA’s efforts did not have the necessary support from National Treasury and the Department of Energy (DoE). In 2011, the sector was awaiting more clarity on the implementation of the REFIT, after the DoE’s integrated resource plan (IRP) was revised towards a higher share of 17 GW of renewable energy [27].

Instead, the Department of Energy announced a new program, the Renewable Energy Independent Power Producer Procurement Program (REIPPPP). The REIPPPP invites independent producers to submit bids for renewable energy production to the DoE. The National Treasury supports the process through its public private partnership unit. NERSA continues to issue licenses for independent power producers.

3.3.2.2. Financial support under the competitive bidding program

In South Africa, financial support comes from the Industrial Development Corporation (IDC) and the Development Bank of Southern Africa (DBSA), and the commercial banks. The IDC provided financial

21 ESKOM. "Annexure It1.2: The ASGI-SA Requirements". (n.d. p.4).

schemes for 19 preferred bidder projects with an approved investment of R7.5 billion[22]. The DBSA approved approximately R9.6 billion for 896.5 MW capacity installed under the REIPPPP[23].

Local content requirements do not link to any of the financial schemes of these banks, unlike in the Brazilian case. In South Africa, localization is compulsory independently from the sources of finance. The interest rates for loans from the IDC and DBSA are similar to the market rates between 11-14% [28].

In South Africa, the mandates for the implementation of the content requirements are less clear than Brazil. The Directorate for Renewable Energy Industries at the Department of Industry (DTI) is responsible for the development of the local content requirements with some support from consultants. The Department of Science and Technology offers general support and a localization strategy, but the concrete requests from the industry land in on the desks of the DTI. The Department of Energy is the principal procurer in the renewable energy program. The Department signs the contracts with the power producers, who then procure through the manufacturers of components and reserves rights to dissolve the contracts in case of non-compliance with the procurement obligations [27]. Financial penalties for non-compliance with the content requirements apply. In case of delayed delivery, the DoE has the right to delay the power purchase agreement. The DoE went on field trips to check on compliance with labour laws and procurement. An IPP Procurement Unit, run by the DoE together with the National Treasury assesses the bids and the local content.

Three bidding rounds were managed successfully, despite minor delays in processing them. In the wind farms bidding process, there are socioeconomic development requirements (defined in scorecards), aiming to create jobs for population groups within a 50 km radius from wind farms [29], [27].

The limited timespan and uncertain future after completion of five bidding rounds prevents large scale investments. The IPP unit of the National Treasury and the DoE, which manages the bidding rounds, lacks an institutional basis and can be closed down any time. This threat has become real over the past two years, when Eskom started refusing to sign the power purchase agreements. A process known as state capture had motivated factions within the government to lobby against the renewable energy program in favour of a nuclear program. The delay in the compliance of the power purchase agreements destabilized the industry and let to job losses and closure of offices and factories. An international blade manufacturer reconsidered its decision to invest into South Africa[24]. The tower manufacturing factories had to be temporarily closed.

3.3.3. Summary

In sum, both governments experimented with price- and quantity- based incentive schemes, in the form of feed- in tariffs and competitive bidding programs. Both governments settled on incentivizing wind energy technology diffusion through competitive bidding schemes. The Brazilian government changed from a compulsory to a voluntary approach to implementing LCR as a condition to access inexpensive loans from the national development bank. All developers in the market chose to respond to this incentive. The South African program, in turn, has no significant financial support built into the program. The LCR are compulsory and fined. The slow increases in local content allowed to build the industry gradually.

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22 Mail and Guardian. 2012. The renewable energy industry's driving force. Special Reports. 22 August 2012. URL: https://mg.co.za/article/2012-08-22-the-green-industrys-driving-force
23 Business Report. 2012. DBSA approves R10 billion for renewables. 22 October 2012. URL: http://www.iol.co.za/business/companies/dbsa-approves-r10bn-for-renewables-1.1408467#.UJFD4kLwiCQ
24 Personal communication with LM Blades

3.4. National technological capability and job creation in the Brazilian and South Africa wind energy industries

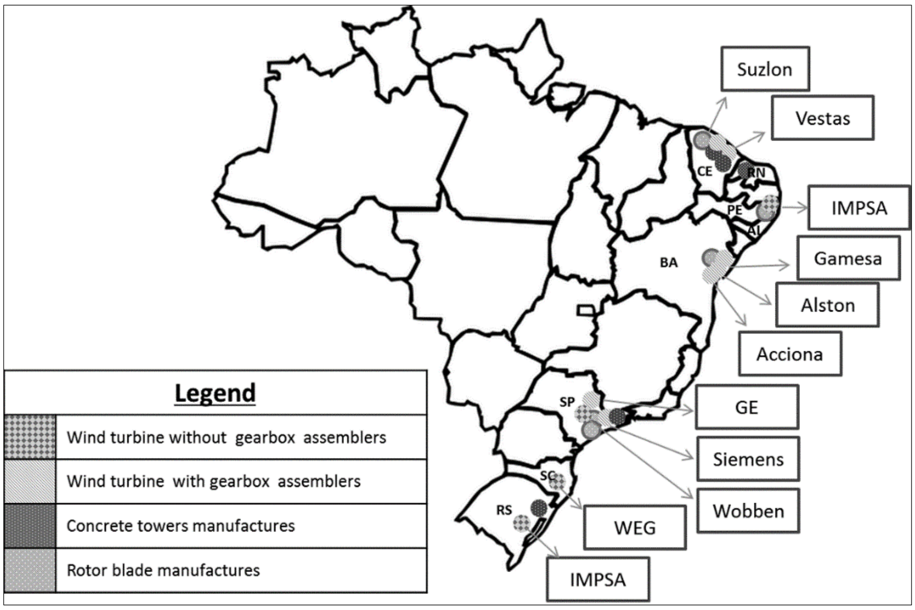
Technological capability, size of demand, wage differential and technology prices appeared as main determining factors in the literature. The interviewees of this research showed that electricity prices and the state of the global industry also played a role in wind energy expansion. National technological capability consists of firm capability and the public administration's ability to advance technological development.

The following section presents the analysis of the technology upgrade and industrial development in both countries as a result of the local content requirements. It also estimates impacts on job creation, despite the lack of reliable data. The Brazilian auction system does not require estimates for job creation, unlike the South African procurement system, where bidders provide such information through socio-economic development scorecards, allowing for monitoring the proposed job creation. Therefore, we present existing estimates and our own data, which we collected through interviews with sector experts.

3.4.1. Brazil's National technological capability and job creation

In Brazil, nine wind turbine assembly companies were installed after the incentive programs, with the following annual capacities: WEG (200 MW), Wobben/Enercon (500 MW), GE (1,000 MW), Alstom (400 MW), Gamesa (400 MW), Acciona (300 MW) e Vestas (400 MW planned) [18]. Suzlon and Siemens did not inform their annual capacities. Figure 3-2 shows the regional distribution of the wind turbines assemblers in Brazil.

Figure 3-2: Regional distribution of main wind turbine assemblers and wind turbine main parts manufactures in Brazil



Source: Adapted from Public Domain in Vectors.org and ABDI [19].

The best winds regimes for electric energy generation are in North-eastern Brazil and those are likely to improve with climate change [30]. Even though many firms are settled in the South and South East regions (especially suppliers of inputs for blades), where most of Brazil's industrial infrastructure is concentrated, some 40%, invested in branches, factories or even headquarters in the Northeast, since that is where most of their operations are located[25].

Suppliers of sub-components for nacelle, cube and tower items are located in São Paulo (SP), Bahia (BA), Minas Gerais (MG), Santa Catarina (SC) e Rio Grande do Sul (RS) states. Groups of suppliers are located close to the assemblers, depending on the type of supply chain (metal-mechanics for concrete towers, for example, heavily developed in the state of São Paulo, as well as the supply chain of resins, fibre, fasteners, adhesives etc. for blades). According to the Ministry of Mines and Energy [32], there are four blade manufactures with capacity to produce 10.400 unities/year and 12 manufactures with capacity of 2.340 unities/ year in Brazil.

Wind power chain handled more than BRL 65 billion (around USD 20.5 billion), with 80% of nationalized production. Currently the country has also more than 1000 suppliers of other components [19].

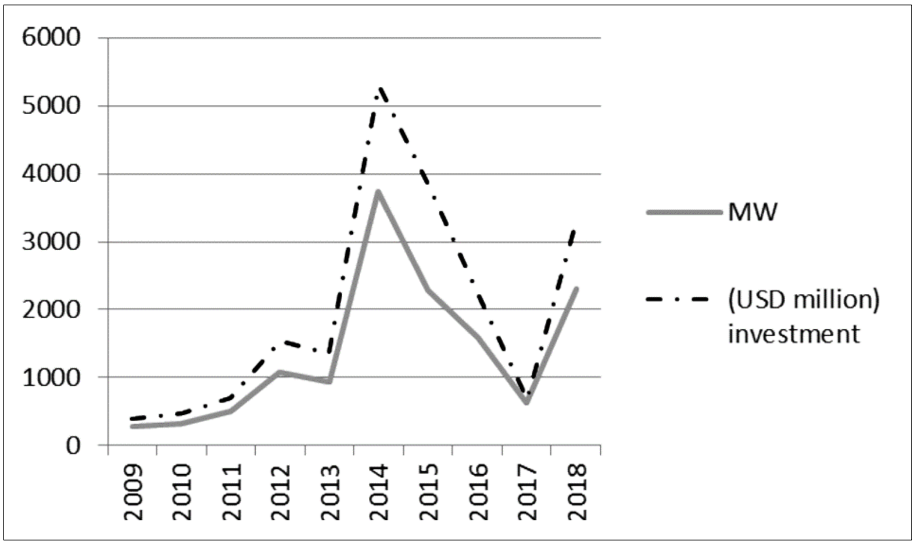
During interviews with some wind industry entrepreneurs, it was possible to identify that:

- Wobben/Enercon benefited from the content requirements[26] under PROINFA and brought up the blade manufacturer Tecsis. Tecsis emerged out of Brazil's aviation industry and became a significant local blade manufacturer through sub-contracts from Wobben[27]. Despite its factories in place, Wobben took some time to attain the BNDES CFI certification and experienced high price competition since the incentive system changed[28].
- IMPSA stated that having a factory at an early stage 'gave them no advantage', because the company needed to remain competitive (Recharge News) in an environment of high technology and labour costs.

The following Figure 3-3 shows investments verified and estimated (up to 2018) according to installed capacity.

25 Interviews No. 6, 8, 12, 21
26 Interview No. 1, 2, 13, 33
27 Interview No. 42, CEO Tecsis https://www.youtube.com/watch?v=_1s07ELbJgk
28 Interviews No.2, 7, 46

Figure 3-3: Verified and estimated annual installed capacity and investments on Brazilian Wind Power sector

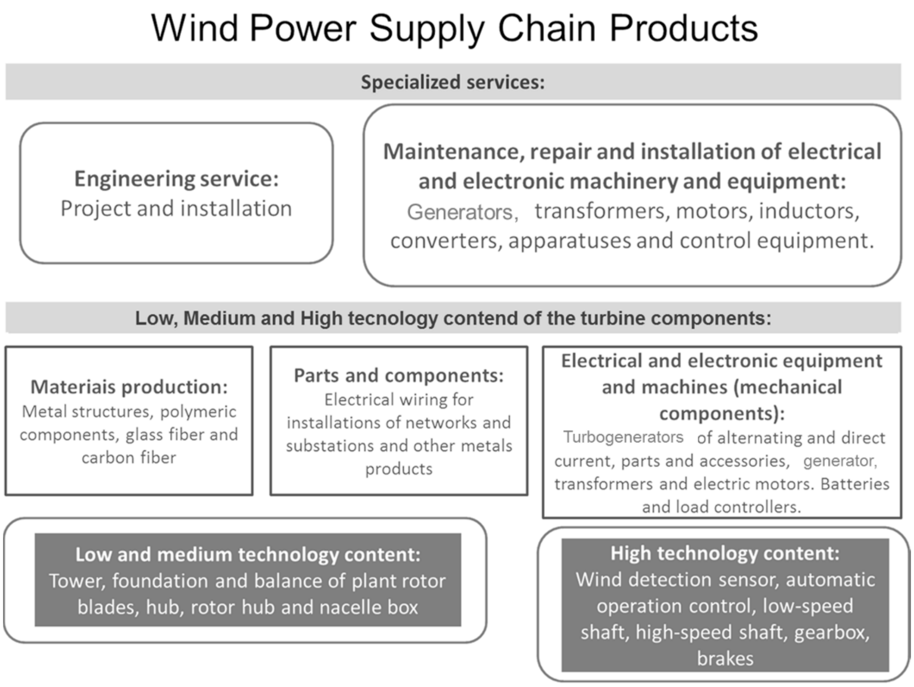


Source: Adapted from Brasil Energia [33].

Equipment costs decreased from 4800 R$/MW (1515 USD/MW) to around 3500 R$/MW (1104 USD/MW) between 2009 and 2015, according to information from auctions provided by EPE [34].

In Brazil, LCR contributed mainly to the development of low technological content products (materials production and parts and components), which is usual in most developing countries due to the difficulty to ship heavy components.

Figure 3-4: Products in wind energy supply chain rated according to level of technology content levels

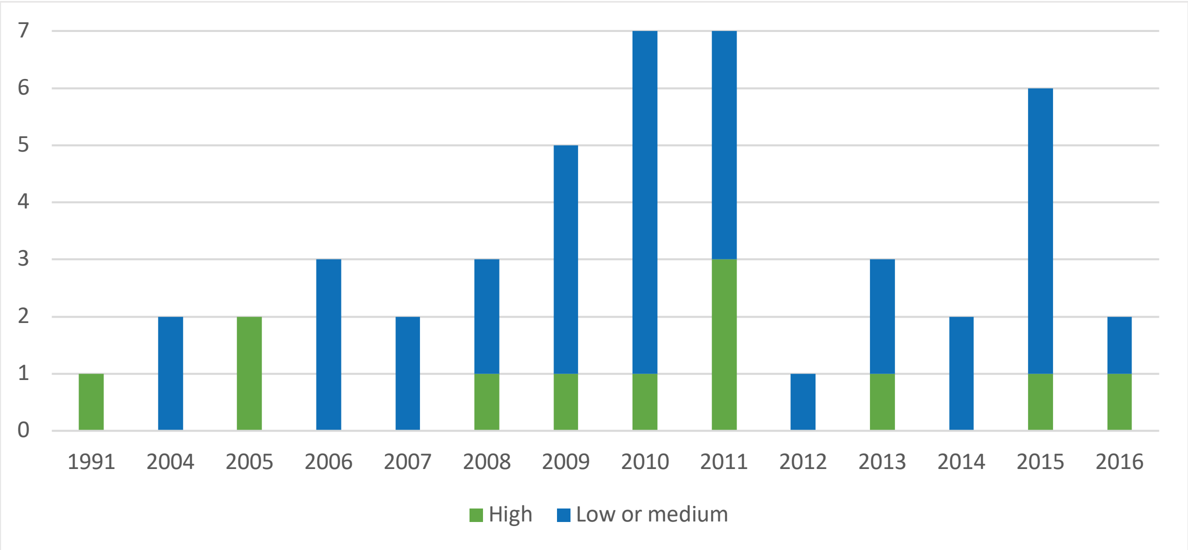


Source: Authors, adapted from ABDI [19].

Since 1991, 46 wind energy patents were registered in Brazil, from which 34 referred to low or medium technological content and 12 to high-embodied technological content. The dominance of low and medium technology components is explained by the need to adapt turbines to local conditions (especially related to the design of blades), where winds are usually more constant (in speed and duration) than in other large manufacturing countries in Europe or China.

Given that the bulk of wind farms in Brazil are located along the coast, the development of new materials and electrical components capable of supporting humidity, salt and sand, which can erode blades and damage electrical components.

Figure 3-5: Registered patents related to wind energy in Brazil according to technology content



Source: EPO Patstat.

The Brazilian Wind Energy Association calculates that 15 jobs are created per installed MW [35], summing up 157.500 direct and indirect jobs since 2009 (considering the current 10.5 GW of installed capacity in January, 2017). Approximately 280000 jobs are estimated by 2020, corresponding to 18.6 GW of wind capacity [36].

Brown [37] investigated the development impacts in the state of Ceará, which hosts the highest concentration of wind parks, adding up to 5.7 GW. The author estimates 10 to 50 temporary construction jobs per project at the local level, and minor increases on local hotel and restaurant business. Direct job creation estimates are 3 to 3.5 jobs per MW for construction, and 0.5 jobs per MW in manufacturing [37]. These consist of 7091 manufacturing jobs and 42543 construction and maintenance jobs (roughly 50000 jobs overall), 85% of these in construction and maintenance, and 15% in skilled manufacturing.

This research concentrated on direct jobs in manufacturing and sales. According to the interviewees´ data, there are 2746 direct jobs in the Original Equipment Manufacturers (OEM) in the Brazilian wind energy sector at the moment. They are concentrated in tower, nacelle and blade manufacturing.

Lack of skilled workers has fostered a market for a dozen firms who specialize in training technicians on site. Currently, enterprises offer training courses for their workers in several levels [33]. The lack of specialized laboratories for tests and innovation is another major bottleneck. Therefore, universities and research centres needed to expand their infrastructure to support R&D efforts together with firms in order to foster the sector.

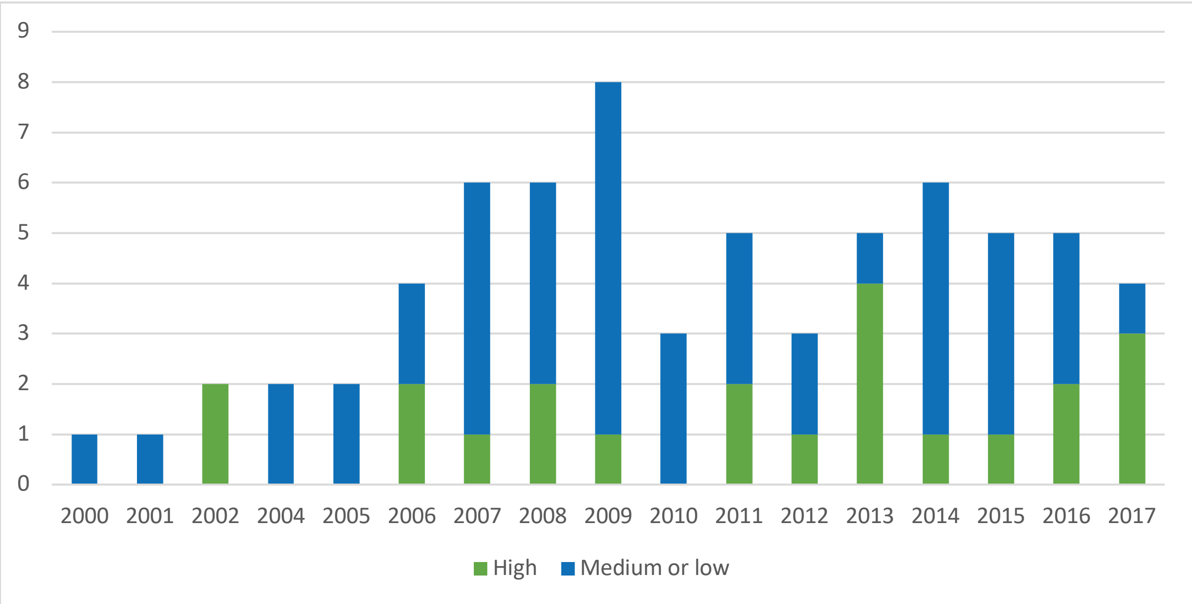
3.4.2. South Africa's national technological capability and job creation in the wind energy sector

The South African wind energy capability was limited to demonstration projects and a turbine manufacture, which manufactured full turbines with a license agreement of a German company. The design of the procurement program shut this manufacturer out of the market because it could not demonstrate the required experience. The desired power purchase agreement outside the REIPPP program never materialized and eventually the company entered liquidation.[29]

The stability of demand is in both cases very much related to the market size communicated in the incentive systems. The government allocates a market size in a competitive bidding or auction systems. The size of this market determines the technology component needed to satisfy the market, competition and possible returns of investment. The Brazilian government announced a significant wind energy market of 11GW in ten years early on, whereas the South African government started off with 3.7 GW of renewable energy technologies as a whole, without specifying the wind energy market. Later another 3.2 GW were added, but the future of the program after the conclusion of the five bidding rounds has not been communicated yet [41], [42]. This uncertainty makes investment decisions for international OEM more difficult[30].

The number of registered patents for wind energy has increased in recent years. A search on the World International Property Organisation (WIPO) site for patents registered by South Africa since 1991 reveal a total of 22 wind energy patents ("High" in Figure 3-6), and only since 2000. In the same period, a further 46 patents were also classified as 'machines or engines for liquids; wind, spring, or weight motors; producing mechanical power or a reactive propulsive thrust, not otherwise provided for' that had no apparent wind energy application ("Medium or low" in Figure 3-6).

Figure 3-6: Registered patents related to wind energy in South Africa, according to application



Source: EPO Patstat.

29 Interview No. 41
30 Interviews No. 21, 24, 22, 43

So far, the local content requirements have attracted investment into two tower manufacturing factories. One is a local company, the other one is of Spanish origin. Both specialize in manufacturing steel towers. Other OEMs took to building concrete towers on site which simplified the logistics.

The only local manufacturer of a full turbine was liquidated. The company did not fulfil the necessary two years experiences to qualify for the REIPPP program, which closed the market access for the company. The agreement to install wind turbines in Saldanha Bay with a major investor became obsolete when a major partner pulled out of the business. The company struggled to find risk capital investment from the IDC, a government department or any commercial bank, without a power purchase agreement. Its manufactured turbine equipment sits unused in Cape Town's harbour.

Wind turbine suppliers in South Africa are Vestas, Siemens, Nordex, ABB, Guodian, and Suzlon, i.e., mainly European companies and a Chinese and an Indian company, and two local tower manufacturing facilities have been established in the Eastern Cape and the Western Cape provinces [43].

Interview data showed that some OEMs opened small offices, whereas others still have employees from their country of origin flying in and out of South Africa. The direct jobs in the OEM offices vary between one and 15 employees.

The localization targets were less than 65% in the REIPPP. The first, second and third bidding rounds had been closed with local content of 21.7%, 36.7% and 46.9% respectively[31]. The local contend threshold was 40% in the BW 3.

The number of capacity to be installed (MW) and job creation during construction and operations in the first 3 Bid Windows (BW) were:

Table 3-1: Results of MW and jobs in the bud window 1, 2 and 3

	BW1	BW2	BW3
Wind power (MW)	634	563	787
Jobs created (Construction)	1810	1787	2612
Jobs created (Operation)	2461	2238	8506

Source: Adapted from Aures, [43].

There are 19 wind energy developments, with more than 600 wind turbines in South Africa adding up to 1,471 MW. And 3.4 GW of wind energy have been procured through the REIPPP according to SAWEA. The local content value according to DoE in the first three bidding windows adds up to 13,050 million Rands [41].

Montmasson and Ryan [45] and Yuen (2014) cited by Aures [43] states that the design of auctions did not succeed so well because of many requirements, including LCR and short-term policy perspectives. However, the scheme has led to technological diversity, and government officials see a potential to boost local manufacturing in a sector that is completely underdeveloped [43].

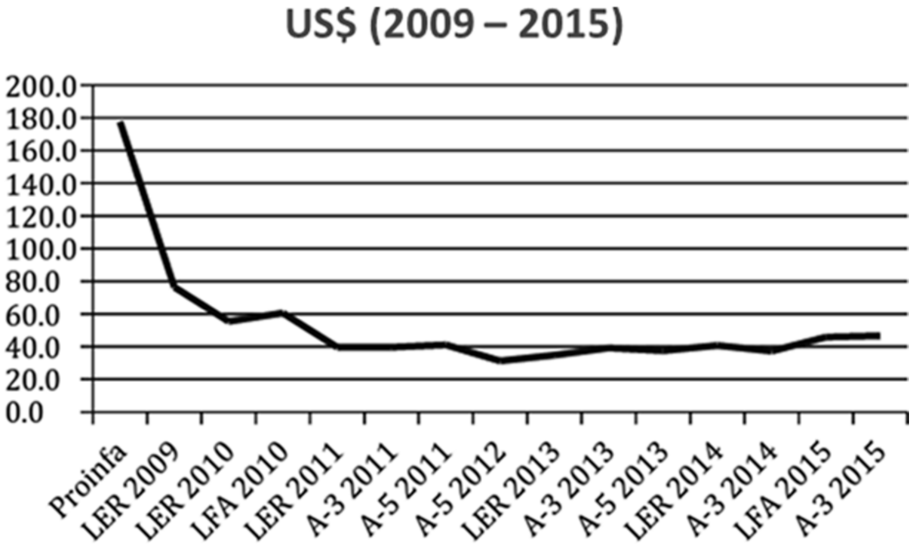
3.5. Electricity prices under auctions or biddings in both countries

Electricity prices turned out to be a further determinant for investment in local industries in both countries. Tough competition in the auctions reduces the expected return of investments. Low margins leave fewer resources for investment in wind energy. The Brazilian auction system made the sector more dynamic. Between 2008 and 2009 the installed capacity increased about 79%. The first

31 Correspondence 25, DTI Director Renewable Industries at Windaba, Cape Town October 2012, DoE 2013

auction in 2009 contracted 1.9 GW for a price of 148.39 R$/MWh (52.62 US$) over 20 years which was half of the initial feed in tariff. In the third auction the price dropped another third to about 100 R$ (35.34 US$) per MWh and it remains at this level as shown in the Figure 3-7. The energy regulator ANEEL capped the bidding price to a maximum of 117 R$ (41.35 US$) per MWh.

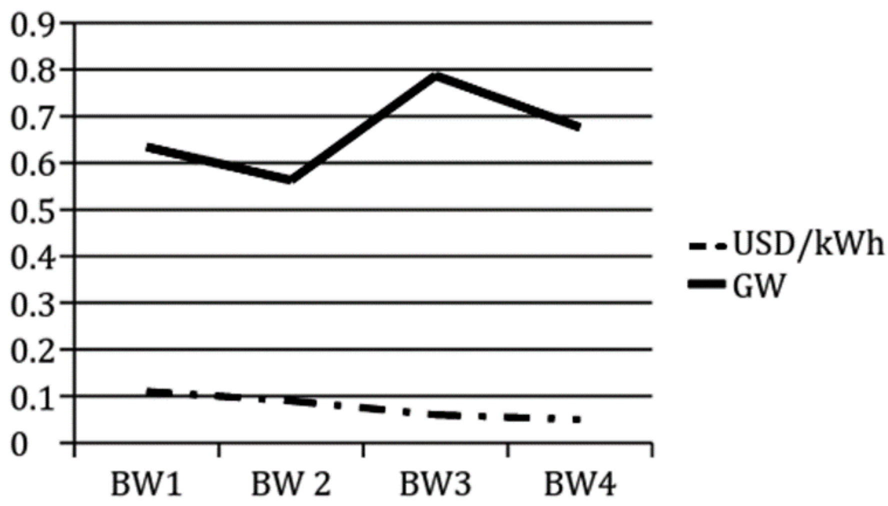
Figure 3-7: Brazilian wind energy auctions prices evolution (Proinfa and 2009-2015)



Source: Authors based on data collected from various Technical Notes from EPE[32].
Note: *Considering USD average value from December, 2015.

In South Africa, the REIPPPP intends to allocate 6.9 GW of renewable energy, including solar, wind, small hydro and biomass technologies. The Department of Energy announced five bidding windows [41]. In the first three bidding rounds the DoE contracted 1.98 GW of wind power of which 561.41 MW are operational [42]. Wind energy prices dropped by 22% from the first to the second bidding round from R1147 (98.03 US$) to R897 (76.69 US$) and by 27% to R656 (56.08 US$) per MWh in Bid Window 3.

Figure 3-8: Wind power installed capacity and wind energy price in Bid Windows (BD) in South Africa



32 EPE Leilões. Notas Técnicas – Various. (Avaiable at: http://www.epe.gov.br/leiloes/Paginas/default.aspx, accessed in april 2016).

Source: Adapted from Aures [43] and Eberhard, Kolker and Leigland [44].

Figure 3-8 shows that prices from wind energy reduced around 50% with the renewable energy auctions rounds (Bid Windows), due to the higher competition.

Reduction in bid prices are related to "reductions in the costs of the technologies, project developers becoming more familiar with the programme, an increased maturity of technologies, aggressive (price) competition, reduced price ceiling for some technologies, and the allocation of a capacity limit for each technology from the second round onwards" [45].

3.6. Summary of determinants

In sum, we can identify similarities and differences between factors in public policy and in the markets.

The Brazilian case demonstrates that the international investment took off with the allocation of a significant market size. The South African program, in turn, makes small and short-term provisions for wind energy.

The financial schemes differ significantly. The Brazilian scheme provides cheap loans conditioned on the provision of local content, whereas the South African scheme provides market rates loans and makes content requirements compulsory independently from access to loans.

The institutional setting differs as the BNDES has a powerful and centralized mandate for the implementation of the financial scheme, content requirements and project approval. In South Africa, the mandate to enforce compliance with the content requirements sits with Department of Energy, independently from the finance of the projects.

In terms of existing technological capability, Brazil already had an OEM based in the country that could provide local content. In South Africa, the industry starts from scratch, with the exception of a local manufacturer who was not qualified for the REIPPPP.

The affirmative above stated by [47] summarizes what the government should follow to obtain more success in the renewable energy sector. Brazil put into practice some of these recommendations, making some important adjustments in the last decade. Nowadays the country runs 414 wind energy plants [48] and the international renewable energy agency IRENA recognizes the Brazilian market already as one of twelve mature markets, although it only emerged over the last three years as the fastest growing market in Latin America [49].

Table 3-2: Overview of the incentive systems and market factors in Brazil and South Africa

	Brazil	*South Africa*
Public Policy Factors		
Type of incentive system	Competitive bidding windows	Competitive bidding windows
Financial support	BNDES loan at 0.97 % interest rate (monthly)	No specific financing
Local content levels	60% to 80% of local content required as a condition for the BNDES loan	Local content of a threshold 40% and a target of 65% compulsory
Local content specification	Started with % of turbine value and weight and now needs to be 80% of total products nationalized	% of project value
Market size	10.5 GW installed, aim for 20 GW by 2024 [46].	Aim for 8.4 GW by 2030 in IRP
Other requirements/ incentives	10% tax breaks for local and imported wind technology components since 2015	Social development criteria in addition to local content, payments to local communities, procurement from designated companies according to national procurement rules
Policy stability	Some uncertainty about continuation of future auctions, but strong commitment to wind and solar under the current electricity crisis	High uncertainty of future of REIPPP after delays in signing bidding rounds 4 and 5, competing coal and nuclear plans and uncertainty in the general electricity plan IRP
Market factors		
National technological capability	One local turbine manufacturer, and blade manufacturer provided local content through feed in, functional aviation industry that wind could draw on	One local manufacturer, which was left out of the procurement program and therefore could not add much to the implementation. Industry built from scratch.
Size and stability of demand	Clear policy signals	Uncertainty
Wage differential	Low wage unskilled, but expensive semi- and high skilled labour which leaves no international low wage advantage in production costs	Low wage unskilled, but expensive semi- and high skilled labour which leaves no international low wage advantage in production costs
Technology and electricity prices	High competition and low margins for return of investment, higher production costs for locally manufactured components	High competition and low margins for return of investment, higher production costs for locally manufactured components

Source: Authors.

3.7. Conclusions

This paper presented that Local Content Requirements policies are not enough and do not replace a coherent industrial policy. It is clear that LCR is not an innovation policy, but just a trigger that accelerates the process.

The status of the global industry is also important, and it was particularly fortunate for Brazil that the global industry was in crisis and desperate for new markets, at the time they entered into the Brazilian market.

South Africa got still bits of this dynamics, but the market didn't offer such a clear incentive, it is currently much smaller, and its future uncertain. Investors, e.g. blade manufacturer, analysed market conditions in both countries, and decide for Brazil, the more prosperous one.

Our analysis also showed that local content requirements have not boosted local production of high technology components.

In the Brazilian case, the local content requirements contributed to establishing an industry for components for local and medium technology content. The market size in the auction system and the cheap BNDES loans created an incentive for foreign investors to invest into local manufacturing. The bank's central role proved advantageous for efficient project implementation and approval of finance. The enforcement of content policies, however, caused confusion in the sectors, as they depended on individual negotiations between the bank and the firms. Clear rules for all institutions involved is one of the lessons that can be learned for future implementation of content requirements.

The content policies raised a national champion in blade manufacturing and created at least 4000 jobs according to our interview data. The content requirements did not support high technology manufacturing or innovation. Support for innovation and R&D will be an urgent next step for the Brazilian decision makers.

The South African case demonstrates that there are still many uncertainties on the positive or negative impacts of LCR. The renewable energy program has no clear financial support through cheap loans, which would support investment into local manufacturing. The narrow bidding windows and requirements for experience make it difficult for new firms to come in. The limit to support installations with a minimum capacity of 5MW makes it difficult for small start- ups to get into the market. The market size is relatively small and the national technological capability is limited, which increases technology prices and makes it increasingly difficult to invest into a local industry. The delays in signing power purchase agreements put the industry in South Africa in disarray.

The desired technological upgrade has not yet happened in the first two bidding rounds. It is questionable if it will happen, as investors might be deterred from the local content requirements of 40-65% in the future bidding rounds, given the small market size. If the investments arrive nevertheless, the South African labour market will benefit with significant job creation. In order to sustain a new local wind manufacturing industry, however, the government will have to provide a more comprehensive incentive scheme, which embeds the local content requirements into a wider innovation policy framework. This framework will have to support the knowledge base in the sector and support small firms and innovators with risk capital.

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3.9. Annex

Interview questions for OEM

- Since when is your company active in South Africa?
- How have you dealt with the local content requirements?
- Are your products certified as local content?
- If yes, which components do you sell as local content?
- If not, why not?
- Did local content requirements have a negative or positive impact on your business?
- Can you describe these impacts?
- Did your strategy change over time?
- Did the equipment prices change? If yes, how?
- Which components do you import?
- Which other countries do you supply?
- How many employees work in you company here in South Africa?
- How many employees work in manufacturing, sales, administration, construction?
- Did these numbers change over time?
- Is your company doing R&D activities in South Africa?
- Why? Why not?
- What could support your R&D activities in South Africa?

Table 3-3: List of Interviewees

Correspondence No.	Interviewee/ correspondent	Organization
1	Former Employee	Wobben, Enercon
2	Director	Wobben Brasil
3	Representative	Alstom Brasil
4	Representative	Siemens Brasil
5	Representative	Siemens South Africa
6	Director	Acciona Brasil
7	Representative	Acciona
8	Representative	IMPSA Brasil
9	Representative	WEG
10	Representative	GE
11	Representative	ABB
12	Representative	Vestas
13	Representative	Gamesa
14	Representative	Sinovel
15	Representative	Sinovel
16	Representative	Sinovel
17	Representative	Goldwind
18	Representative	Iberdrola
19	Representative	Conco
20	Representative	LM Windpower
21	Representative	Suzlon Brasil
22	Representative	Suzlon South Africa
23	Representative	Darling Windfarm
24	Representative	Nordex
25	Director RE Industries	Department of Trade and Industry, SA
26	Director Technology Localization	Department of Science and Technology, SA
27	Deputy Director General	Department of Energy, SA
28	Researcher	Council for Scientific and Industrial Research
29	Representative	DTI TIPS
30	Director	South African Wind Energy Association
31	Director	Brazilian Wind Energy Association
32	Director	Global Wind Energy Council
33	Representative	BNDES
34	Representative	BNDES
35	Representative	Energy Research Enterprise
36	Researcher	UFRJ COPPE
37	Researcher	UFRJ
38	Representative	Green Cape
39	Representative	German International Cooperation Brazil
40	Representative	German International Cooperation SA

4. CASE STUDY: China's PV Sector

Fei Teng (TU)

Abstract

This chapter analyses different solar PV technologies and the Chinese PV sector. PV has become a key technology in China's renewable portfolio and contributes significantly to the reduction of GHGs and air pollutants within China. Although China can produce PV through domestic technologies, there remains still a large gap between Chinese PV technology and the highest level of advanced technology at the international level. Most of the technology gaps are not only in design and manufacturing within the PV industry, but more importantly they are in the upstream industry of material and basic industry. Insights learned in this sector can be applied to similar technologies as improvements in the basic material industry and manufacturing industry is a cornerstone for any technology transfer.

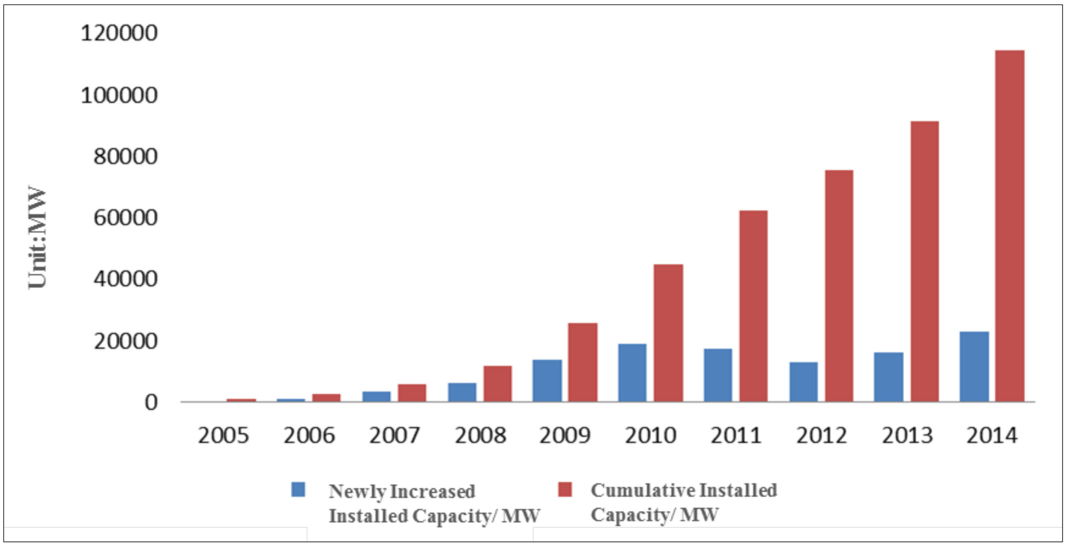
4.1. Introduction

The development of a low-carbon economy is crucial to pursue the goal of limiting the global temperature rise within 2°C. Besides vigorous efforts for energy conservation and emission reduction, the fundamental way for developing a low-carbon economy and changing the energy structure is to strengthen the exploitation and utilization of renewable energy and make it an important alternative energy, which will be remarkably important in future energy supply.

According to the 13th Five-Year Plan for the Development of Strategic Emerging Industries issued by the State Council (Government of China, 2016), the goal is to maintain an annual average growth rate of strategic emerging industries above 20%, and increase value added of strategic emerging industries-to-GDP rate to about 8% by 2015. The Five-Year Plan specifies the development roadmap for wind energy, solar energy and biomass energy by 2020, presents their development goals, improves major policies and major supporting actions and thereby, provides vast room for renewable energy development.

At present, China gives the priority of renewable energy development to wind energy, PV power and biomass energy. In 2014, newly increased installed capacity of wind power of China (excluding Taiwan) was at 23,196MW, a year-on-year growth of 44.2%; the cumulative installed capacity was 114,609MW, a year-on-year growth of 25.4%. China ranked top for both newly increased installed capacity and cumulative installed capacity.

Figure 4-1: Installed Wind Power Capacity of China, 2005-2014



Source: Authors.

In 2014, China's newly increased installed PV capacity was 10.6GW, up slightly than the previous year, of which ground PV power stations accounted for 8.55GW and distributed PV 2.05GW. As of the end of 2014, China's cumulative installed PV capacity had amounted by 28.05GW, a year-on-year growth of 60%, of which distributed PV accounted for 4.67GW and ground PV power stations 23.38GW. PV power stations remained dominating the domestic market.

The rationale to development renewable technologies has various folds. Firstly, the overconsumption of fossil fuel has caused serious environmental problems including air pollution and water quality issues (Zhang et al, 2012). In China, environmental protection is more important than energy acquisition and energy structure transition is more urgent than the adjustment of economic structure.

Representing the future orientation of energy development, renewable energy serves as an important measure to reduce greenhouse gas emissions and tackle climate change. China's climate change schemes present explicitly policies and measures for controlling greenhouse gas emissions, including "to improve the energy structure gradually, develop such renewable energy resources as hydropower, wind power, solar energy, geothermal energy, tidal energy and biomass energy vigorously and promote nuclear power construction proactively".

The second driver is the climate change concern to reduce GHG emissions. At the end of 2015, the United Nations Climate Change Conference established the objective for temperature rise, and urged countries to put forward their respective emission reduction plans and objectives for the years after 2020. Many countries have advanced great objectives for greenhouse gas emission reduction and energy structure adjustment. According to Intended Nationally Determined Contributions (INDC) submitted by China (NDRC, 2015), the country will get to the peak of CO2 emission around 2030 and will strive to do so as early as possible; CO2 emission per unit of GDP will fall from 65% in 2005 to 60%, and non-fossil energy-to-primary energy consumption rate will reach 20% or so. All these objectives request a large-scale effective growth in the renewable energy sector; otherwise, China will be unable to support the corresponding goals of climate change.

Table 4-1: Future opportunities of Solar PV

Thin-film PV cell technology	Employment	Employment[33]: 0.42 people/10,000 RMB; 1580 or more jobs in 2012-2013, more installation staff needed[34]
	Energy security	Less effective in improving energy security
	Poverty relief	Widely applied, quite effective in electricity provision for remote areas, helpful in poverty relief
	SO_2/ton/year	8.75×10^4 (2020)
	NO_X/ton/year	9.95×10^4 (2020)
	PM/ton/year	1.94×10^4 (2020)
	Influence on competitiveness	Output value is projected to reach 32.4 billion RMB by 2020[35]

Source: Authors.

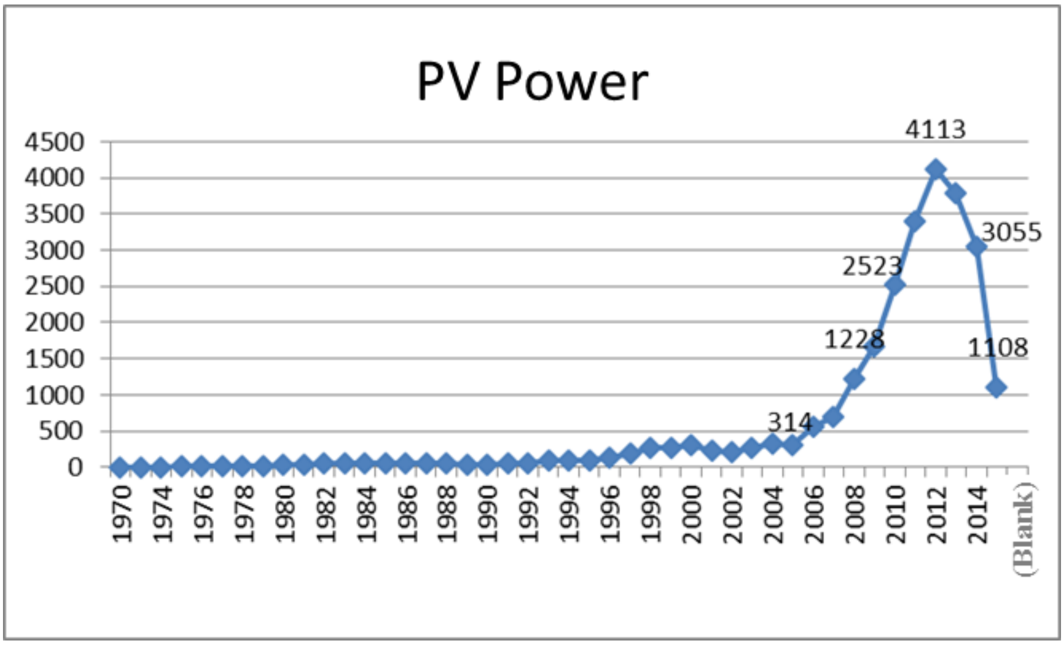
4.2. Patent analysis of PV (Photovoltaics) Power Technology

A thin-film cell is a solar cell made up of a piece of film. As little silicon is used, it's easier to reduce the cost. As a kind of efficient energy products as well as a new type of building materials, thin-film cells can be incorporated into buildings more easily. Since the international market suffers a constant lack of silicon raw materials, thin-film solar cells have become a new trend and a new hot for the international PV market. Presently, there are three kinds of thin-film cells that can be produced at a large scale, including silicon-based thin-film solar cells, CIGS thin-film solar cells and CdTe thin-film solar cells. Hinders for the popularization of thin-film cell PV power technology in China include the low conversion efficiency of thin-film PV cells, the dependence on import of key manufacturing equipment, immature manufacturing technology, etc.

[33] According to the 12th Five-Year Plan, China's installed PV power capacity will reach 20 million KW and PV power generation will be 24 billion KWH in 2015. Given that 1KWH=1RMB output value, it will provide 1 million jobs.
[34] Renewable Global Status Report 2014
[35] Estimated on the basis that 1KWH=1RMB output value.

Patent analysis indicates PV power technology developed slowly before 2005, but relevant technologies started full-speed growth from 2006 and got to the peak in 2011. The decrease in the number of patents after 2011 is caused by the time lag of Derwent Patent database (https://clarivate.com).

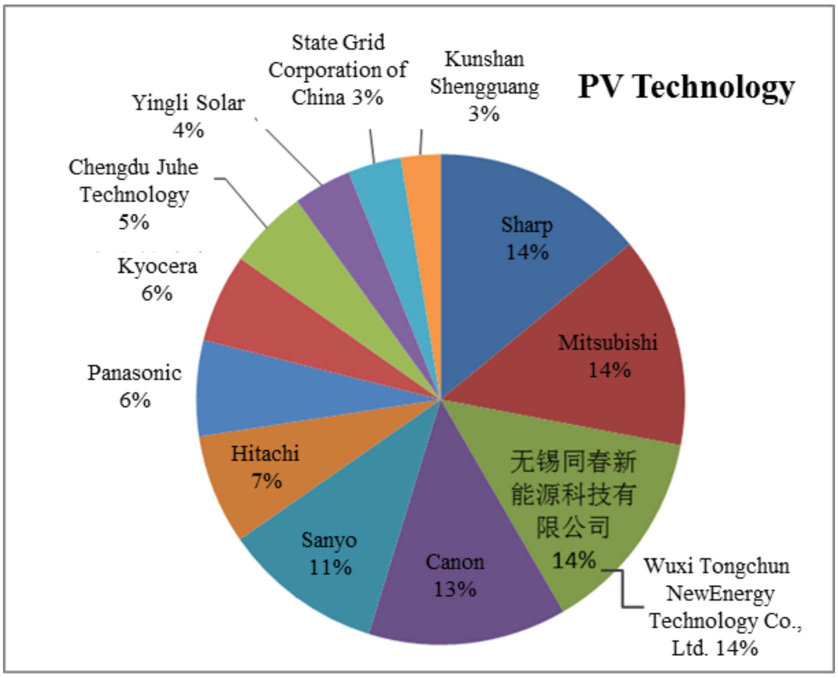
Figure 4-2: Statistical Data on Time of PV Power Technology Patents



Source: Derwent Patent Database

Almost 70% of PV patent are hold by Japan companies in this field. Comparison among patent applicants shows that China remains lagged behind in PV power technology. Foreign companies have applied for a huge number of patents in relevant fields, which raises the technology threshold.

Figure 4-3: Distribution of PV Power Technology Patent Applications of Selected Companies



Source: Derwent Patent Database

4.3. Key technology gaps

Thin-film PV cell technology is the second-generation or the third-generation PV power technology whose conversion efficiency is up to 13% now. It is applied widely. Besides the plane structure, it can be also in a non-plane structure thanks to the flexibility. It can be combined with or serve as a part of a building. Along with the development of green buildings and distributed PV power stations, thin-film PV cells will have a brilliant future. Thin-film cell PV power technology includes:

Amorphous silicon thin-film solar cell: Compared with crystalline silicon solar cells, amorphous silicon thin-film solar cells are advantageous with high absorbance, light weight, simple process, low cost and low energy consumption. But the efficiency of conversion is small and declines as time passes by.

Polycrystalline silicon thin-film solar cell: As a hot subject of solar cell research in recent years, polycrystalline silicon thin-film solar cells are highly sensitive to long-wave light, can absorb visible light efficiently and possesses strong stability of light. It's an ideal type of materials with high efficiency and low energy consumption acknowledged by the general public.

Compound thin-film solar cell: CIGS thin-film solar cell is among the solar cells that the international community believes most likely to be applied in a large scale and has attracted high attention, thanks to the approximately optimal optical gap, the high absorptivity, the high anti-radiation ability and the strong stability.

Compound thin-film solar cell: The basic principle of operation is the photovoltaic effect of semiconductor heterogenous junction (p-n junction) or metal/ semiconductor interface.

At present, thin-film solar cells that have been put into industrial production include amorphous silicon, CIGS and CdTe thin-film solar cells. CIGS (Copper indium gallium selenide) is one of three mainstream thin film PV technologies, the other two being cadmiumtelluride and amorphous silicon. Like these materials, CIGS layers are thin enough to be flexible, allowing them to be deposited on flexible substrates. China starts later in the CIGS thin-film solar PV industry than Europe, US and Japan and its technologies[36] in this respect are relatively backward.

Laboratory technology has been basically mature, through which the battery packs developed register a conversion rate of 7%, marking a step-over from small-area lab development to large-area pilot production.

Industrial production of CIGS elements is in the initial stage, practiced by US, Germany, Japan and other developed countries mainly. Each process has its own characteristics while most adopt the vacuum sputtering technology, with the difference in some processes for manufacturing CIGS absorbing layer. Table 1 presents a comparison on the production processes of selected companies.

Table 4-2: Comparison on Processes of Main CIGS Element Manufacturers across the World

Company	Absorbing Layer	Absorbing Layer Technology	Area of Element/mm^2	Efficiency of Element
Showa	CIGSSe	Sputtering and selenylation	600×1200	13.6%
Honda	CIGS	Sputtering and selenylation	600×1200	12.7%
Centrothem	CIGS	Sputtering and evaporation RTP	1100×1400	11%
Wuerth	CIGS	Evaporation	300×300	13%
Johanna	CIGSSe	Sputtering and selenylation	500×1200	10.5%
Avancis	CIGSSe	Sputtering RTP	300×300	15.1%
Nanosolar	CIGS	Particle printing		
IBM	CIGS	Chemical process		

Source: China's Technology Needs Assessment (NDRC, 2016).

Magnetron sputtering, a mature technical route, is usually adopted for the bottom electrode Mo and the top electrode n-ZnO of CIGS thin-film solar cells. Technological difficulties are to be removed from the manufacturing of the absorbing layer, the most critical part. Main methods include co-evaporation, sputtering and selenization, electrochemical deposition, spraying pyrolysis and silk-screen printing. Co-evaporation and sputtering and selenization attract most studies, register a high conversion efficiency of cells and are applied most widely.

Anomic layer deposition (ALD) technology, a method for thin film manufacturing by chemical sedimentation, similar with CVD, has developed rapidly in recent years. According to it, efficiency of battery packs is expected to reach 15%-18%. Research departments of IBM are developing a process

36 US takes NREL as the R&D centre to manufacture small-area high-quality CIGS thin-film cells with high conversion efficiency. Similarly, Global Solar resorts also to the CIGS technology route to develop 900cm2 cell modules whose conversion efficiency is as high as 13.2%.

Japan New Energy Development Organ (NEDO) launched the CIGS industrial development project in 1994, for which Showa Shell and Panasonic are major R&D organs. Pilot production is not realized for the co-evaporation process adopted by Panasonic as the cells are instable, though the conversion efficiency reaches 15-16%.

In Germany, Wurth Solar is a major research institute in this respect, where 60cm×120cm battery packs are developed successfully through co-evaporation of Cu, In, Ga and Se is adopted and then secondary selenization.

for manufacturing CIGS solar cells at room temperature, for which the objective of photoelectric conversion efficiency is above 15%.

4.4. Barriers analysis

4.4.1. Domestic policy barriers

Political barriers are among the important factors hindering international technology transfer, as reflected below:

1. Relevant countries' restrictions on high technology transfer. For instance, US imposes strict restrictions on high technology transfer and even limits the transfer of manufacturing materials. Moreover, the customs do not allow the clearance of relevant production materials even if US enterprises agree to sell them;

2. Government subsidy restrictions. It is difficult to apply for government subsidy for the cooperation with Chinese enterprises. For instance, a relief of Production Tax Credit (PTC) by 2.1 cents/KWH or Investment Tax Credit (ITC) by 30% is provided for wind power developers on the US market, with the aim to help the development of enterprises in the US and bring forth more job opportunities, under the framework of the American Recovery Act.

3. Other countries' anti-dumping investigation against China. For their benefits, some countries such as EU and US have anti-dumping investigations to impact the wind and solar PV power development of China.

4.4.2. Technology barriers

Under market mechanism, technology is the worst choice compared to export trade and direct investment for enterprises that seek the maximum interest. Therefore, foreign enterprises resort always to technology blockage and the technologies transferred have basically gone through the mature stage. As a result, companies of developing countries can only obtain relatively backward or outdated technologies, though they pay high transfer fees.

Technologies are usually transferred through the construction of plants solely owned by the supplier or sale of equipment, instead of joint ventures or sale of technology permits. In fact, it is another form of technology blockage.

4.4.3. Improper protection of intellectual property rights (IPR)

Technology transfer will impact the economic benefits of the owner of the technology and its substitutions. IPR protection can prevent the technology recipient through access to technology to enhance research and development capabilities, and therefore can protect technology owner's interests. Enterprises in developed countries always stress the protection of intellectual property rights due to their ownership of the majority of mitigation technologies so that developing countries have to pay high IPR use fee and it's more expensive for technology recipients to improve technology capacity.

4.4.4. Weak infrastructure and absorption capacity of technology

As a technology-intensified industry, the renewable energy requests a high industrial foundation capacity of the country, especially for the manufacturing and equipment producing capacity in wind power generation, solar thermal power generation and thin-film PV cell production. Thus, the technology capacity is not limited to the upstream but also constrained by capacity in downstream industries.

4.4.5. Lack of skill labour

In the renewable energy filed, a technology and capital-intensified industry, various kinds of talents are needed, besides vast capital. Relevant industries are just starting in China. Compared with thermal power and hydropower, renewable energy industry is faced with a lack of cultivation system of talents in design, manufacturing, installation, commissioning and operational management. In recent years, China's installed capacity of renewable energy has witnessed an explosive growth, with an increasing demand for professional talents. A talent barrier is formed due to the lack of renewable energy research and management personnel, especially inter-disciplinary talents with both professional theories and practical experience in engineering design.

4.4.6. Lack of capital

It is hard to obtain bank loans because most renewable energy technologies are dependent on government subsidy and economic performance of relevant projects is not excellent. Besides high requirements for technology, renewable energy industry demands huge investments so that powerful capital support is needed. Though the rapid development of renewable energy has promoted the fast growth of some supporting enterprises in China in recent years, the small capital size and the great difficulties in loan financing have restricted the sustainable development of renewable energy enterprises in the country.

4.5. Summary

We summarize the solar PV technology in China based on the following tables. In this case study, we use PV technology as a case to study the policy circumstance, technology gaps and barriers in PV industry. It can be seen that PV has become a key technology in China's renewable portfolios and contribute significantly to the reduction of GHGs and air pollutants in China. Although China can produce PV through domestic technologies, there is still a huge gap between the Chinese technology and the most advanced technology at international level. Most of those technology gaps are not only in design and manufacturing in PV industry, but more importantly in the upstream industry of material and basic industry. This is not an isolated case but can be proved in many other similar technologies. The improvement of the basic material industry and manufacturing industry is a cornerstone for any technology transfer.

Table 4-3: Summary of Solar PV technology in China

Technology Name	Thin-film PV cell technology
Best practice level of China	Inferior to foreign countries in terms of CIGS efficiency
International best practice level	MANZ, a high-tech equipment manufacturer of Germany, improves the lab conversion efficiency of CIGS thin-film solar cells from 21% to 21.7%, a record high.
Overall performance gap	There are gaps in electricity generation efficiency, manufacturing process and percent of pass.
Gap in critical core technology	There are gaps in the manufacturing of TCO glass substrates used for thin-film cells and thin-film cells whose efficiency is above 10% (sputtering) and other core technologies
Possible emission reduction effects thanks to narrowing of gap	GHG emission reduction: 2.58×10^7/t/year by 2020
Possible synergy effects thanks to narrowing of gap	Investment for every 10,000 RMB will bring forth 0.42 job opportunity.

Source: Authors.

4.6. References

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Zhang Qiang, He Kebin, Huo hong, 2012, Cleaning China's air, Nature;

5. CASE STUDY: Technological potential and competitiveness in electric mobility technologies: the case of Italy

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Abstract

This chapter assesses Italy's technological potential and competitiveness in electric mobility technologies. Both the qualitative and the quantitative analysis display that there is only a weak development of industrial capabilities in Italy regarding the components of electric vehicles, such as batteries and electric engines. In trade, Italy is a net importer of these components and its commercial competitiveness is weak. Nonetheless, there are opportunities to convert the existing know-how in electric motors into capabilities to manufacture electric engines. However, compared to other European countries like Germany, France and the UK, an Italian strategy to facilitate the development of an electric vehicle manufacturing industry is very slow in taking shape. To be a significant player in areas such as battery manufacturing, large investments would be needed. Depending exclusively on external actors represents a serious element of vulnerability which could see entire segments of its value chain (those characterizing internal combustion engines) become obsolete and disappear. This presents heavy consequences for workers and local communities. Countering such a risk requires to first strengthen the research base and the training (and re-training) of the workforce so that it is ready and capable to respond to private investment, as well as to support some of the most competitive national enterprises.

5.1. Introduction

After the paper on "International trade in low-carbon energy technologies - The Italian case" previously delivered this report focuses on the technological potential and the competitiveness of Italy in the area of electric mobility. The report is structured in two sections.

The first section provides a general overview of the Italian manufacture of vehicles and their components focusing on technologies and products related to electric mobility and looking at the technological potential in Italy in the latter products. The discussion is based on a synthesis of existing recent studies on this sector carried out at the national level and based on statistical surveys or qualitative analyses. The purpose of this section is to frame the discussion on the competitive position of Italy in electric vehicles and in batteries for this type of vehicles.

The second section reports on our own analysis of Italian trade data concerning batteries for electric vehicles, carried out specifically for the COP21 RIPPLES project, to look at the competitive position of Italy in the manufacturing of this type of products. The analysis is conducted at a higher level of product disaggregation than the one reported in chapter 2: this allows a finer distinction between batteries for electric vehicles and standard lead-acid batteries used in vehicles with thermal engines, and to obtain somewhat different insights (and a soberer view) on Italian competitiveness in this area.

5.2. Italian vehicle manufacture and technological potential for electric mobility technologies: an overview

Much of this descriptive picture draws from a report on electrical mobility carried out in 2017 by The European House - Ambrosetti for ENEL[37]. This study analysed the entire value chain of electric vehicles in Italy, looking at its strengths and weaknesses, and at its possible future evolution in the broad context of vehicle manufacturing.

Italy can claim an important tradition in car manufacturing and currently has a position of specialization in parts, components and body-work. Overall, vehicle manufacturing (including manufacturing, assembling, parts, components and accessories of cars, trucks, buses and motorcycles) in 2014 involved nearly 10,000 firms and 294,000 employees generating total revenues for EUR 88.5 billion[38].

Currently the production of vehicle parts and components involves about 2000 enterprises, with EUR 38.8 billion total revenues and exports of about EUR 20 billion per year[39], mostly towards Germany (19%) and France (11%). This sector represents for Italy about 4.8% of total exported goods and has a trade surplus of about EUR 6 billion.

An Italian point of strength is represented by gearboxes and clutches, but also by R&D in car engineering and design[40]: for body-work Italy can claim high level skills and in R&D there is a solid and prestigious tradition of engineering and industrial design firms.

While in the production of traditional vehicles with internal combustion engines body-work and components represent about 49% of the total value chain, in electric vehicles this share is smaller (29%)[41] owing to the vehicle's higher total cost: the biggest component in their total value, in fact, is given by the battery.

37 The European House- Ambrosetti: E Mobility Revolution.
38 Ibid page 59.
39 Ibid. page 20, page 63
40 Ibid page 20
41 Ibid. page 70

Expertise and competitiveness in the production of body parts and components by itself cannot be considered as an indication of potential capability to develop expertise in the "core" technologies of electric vehicles represented by electric engines and batteries.

In fact, in the strategic vision of the Italian manufacturers of automotive parts and components green mobility has not yet emerged as significant component of their business strategy, as shown by a survey carried out among them by ANFIA, Chamber of Commerce of Turin, and the Center for Automotive and Mobility Innovation[42]. The survey shows that only 3.6% of the firms surveyed indicated green mobility as one of their strategic reference points. On the other hand, 45.5% of respondents had participated in projects involving innovative technologies such as autonomous drive, alternative powertrains, ICT and connectivity services and new materials. Particularly significant is the fact that 18.4% of respondents stated they had taken part in projects involving alternative powertrains (electric, hybrid, or fuel cells)[43].

But let us take a look at the situation of the Italian automotive industry in those technologies and components that characterize electric vehicles, and particularly electric engines and batteries.

5.2.1. Hybrid/electric engine

Concerning electric or hybrid engines (about 5-6% of production costs of an electric vehicle), many foreign countries have moved earlier than Italy along the entire value chain. Except for Magneti Marelli (leader in the Italian powertrain market) and some companies in the sector of motorcycles (like Energetica, a company producing electric motorcycles characterized by a sophisticated electronic control system of the engine, and whose supply chain is more than 80% Italian) very few Italian companies are active in this sector. To improve capabilities in this area, R&D efforts would need to be strengthened.

For manufacturing of electric engines and powertrains, the three main car manufacturers are not Italian (Nissan, Mitsubishi and GM), but the flexibility and expertise of Italian SMEs could support the competitiveness of Italy in this sector[44]. Italy has a longstanding tradition in the manufacture of electric motors for all sorts of applications which could be transferred to the production of electric engines.

Although manufacturing is dominated by Chinese, German, Japanese and South Korean firms, Italy could exploit its consolidated experience in the production of inverters for industrial automation or for renewable energy production, and transfer/adapt this know-how to e-mobility applications. Inverters represent a non-trivial cost fraction (on average about 6%) in the manufacturing of an electric vehicle. Furthermore, in the recycling phase, inverters follow a disassembling/disposal process that is usually done "in house", thus opening opportunities for market development and the creation of specific competences in this area. On this aspect COBAT has launched a few projects (such as "COBAT Zero Waste"[45]) that entail the collaboration with some Italian companies for the sustainable disposal of products like inverters at the end of their useful life.

5.2.2. Battery energy storage.

This is a relevant cost item in electric vehicle manufacturing, presently close to 40% (estimates by The European House – Ambrosetti, 2017[46]), the one that confers to the vehicle the characteristics of autonomy and power that are most important to the consumer. Battery manufacturing for electric

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42 ANFIA, CCIAAT, CAMI: *Osservatorio sulla Componentistica Automotive Italiana 2017*, Edizioni Ca'Foscari, 2017, Chapter 7 *pages 213-14*
43 *Osservatorio sulla Componentistica Automotive Italiana 2017, pages 213-14*
44 Ibid, page 63.
45 Ibid, pages 20-21
46 Ibid, page 70

vehicles is mostly controlled by China, Japan, South Korea, Germany and France, although signs of possible future developments for Italy emerge[47]. On electric storage systems Italy is currently in a position of relative technological weakness with respect to foreign competitors but displays some growth potential represented by existing domestic producers such as FIAMM, presently owned by the Hitachi group and main producer in Italy, and MIDAC. The finding of a weak position of Italy in the battery storage systems for electric vehicles is supported by a survey of this specific industrial segment in terms of number of manufacturers and people employed, but, as will be shown in section 5.4, is also strengthened by the analysis of disaggregated trade data.

One related market is that for large stationary power storage systems. At present, the storage systems installed capacity in Italy amounts to 7 GW (equal to 4.1% of global capacity), that places it among the first 10 countries in the world [Source: *Rapporto Agici-OIR 2016 sul mercato mondiale dei sistemi di accumulo*, 2016]. Thanks to the investments being made to support the development of new battery technologies, the Italian market for stationary electric storage in both the energy and industrial system could reach a value of EUR 1.35 billion by 2020, which could contribute to the stability of the power grid. This market could benefit also from the second life of car batteries, used as power storage systems in households or industrial applications, because lithium-ion batteries have interesting applications for peak shaving and load balancing. This positive spill-over, however, is one-way: if we look at the other technologies now prevailing in the stationary storage market, and being developed also in Italy, none of them has applications for mobility purposes and particularly for electric vehicles. FIAMM is present in the stationary applications for power storage, manufacturing Ni-NaCl batteries, but this technology is not fit for electric vehicles.

5.2.3. Charging equipment and devices

Italy, on the other hand shows excellence in manufacturing of battery recharging stations and equipment, and particularly in the industrial and technical design – with operators like Enel, Bitron, Ducati Energia, Scame and ABB[48] (which has based in Italy its world class centre of expertise for battery charging equipment and infrastructure) – This is expected to facilitate the launch and implementation, in the short term, of a development plan for the network infrastructure at national level.

5.2.4. Other components

Main areas of expertise that can be used in electric vehicles are in manufacturing, particularly of electronic components, electric conductors for tensions above 80V[49], in which Italy (with Magneti Marelli) maintains a qualified presence.

Other potential spill-overs leading to production of electric engines for Italy, as mentioned, could come, rather than from the automotive industry from the one of industrial automation and its applications, in particular in the field of productions for renewable source technologies as in the case of inverters. In this area Italy maintains good industrial and technological capabilities. The technology to manufacture inverters for PV applications can very easily be adapted to mobile applications and this could very well be an area where Italian trade competitiveness could emerge.

5.3. Policy measures

To complete the picture, a few words on the policy framework for electric mobility in Italy.

Some among the main EU (France, Germany, United Kingdom, Denmark, The Netherlands, Norway and Sweden) and extra-EU economies (USA, China, Japan and India) have adopted a long term strategic and industrial vision and defined a coherent and integrated set of policy measures to

47 Ibid, page 62
48 Ibid: page 22
49 Ibid. Page 20 and 22

accompany the transition towards electric mobility: Italy, instead, still lacks this vision and planning strategy.

Recently the Directive on Alternative Fueling Infrastructure -DAFI has been adopted in Italian legislation, however implementation measures are still not in place. On the other hand, measures in the sector of electric mobility are not entirely missing.

In some cities incentives to electric and hybrid vehicles are being offered. They include free parking spaces, lower parking rates or full access to limited access zones; reductions between 30% and 50% in the insurance policies; waiver of the circulation tax to the vehicle owner for the first 5 years and 75% reduction thereafter; public procurement rules obliging public administrations to purchase low or zero emission vehicles for at least 25% of the vehicles being replaced; obligation for Municipalities to provide EV recharging facilities (at least at 22 kW and 50 kW).

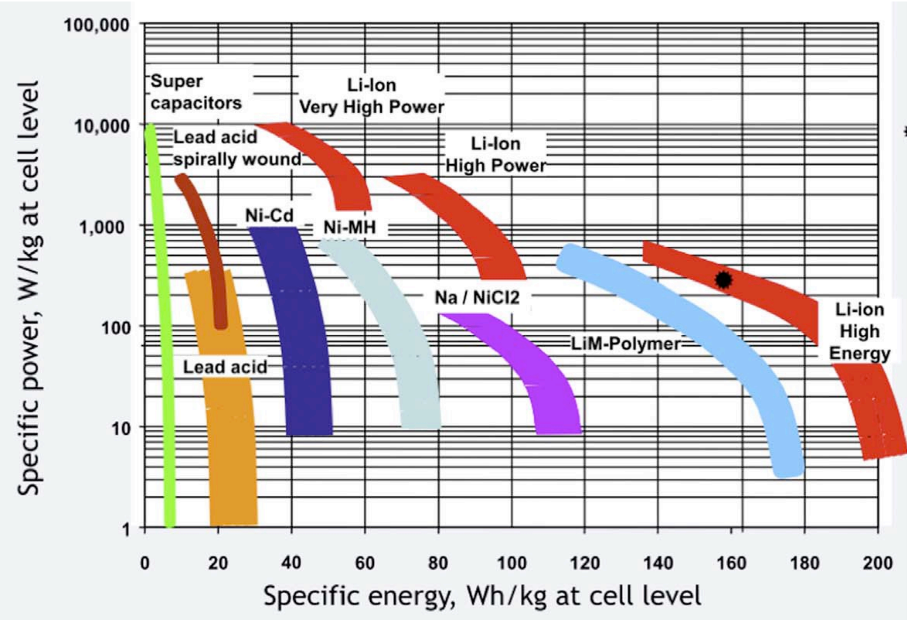
5.4. Batteries and Electric Vehicles: an analysis for Italy on trade data

Battery electric vehicles could lead to the decarbonisation of the Vehicle fleet and to lower reliance on oil. The technology on vehicle batteries is evolving rapidly. However, electric vehicles still have to overcome some significant economic barriers to obtain appreciable market penetration. For electric cars, a lot of R&D effort is spent on the reduction of production costs and on extending the energy density and reducing the weight of the batteries. But the increasing adoption of electric and hybrid vehicles should provide opportunities for growth in industrial manufacturing.

To understand how these opportunities can develop in the context of the Italian manufacturing sector, a deeper understanding of current Italian international competitiveness in electric vehicles and batteries relevant for electric vehicles is needed.

First of all, in order to correctly identify the battery technologies that are relevant for electric vehicles it is important to have as a basis a general overview of different electricity storage options. The following Figure 5-1 shows a general comparison of the specific power density and specific energy density of a number of battery technologies. It can be noted that they differ greatly from one technology to another and that for a given technology the design allows for additional trade-offs between power and energy.

Figure 5-1: Specific energy and power of the main battery technologies



Source: IEA, IRENA.

Although there is an inverse relationship between specific energy and specific power (i.e., an increase in specific energy correlates with a decrease in specific power), lithium-ion batteries have a clear edge over other electrochemical approaches when optimised for both energy and power density. Within the lithium-ion family, there is a range of different types and configuration of batteries. These vary in terms of characteristics such as battery life, energy, power and abuse tolerance. Compared to other mature battery technologies, lithium-ion technology is considered as the most promising for the near future offering many benefits making it ideal for battery electric vehicles. Technologies such as nickel-metal hybrid are also being deployed in hybrid and full electric vehicles. Traditional lead acid batteries present much less interest.

In this section we report on the results of an analysis of the Italian trade competitiveness in electric vehicles and in batteries for electric vehicles: the analysis is developed on the basis of trade data on these products organized according to the European Combined Nomenclature (CN)[50].

The EU Combined Nomenclature serves as a classification tool for goods traded, businesses and is adopted by the customs administrations in the European Union member countries. It is used to determine various rates of customs duty, and how the goods are treated for statistical purposes. The Combined Nomenclature forms the basis for the declaration of goods at importation or exportation or when subject to intra-Union trade statistics.

The Combined Nomenclature consists of 8 digits: the first 6, representing the so-called HS code (harmonized system), are attributed by the World Customs Organisation and correspond to the category of the goods. The last 2 correspond to subdivisions of HS and are determined at the European level to meet the European Union's common tariff criteria and statistical needs. Therefore, this

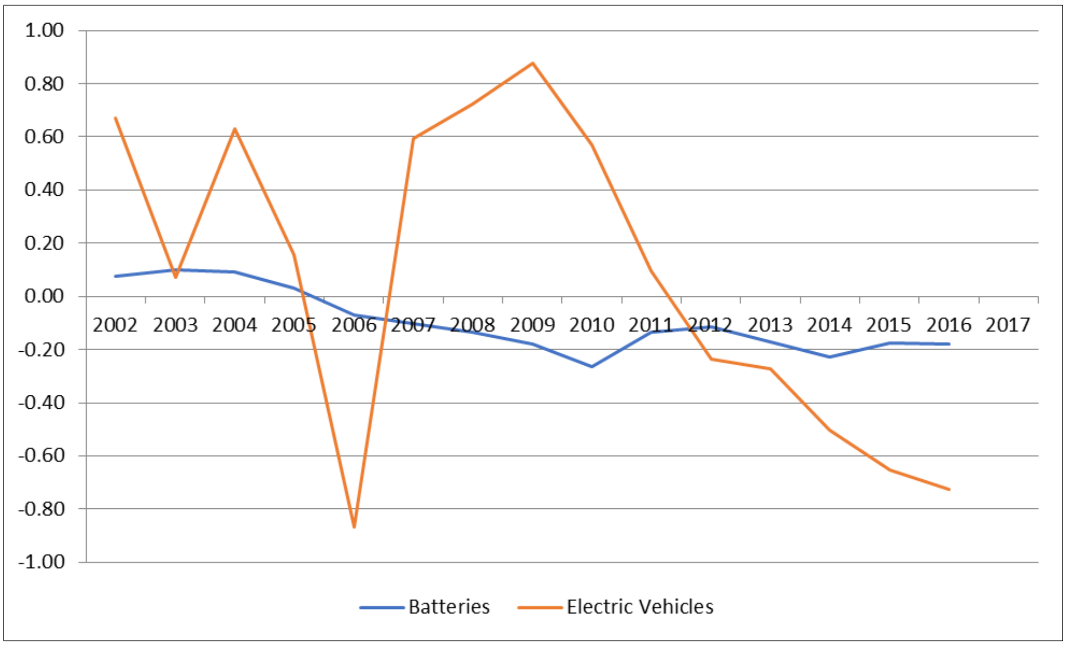
50 The Combined Nomenclature was established by Council Regulation (EEC) No 2658/87 on the tariff and statistical nomenclature and on the Common Customs Tariff. It is updated every year and is published as a Commission Implementing Regulation in the Official Journal of the European Union, L Series. The latest version is now available as Commission Implementing Regulation (EU) 2017/1925 in EU Official Journal L 282 of 31 October 2017. This version applies from 1 January 2018.

analysis is conducted at a higher level of product disaggregation than the one carried out in chapter 1, which was based on the 6-digit Harmonized Code.

Regarding the analysis of Italian international competitiveness, interviews carried out with technology experts[51] allowed for a more precise identification of the items in the Combined Nomenclature Codes which are relevant for Electric Vehicles (EV) and particularly the typology of Batteries for this kind of vehicles (Annex 1). We identified this way a subset of 36 products over a total of 62 battery types. The discussion that follows concerns exclusively batteries relevant for Electric Vehicles (EV).

In addition to these products we have looked at electric vehicles for passenger transport identified by code '*87039010- Motor Cars and other vehicles principally designed for the transport of persons with electric motors*'. The Italian normalized trade balances[52] with the rest of the world for electric vehicles and batteries relevant for electric vehicles, as a whole show clearly a weak competitiveness in these products especially in recent years (Figure 5-2).

Figure 5-2: Electric Vehicles and Batteries relevant for EVs - Italian normalized trade balances with the rest of the world, 2002-2017

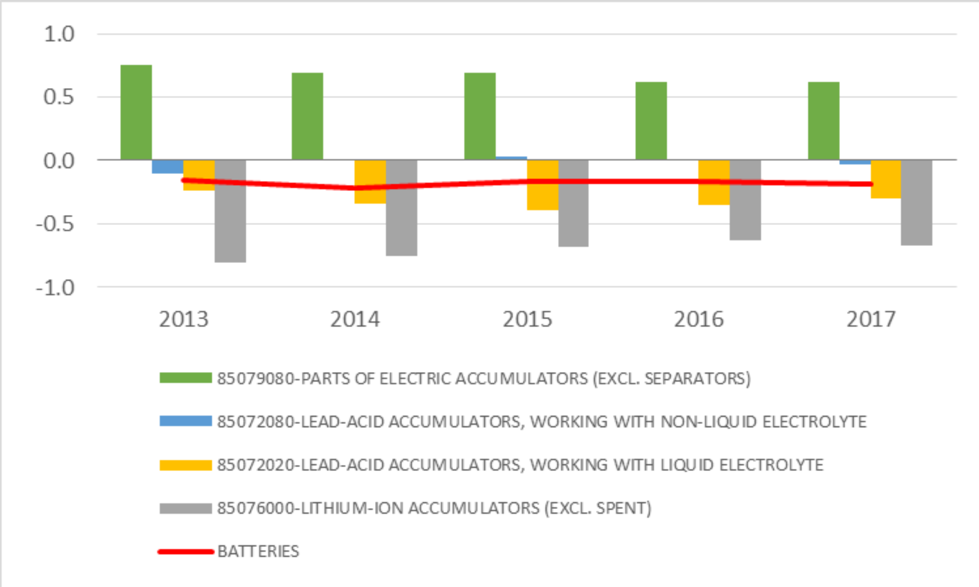


Source: ENEA elaboration on Eurostat trade data.

Regarding the international exchange of the various types of batteries relevant for electric vehicles, Figure 5-3 shows the Italian normalized trade balances with the rest of the world of the batteries that have the greatest weight in the international trade. In particular, in 2017 the four products shown in the figure represent as a whole about 86% of the total interchange of the batteries identified by product code as being relevant to EVs.

51 Maria Pia Valentini and Fernando Ortenzi, Italian Agency for New Technologies, Energy and Sustainable Economic Development (ENEA).
52 The normalized balance is given as the ratio between the trade balance (exports minus imports) and the total value of trade (exports plus imports). Its range of variation is between -1 and +1, with a value of '0' corresponding to a perfect imports/exports balance.

Figure 5-3: Batteries relevant for EVs - Italian normalized trade balances with the rest of the world, 2013-2017

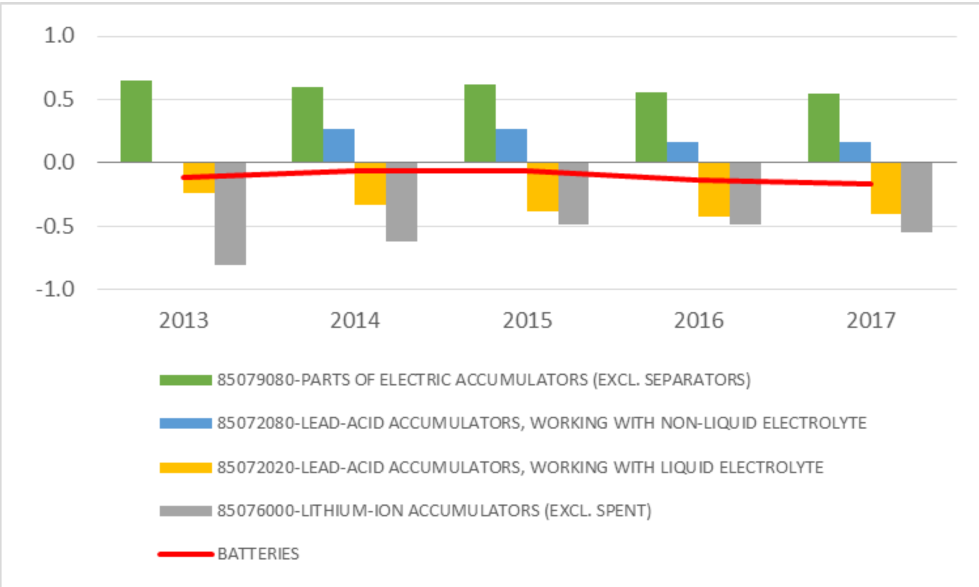


Source: ENEA elaboration on Eurostat trade data.

The lead acid batteries are mature battery technologies and the potential for their improvement is low. These types of batteries were originally used in early electric vehicles. However, their low cost makes it appropriate for use with low performance, small range neighbourhood vehicles.

The only product that shows a positive normalized trade balance from 2013 to 2017 is the one identified with the Combined Nomenclature Code *'85079080- part of electric accumulators'* both in the trade with the rest of the world and with the EU 28 (Figure 5-3 and Figure 5-4).

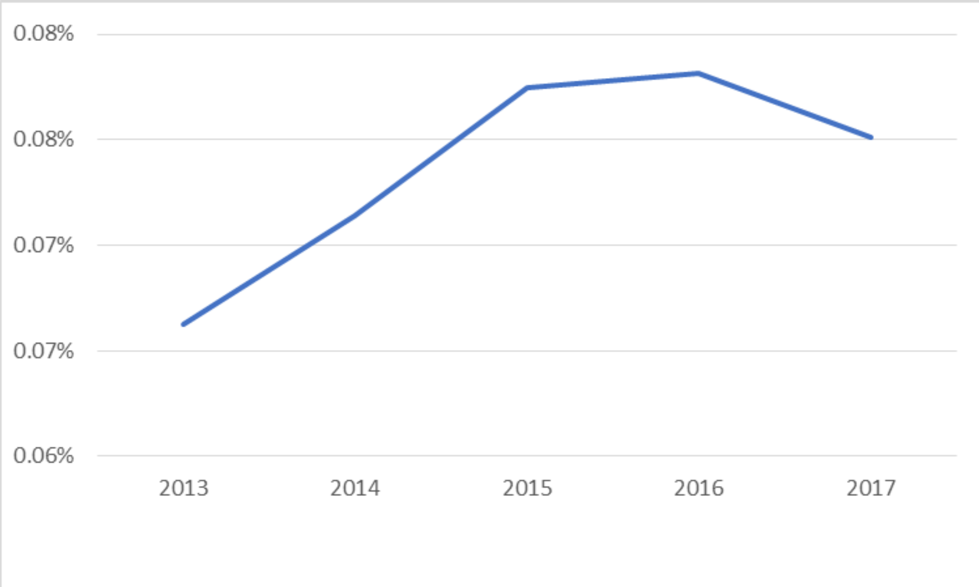
Figure 5-4: Batteries relevant for EVs - Italian normalized trade balances with the EU 28, 2013-2017.



Source: ENEA elaboration on Eurostat trade data.

However, the total normalized trade balance for this type of batteries is negative (represented by the red line in Figure 5-3 and Figure 5-4) showing a slightly better trade performance for international exchange with EU28 Member States than with non-EU 28.

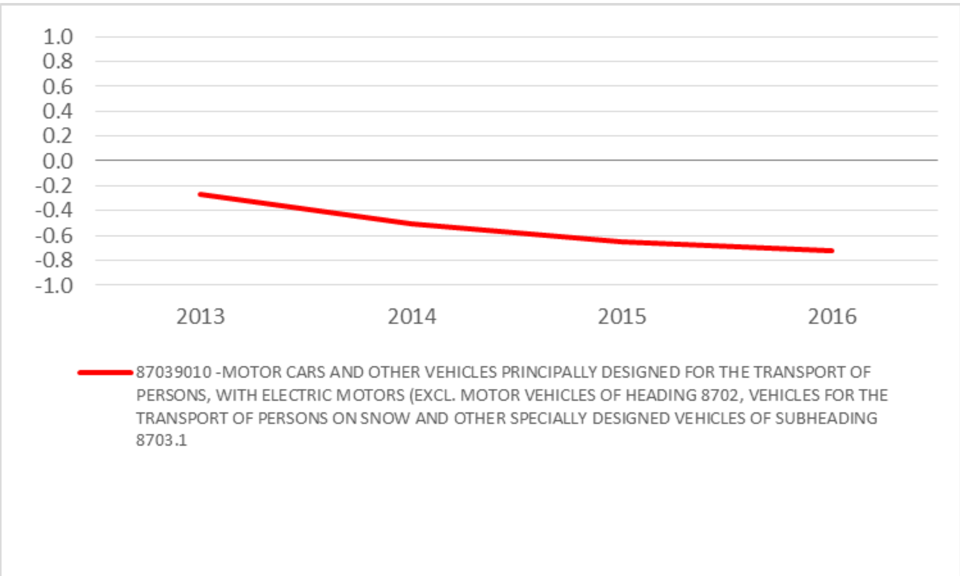
Figure 5-5: Export share of batteries relevant for EVs on total manufacturing, 2013-2017



Source: ENEA elaboration on Eurostat trade data.

Concerning electric vehicles, the time series data show a clear weakness in the international competitiveness of Italy. The normalized trade balance in 2016 is equal to -0.72 resulting from a growth of imports accompanied with stationary trends in exports (Figure 5-6).

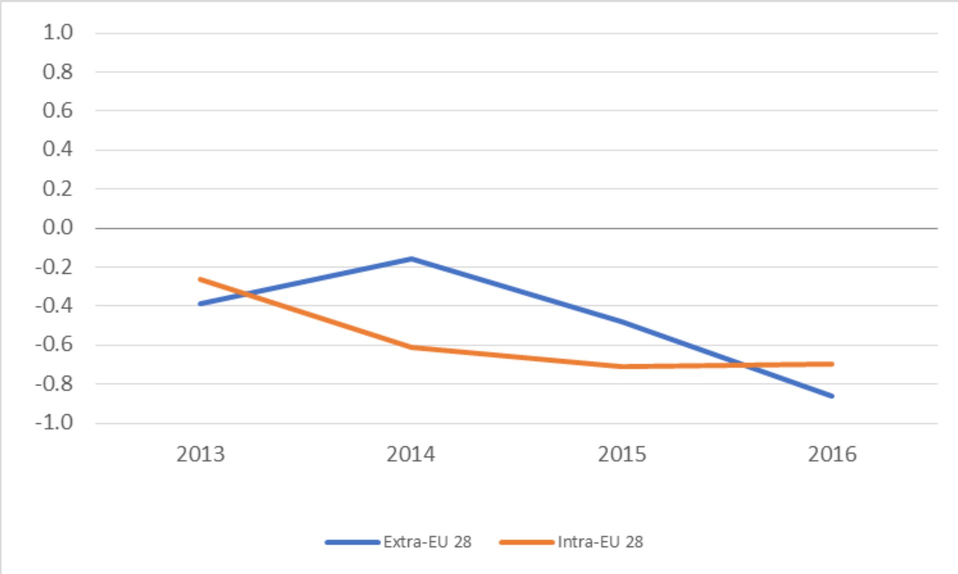
Figure 5-6: Electric vehicles - Italian normalized trade balance with the rest of the world



Source: ENEA elaboration on Eurostat trade data.

During the years 2014 and 2015 the exports towards non- European member countries increased but were not able to compensate for the simultaneous increase of imports. The normalized trade balance with European member countries appears worse than the trade balance with Extra-EU 28 countries for most of the time. This reflects the fact that about 80% of total imports of electric vehicles came from European member countries (Figure 5-7).

Figure 5-7: Electric vehicles - Italian normalized trade balance by partner area



Source: ENEA elaboration on Eurostat trade data

The share of Italian exports of EV on total exports of manufactured products is extremely low but growing modestly in the last year (Table 5-1).

Table 5-1: Batteries relevant for electric vehicles and Electric Vehicles – Italian Gross Exports (Million EUR)

	2013	2014	2015	2016	2017
BATTERIES	258.45	284.72	319.46	326.06	336.72
Electric Vehicles	13.21	9.97	8.69	9.71	n.d.
Total Manufacture	390232.59	398870.41	412291.29	417268.91	448106.66

Source: Eurostat trade data

5.5. Concluding remarks

Albeit more slowly than in more affluent parts of Europe, a market in Italy for electric vehicles is starting to open up, often encouraged by policies at local level designed to contrast air quality problems. However, whether or not Italy will be able to seize the opportunities for growth in industrial manufacturing provided by battery electric vehicles and related technologies remains an open question.

The elements provided in the previous pages indicate a situation of lack of readiness in Italian manufacturing to take advantage of this opportunity. Both the qualitative and the quantitative analysis show that in Italy there is only a weak development of industrial capabilities in what represent the characteristic components of electric vehicles, such as batteries and electric engines. In trade, Italy is a net importer and its commercial competitiveness mostly negative with some exceptions for a few selected products (parts of electric accumulators).

There are opportunities to convert existing know-how in electric motors into capabilities to manufacture electric engines. Other points of strength are represented by inverters, electric conductors, electronic components, and battery charging equipment where Italy has sound capabilities. And it is possible that large international players in the automotive industry, including former national champion FIAT (now FCA), will choose to produce in Italy some of the characteristic components of electric vehicles, driving this industrial reconversion.

However, compared to other European countries like Germany, France and the UK, an Italian strategy to facilitate the development of an electric vehicle manufacturing industry is very slow in taking shape. To be a significant player in such areas as battery manufacturing, huge investments would be needed, and they may be out of the reach of individual national producers. Given that the Italian automotive industry operates largely as a segment of a value chain based elsewhere it is possible that the demand pull from bigger European players may represent a decisive factor in reorienting Italian production. But depending exclusively on the choice of external players represents a serious element of vulnerability for a manufacturing sector that could see entire segments of its value chain (those characterizing internal combustion engines) become obsolete and disappear, with heavy consequences for workers and local communities.

Contrasting such a risk requires first of all strengthening the research base and capabilities, training (and re-training) of a workforce that can be ready and capable to respond to private investment, and some nurturing of the most competitive national enterprises.

5.6. References

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5.7. Annex

NC	NC Description	HS	HS Description
85072020	LEAD-ACID ACCUMULATORS WORKING WITH LIQUID ELECTROLYTE (EXCL. SPENT AND STARTER BATTERIES)	850720	Electric accumulators - Other lead-acid accumulators
85072031	LEAD-ACID ACCUMULATORS FOR VEHICLE TRACTION WORKING WITH LIQUID ELECTROLYTE (EXCL. SPENT AND STARTER BATTERIES)(1996-2005);LEAD-ACID ACCUMULATORS FOR VEHICLE TRACTION WORKING WITH LIQUID ELECTROLYTE (EXCL. STARTER BATTERIES)(1992-1995)	850720	Electric accumulators - Other lead-acid accumulators
85072039	LEAD-ACID ACCUMULATORS FOR VEHICLE TRACTION WORKING WITH NON-LIQUID ELECTROLYTE (EXCL. SPENT AND STARTER BATTERIES)(1996-2005);LEAD-ACID ACCUMULATORS FOR VEHICLE TRACTION WORKING WITH NON-LIQUID ELECTROLYTE (EXCL. STARTER BATTERIES)(1992-1995)	850720	Electric accumulators - Other lead-acid accumulators
85072041	LEAD-ACID TRACTION ACCUMULATORS WORKING WITH LIQUID ELECTROLYTE (EXCL. SPENT AND STARTER BATTERIES)	850720	Electric accumulators - Other lead-acid accumulators
85072049	LEAD-ACID TRACTION ACCUMULATORS WORKING WITH NON-LIQUID ELECTROLYTE (EXCL. SPENT AND STARTER BATTERIES)	850720	Electric accumulators - Other lead-acid accumulators
85072080	LEAD-ACID ACCUMULATORS WORKING WITH NON-LIQUID ELECTROLYTE (EXCL. SPENT AND STARTER BATTERIES)	850720	Electric accumulators - Other lead-acid accumulators
85072081	LEAD-ACID ACCUMULATORS WORKING WITH LIQUID ELECTROLYTE (EXCL. SPENT THOSE FOR USE IN CIVIL AIRCRAFT OF SUBHEADING 8507.20.10 STARTER BATTERIES AND TRACTION ACCUMULATORS)(1996-2005);LEAD-ACID ACCUMULATORS WORKING WITH LIQUID ELECTROLYTE (EXCL. THOSE OF	850720	Electric accumulators - Other lead-acid accumulators
85072089	LEAD-ACID ACCUMULATORS WORKING WITH NON-LIQUID ELECTROLYTE (EXCL. SPENT THOSE FOR USE IN CIVIL AIRCRAFT OF SUBHEADING 8507.20.10 STARTER BATTERIES AND TRACTION ACCUMULATORS)(1996-2005);LEAD-ACID ACCUMULATORS WORKING WITH NON-LIQUID ELECTROLYTE (EXCL.	850720	Electric accumulators - Other lead-acid accumulators
85072091	LEAD ACID TRACTION ACCUMULATORS (EXCL. THOSE FOR STARTING PISTON ENGINES)	850720	Electric accumulators - Other lead-acid accumulators
85072098	LEAD-ACID ACCUMULATORS WORKING WITH NON-LIQUID ELECTROLYTE (EXCL. SPENT STARTER BATTERIES AND TRACTION ACCUMULATORS)	850720	Electric accumulators - Other lead-acid accumulators
85072099	LEAD ACID ACCUMULATORS (EXCL. THOSE FOR CIVIL AIRCRAFT OF SUBHEADING NO 8507.20-10 AND THOSE FOR STARTING PISTON ENGINES OR FOR TRACTION)	850720	Electric accumulators - Other lead-acid accumulators
85073093	NICKEL-CADMIUM ACCUMULATORS NOT HERMETICALLY SEALED FOR VEHICLE TRACTION (EXCL. SPENT)(1996-2005);NICKEL-CADMIUM ACCUMULATORS NOT HERMETICALLY SEALED FOR VEHICLE TRACTION(1992-1995)	850730	Electric accumulators - Nickel-cadmium
85074000	NICKEL-IRON ACCUMULATORS (EXCL. SPENT)	850740	Electric accumulators - Nickel-iron
85074090	NICKEL-IRON ACCUMULATORS (EXCL. SPENT AND THOSE FOR CIVIL AIRCRAFT OF SUBHEADING 8507.40.10)(1996-2005);NICKEL-IRON ACCUMULATORS (EXCL. THOSE FOR CIVIL AIRCRAFT OF SUBHEADING NO 8507.40-10)(1988-1995)	850740	Electric accumulators - Nickel-iron
85075000	NICKEL-METAL HYDRIDE ACCUMULATORS (EXCL. SPENT)	850750	Electric accumulators (2012-) - Nickel-metal hydride

85076000	LITHIUM-ION ACCUMULATORS (EXCL. SPENT)	850760	Electric accumulators (2012-) - Lithium-ion
85078000	ELECTRIC ACCUMULATORS (EXCL. SPENT AND LEAD-ACID NICKEL-CADMIUM NICKEL-IRON NICKEL-METAL HYDRIDE AND LITHIUM-ION ACCUMULATORS)	850780	Electric accumulators - Other accumulators
85078020	NICKEL-HYDRIDE ACCUMULATORS (EXCL. SPENT)	850780	Electric accumulators - Other accumulators
85078030	LITHIUM-ION ACCUMULATORS (EXCL. SPENT)	850780	Electric accumulators - Other accumulators
85078080	ELECTRIC ACCUMULATORS (EXCL. SPENT LEAD-ACID NICKEL-CADMIUM NICKEL-IRON NICKEL-HYDRIDE AND LITHIUM-ION ACCUMULATORS)	850780	Electric accumulators - Other accumulators
85078090	ELECTRIC ACCUMULATORS (EXCL. THOSE FOR CIVIL AIRCRAFT OF SUBHEADING NO 8507.80-10 AND LEAD-ACID NICKEL-CADMIUM OR NICKEL-IRON ACCUMULATORS)	850780	Electric accumulators - Other accumulators
85078091	NICKEL-HYDRIDE ACCUMULATORS (EXCL. SPENT AND THOSE FOR USE IN CIVIL AIRCRAFT OF SUBHEADING 8507.80.10)(1996-2005);NICKEL-HYDRIDE ACCUMULATORS (EXCL. THOSE OF SUBHEADING 8507.80-10 FOR USE IN CIVIL AIRCRAFT)(1992-1995)	850780	Electric accumulators - Other accumulators
85078094	LITHIUM-ION ACCUMULATORS (EXCL. SPENT AND THOSE FOR USE IN CIVIL AIRCRAFT OF SUBHEADING 8507.80.10)	850780	Electric accumulators - Other accumulators
85078098	ELECTRIC ACCUMULATORS (EXCL. SPENT THOSE FOR USE IN CIVIL AIRCRAFT OF SUBHEADING 8507.80.10 AND LEAD-ACID NICKEL-CADMIUM NICKEL-IRON NICKEL-HYDRIDE AND LITHIUM-ION ACCUMULATORS)	850780	Electric accumulators - Other accumulators
85078099	ACCUMULATORS ELECTRIC (EXCL. THOSE OF SUBHEADING 8507.80-10 FOR USE IN CIVIL AIRCRAFT AND EXCL. LEAD-ACID NICKEL-CADMIUM NICKEL-IRON AND NICKEL-HYDRIDE ACCUMULATORS)(1996-2002);ACCUMULATORS ELECTRIC (EXCL. THOSE OF SUBHEADING 8507.80-10 FOR USE IN CIV	850780	Electric accumulators - Other accumulators
85079020	PLATES FOR ELECTRIC ACCUMULATORS (EXCL. PLATES OF VULCANISED RUBBER OTHER THAN HARD RUBBER OR OF TEXTILES)	850790	Electric accumulators - Parts
85079030	SEPARATORS FOR ELECTRIC ACCUMULATORS (EXCL. SEPARATORS OF VULCANISED RUBBER OTHER THAN HARD RUBBER OR OF TEXTILES)	850790	Electric accumulators - Parts
85079080	PARTS OF ELECTRIC ACCUMULATORS (EXCL. SEPARATORS)	850790	Electric accumulators - Parts
85079090	PARTS OF ELECTRIC ACCUMULATORS (EXCL. PLATES AND SEPARATORS)	850790	Electric accumulators - Parts
85079091	PLATES FOR ELECTRIC ACCUMULATORS (EXCL. THOSE OF SUBHEADING 8507.90.10 FOR USE IN CIVIL AIRCRAFT AND EXCL. PLATES OF VULCANISED RUBBER OTHER THAN HARD RUBBER OR OF TEXTILES)	850790	Electric accumulators - Parts
85079093	SEPARATORS FOR ELECTRIC ACCUMULATORS (EXCL. THOSE OF SUBHEADING 8507.90.10 FOR USE IN CIVIL AIRCRAFT AND EXCL. SEPARATORS OF VULCANISED RUBBER OTHER THAN HARD RUBBER OR OF TEXTILES)	850790	Electric accumulators - Parts

85079098	PARTS OF ELECTRIC ACCUMULATORS (EXCL. THOSE OF SUBHEADING 8507.90.10 FOR USE IN CIVIL AIRCRAFT AND EXCL. PLATES AND SEPARATORS)	850790	Electric accumulators - Parts
85079099	PARTS OF ELECTRIC ACCUMULATORS N.E.S.	850790	Electric accumulators - Parts
85322400	FIXED ELECTRICAL CAPACITORS CERAMIC DIELECTRIC MULTILAYER (EXCL. POWER CAPACITORS)	853224	Ceramic dielectric, multilayer
85322410	FIXED ELECTRICAL CAPACITORS CERAMIC DIELECTRIC MULTILAYER WITH CONNECTING LEADS (EXCL. POWER CAPACITORS)	853224	Ceramic dielectric, multilayer
85322490	FIXED ELECTRICAL CAPACITORS CERAMIC DIELECTRIC MULTILAYER (EXCL. THOSE WITH CONNECTING LEADS AND POWER CAPACITORS)	853224	Ceramic dielectric, multilayer
87039010	MOTOR CARS AND OTHER VEHICLES PRINCIPALLY DESIGNED FOR THE TRANSPORT OF PERSONS WITH ELECTRIC MOTORS (EXCL. MOTOR VEHICLES OF HEADING 8702 VEHICLES FOR THE TRANSPORT OF PERSONS ON SNOW AND OTHER SPECIALLY DESIGNED VEHICLES OF SUBHEADING 8703.10)	870390	Motor cars and other motor vehicles principally designed for the transport of persons (other than those of heading No. 87. 02), including station wagons and racing cars: Other

6. CASE STUDY: South Africa's Technology Innovation System for Concentrated Solar Power

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Abstract

This chapter presents an analysis of a technology innovation system (TIS) which is specifically aimed at identifying low-carbon technologies and related products in South Africa which can potentially develop a comparative advantage. Data were collected during a study tour to Upington and Stellenbosch where consultations and interviews of 20 representatives from the renewable energy industry, R&D and universities occurred. The study inquiries into documents and patent analyses. We found that South Africa is developing a comparative advantage in three CSP-related technologies, namely heliostats, air-cooled condensers and packed (rock) bed thermal energy storage. These developments are largely due to the steady investments over the last decades in the TIS, largely from public funds but also with increasing private sector participation. South Africa has recently made large investments in the deployment of utility scale CSP in South Africa. This has yet to drive CSP innovation in the domestic TIS. Improved strategic stability in the utility scale CSP programme and clearer commitment to the programme could improve this situation. Even so, further developments of the three technologies have a favourable chance of success in global supply chains.

6.1. Key findings

1. The analysis of interview data from CSP project developers and research leaders at the core of renewable energy technology research and development in South Africa identified CSP as the technology with most potential. The research leaders stated that at this stage they were not aware of an existing or developing comparative advantage in any other low-carbon technologies.
2. We identified three low-carbon technologies in which South Africa could develop a comparative advantage. These are all related to CSP and are: Air cooled condensers (ACC), Heliostats and packed (rock) bed thermal energy storage systems (TESS).
3. The knowledge development and dissemination function of the South African technology innovation system (TIS) has operated successfully so far for the three technologies.
    a. The main export at present would most likely be limited to license fees related to IP for the three technologies, with commercialisation and manufacture taking place in other countries. There is potential for manufacture in South Africa too but this would require greater strategic commitment in local markets.
    b. A serious programme to assist developing countries to manufacture and export low-carbon technologies could easily lead to success in assisting South Africa to manufacture the technologies domestically.
    c. This **would be strongly supported if the South African government could provide more stability in the domestic CSP market.**
4. While South Africa has seven utility scale CSP independent power producer (IPP) projects (see Table 6-1), these have not played a significant role in CSP innovation by the domestic TIS. Ideally, such projects could drive local innovation, but this would require conditions that are identified in the text below, especially more certainty about commitment to local IPP procurement.
5. **Heliostat.** This is the apparatus used to reflect sunlight at the CSP tower receiver. The technological advances occur in both hardware and software. Innovation includes wireless electrical linear activators as well as a self-supporting and self-positioning 'plonkable' heliostat pod that has no need for the building of foundations. Innovations that provide additional flux, or energy intensity, include firstly, the development of a self-learning mirrors that allow for a higher quantity of mirrors in the array; secondly, higher optical performance; thirdly, smaller size mirrors, which focus more light onto a smaller area of the tower receiver.
6. **Air-cooled condensers (ACC).** These devices boost heat transfer and increases CSP plant efficiency. Air-cooled steam condensers (ACCs) use ambient air as the cooling medium for thermal power plants. ACCs do not consume any water, making the CSP less dependent on fresh water resources. Air cooling is, however, a poor heat transfer technology. The South African developed technology has developed effective methods to address these issues.
7. Identification of the actors and networks in the CSP TIS in South Africa reveal **that international support and partnerships are essential.** European partners have played important roles in R&D partnerships and funding, as well as project development. Access to global markets are necessary to warrant new technology development. The utility scale **CSP plants in South Africa form part of global value chains**, and include for example developers and funders in Spain, Saudi Arabia and USA. Potential for the South African technologies relies on integration with global supply chains.
8. **The results of knowledge development are not necessarily fully retained** by a research unit, or company or even country. One example is that the patent registered by Stellenbosch University for ACC unique configuration design failed to gain local funding to develop further. Then the German manufacture partner developed the idea further to the point that the final merits re-patent, which would be co-owned by the South African and German partners. A

second example is the Redstone CSP project, the first solar tower plant with molten energy storage in South Africa, for which the signing of the power purchase agreement was delayed to the extent that the company reportedly gave away the intellectual property rights.

9. The South African Technology Innovation System in CSP **lacks integration with national energy planning, other relevant policy and planning processes and industry**. It faces considerable competition from other technologies. R&D is constrained by fragmented policy and planning processes, policy uncertainty and inconsistent funding. During periods of low funding, the country loses skills and expertise through researcher emigration. CSP technology researchers report that links with industry are required to develop concepts to prototypes and for commercialisation.
10. South Africa's domestic **CSP market is in a formative stage.** A number of potential applications and new niche markets for heliostat innovations have been identified, although many of these are global. However, a more supportive domestic market could play a key role. The three technologies identified are ready for commercialization in and outside South Africa.

6.2. Introduction

The purpose of this study is **to assess the** technology innovation system (**TIS) and related technologies where South Africa could have the potential to develop a comparative advantage.** We use Bergek's (2008) Technology Innovation System (TIS) framework to assess technological development in an integrated way. This scheme of analysis acknowledges the role of innovators, R&D, industry dynamics and the political environment. The framework helps to identify the different functions that enable technological development. This systematic approach to technological development helps practitioners and policy makers to gain an understanding of the structure and dynamics of the technology system and ways to support it with specific measures (Jacobsson, 2004).

The paper is structured as follows. After a very brief country background, section 6.4 introduces the analytical framework based on a brief summary of the current research literature on technology innovation systems analysis. Section 6.5 presents the analysis of the South African Technology Innovation System. Section 6.6 concludes.

6.3. Country background

Achieving 1.5°C or even 2°C global warming scenarios relies on low-carbon technology innovation. Opportunities for South Africa to lead in low-carbon technology innovation may be important in shifting its development pathway, and more widely in contributing to developing low-carbon technology innovation. South Africa is an upper middle-income country, currently locked into high carbon development pathways with the development of two coal mega-power stations in the lead up to 2020 and high energy intensive industries.

The South African government has submitted its Nationally Determined Contributions (NDC) as a signatory party of the Paris Agreement. Domestically, the government incentivizes the renewable energy technology diffusion through a competitive bidding program for renewable energy called the renewable energy independent power producer procurement programme (REI4P). The program allows independent power producers to propose development of solar photovoltaic (PV), wind, biogas, small hydro and concentrated solar power (CSP) plants. Solar PV and wind technologies are fairly mature in their technological development and well-studied, while the uptake of biogas and small hydro has been relatively low.

South Africa does not currently manufacture or export a significant quantity of any low-carbon technology. Thus, the ERC study looks at potential based on an initial scan of low-carbon innovation in South Africa. By using our own long-term involvement with the sector and expertise, and by examining publicly available information and interviewing industry insiders at the core of renewable energy technology innovation we first identified CSP as the technology with most potential.[53]

Concentrated solar power (CSP) is a technology in which South Africa has achieved successful innovations. CSP has gained importance in the recent national renewable energy power procurement programme. In the context of South Africa's reliance on coal thermal power with its base load characteristics, CSP is an attractive low-carbon electricity generation option on the basis of energy storage potential.

6.4. A brief introduction to the framework of analysis: technology innovation systems

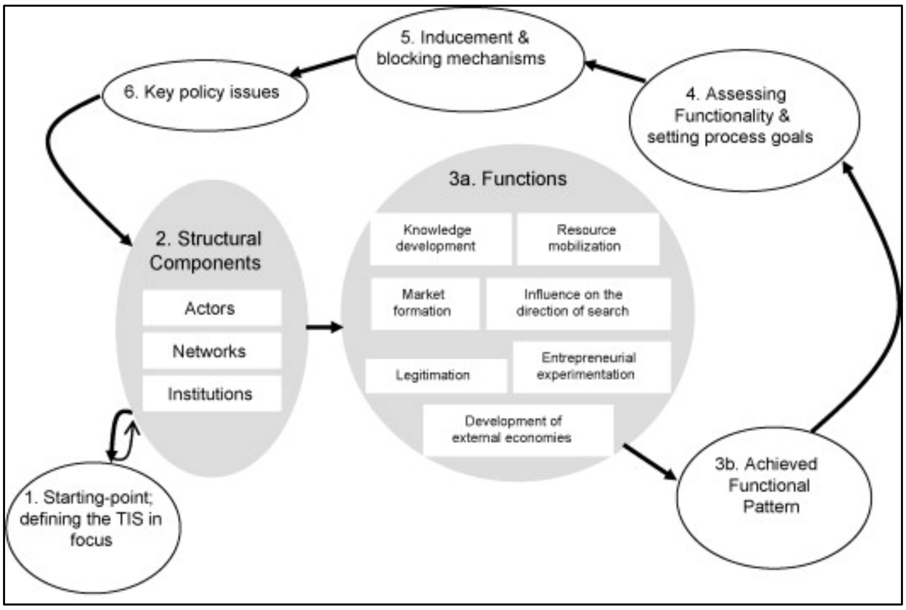
Innovation results from interactions between actors in a system. This is the main finding of the research literature on innovation systems. Back in the 1950s and 1960s, academics and governments

53 This included a comprehensive scan of ALL patents produced by South Africa from 2012-2018, see Addendum-A for details of the patent analysis.

operated under the assumption of linearity in research and innovation. The experiences of the Second World War and the Manhattan project, in particular, had stipulated the idea that funding into basic research will trigger into applied research and innovation. This assumption had then lead to research funding via Science Councils for basic research around the globe. The idea of national innovation systems first broke with this assumption and proposed the idea that interaction between various actor in the private firms, universities and government agencies lead to innovative outcome and market innovation. The idea of National Systems of Innovations (NSI) focused on these networks of innovators within the borders of nation states (e.g. Lundvall 1992). Soon the idea of innovation systems was applied to regional systems of innovation and technological systems of innovation (TIS).

The idea of the TIS is to focus on the technology itself, within and beyond national boundaries. The framework has been vastly applied and intensively discussed and criticized (Markard et al 2015). A useful paper presented seven functions in the TIS and a couple of steps for the analysis (Bergek et al 2008).

Figure 6-1: Scheme of analysis



Source: Bergek et al. (2008).

We will apply the functions within the TIS to the case of South African CSP as presented in Bergek et al. (2008) in the following section and explain the functions of the TIS in more detail, to avoid repetition.

6.5. A technological innovation systems analysis of CSP in South Africa

CSP research began in South Africa the 1980/90s. That involved technologies related to current successes namely solar reflectors (parabolic trough technology), dry-cooling research and solar chimneys. Then in the 2000's the SANEDI/DST "solar thermal spoke" project was established. This is the TIS that has directly generated the three current promising technologies. It is represented in the Solar Thermal Energy Research Group (STERG), which is detailed later.

6.5.1. Structural components of the TIS for CSP in South Africa

The structural components of the technological innovation systems comprise a combination of actors, their networks and institutions.

6.5.1.1. Actors

A dedicated research unit in South Africa is the Solar Thermal Research Group (STERG), which is housed in the Department of Mechanical and Mechatronic Engineering at Stellenbosch University (SUN) and affiliated with the Centre for Renewable and Sustainable Energy Studies (CRES) also at SUN. CRES is the South African national academic hub for research in renewable and sustainable energy at South African universities. Research spokes include also a wind energy research group (at SUN and University of Cape Town) and solar photovoltaic research groups (at SUN, University of Pretoria, University of Fort Hare and Nelson Mandela Metropolitan University).

In terms of research plants, one is the STERG university research project and the other one is a national utility planned project that has stalled.

Related to the commercial deployment of utility scale IPPs by international technology companies, there is also involvement of financial actors for the REI4P projects include local investment and commercial banks, private equity funds, European development banks and agency, multilateral development banks, local and United States national development institutions. Within the supply chain, from developers and technology manufacturers and suppliers, to engineering, procurement and contracting, operations and maintenance, actors are from Europe (notably Spain, and also Belgium and Germany), Saudi Arabia and the United States. The REI4P projects have local partners and supply, in line with local content and Black Economic Empowerment requirements. The local technologies are generally standard construction and infrastructure and not low-carbon innovative technology.

Actors in electricity supply include National Energy Regulator (NERSA) (supply licensing), the state-owned national utility Eskom that owns the national electricity distribution grid (distribution and re-sale), and SANEDI (certification and tax return coordination in terms of renewable energy production tax incentives)

6.5.1.2. South African renewable energy independent power producer procurement programme (REI4P)

The REI4P program was initiated in 2011 and uses reverse auctions to procure renewable energy independent power producers (IPP). An IPP unit administers the REIPPP on behalf of the Department of Energy and the National Treasury. IPPs must be licensed by the National Energy Regulator of South Africa (NERSA) as required under the Electricity Regulation Act, 2006. National energy planning in the Integrated Resources Plan describes targets for renewable energy, including for CSP. The programme requires local content but this has not yet driven CSP innovation. Seven out of South Africa’s nine CSP plants have emerged from this program.

Table 6-1: Utility Scale CSP power generation[54] projects in South Africa

	Capacity (MW)	Programme	Nearest town	Status
Eskom CSP	100	Other	Upington	Halted/aborted
Helio 100 Pilot CSP project		STERG	Stellenbosh	Research
KaXu Solar One	100	REIPPP Window 1	Pofadder	Fully operational
Khi Solar One	50	REIPPP Window 1	Upington	Fully operational
Bokpoort CSP Project	50	REIPPP Window 2	Groblershoop	Fully operational
Ilanga CSP 1 (Karoshoek Consortium)	100	REIPPP Window 3	Kimberley	Construction
Kathu Solar Park	100	REIPPP Window 3	Kuruman	Fully operational
Redstone CSP	100	REIPPP Window 3	Postmasburg	Approvals, planning and financing
Xina CSP South Africa	100	REIPPP Window 3	Pofadder	Fully operational

Source: Authors.

6.5.1.3. Networks

Networks are apparent among REI4P consortia partners within each CSP project, across two CSP industry associations, Solar Thermal Association of Southern Africa (STASA) and Southern Africa Solar Thermal and Electricity Association (SASTELA). Funding networks are local and international, predominantly European.

Networks linking industry to public interest bodies and academia emerged, conceivably in part at least, in response to resistance from the local electricity monopoly to the REI4P. These networks are apparent in the increased participation of industry actors in local conferences and in CSP plants hosting technical tours by the public.

The annual research symposium, hosted by the Solar Thermal Energy Research Group (STERG) at Stellenbosch University brings together academia, government research and funding and national public interest research bodies, the national public utility company, Eskom, and industry actors. The symposium links to international CSP networks and is endorsed by SolarPACES international research network, that endorses the symposia as the “annual South African CSP get-together”

6.5.1.4. South African government research funding

The National Research Foundation (NRF) supports the STERG programme at the University of Stellenbosch. Tax incentive certification and tax return coordination for renewable energy electricity production is implemented by the South African National Energy Development Institute (SANEDI) (Schwartz, 2013) (Craig, 2017).

54 Seven of these are commercial deployments by international technology firms, one is halted/aborted and just one a dedicated local R&D/innovation project.

6.5.2. Knowledge development and diffusion

The function of knowledge development and diffusion captures the knowledge base of the TIS. Knowledge includes scientific, technological, production, market, logistical and design knowledge (Bergek et al 2008).

One measure of knowledge is number of relevant patents. We carried out a 'manual' expert analysis of patents relating to CSP in South Africa. The details are presented in *Addendum A - Expert 'manual' patent analysis.* Our conclusions from this analysis were that:

- The number of relevant South African patents identified in this analysis is insufficient to rely on the methodology developed by Hausman et al (2014) to identify potential Revealed Comparative Advantage.
- Nonetheless, this assessment of local patents provides a useful overall view of the extent of CSP related research results in South Africa, and also of other low-carbon renewable energy related research.
- For the overall WP3.5 report, these results could be useful to compare South Africa with the industrialised countries that have been analysed.

With regard to R&D, the STERG research centre leads CSP technology innovation in South Africa. The centre hosts more than 75 members, and include 15 faculty members, approximately 55 post-graduate students and 75 affiliates and visiting researchers. By 2018, the centre graduated fifteen PhD dissertations directly connected with solar thermal R&D and more than 50 MSc and M.Eng theses. On average, five peer-reviewed literature journal articles are published each year and many more international conference proceedings. Key STERG IP include nine patents in sunspot technology, four in heliostat technology and 1 patent application in rock-bed energy storage.

STERG research infrastructure includes a 1,000m2 solar roof laboratory, staff office, workshop & control room, 18 m lattice tower (multi-use), 600 °C, 5 tonne, 5 m^3 packed bed storage rig & 1,200 °C kiln, operating prototype, air-cooled condensers (ACCs), as well as a 40m2 smart heliostat field, a 100kW Helio facility and plans for a 400m2 field to test its 'plonkable' small-heliostat subsystems (six or 8 ~ 18m2 heliostats). These self–positioning units require no foundations, they are linked via smart control systems and they self -learn to target the solar receiver.

6.5.2.1. Air-cooled condensers

The ACC innovation focuses on the unique configuration to increase plant efficiency. European produced air-cooled condensers run water over tubes under very high temperature condition; however, air-cooling is a poor heat transfer technology. The novel and unique configuration in air-cooled condensers boosts heat transfer and increases CSP plant efficiency. The design patent registered through Stellenbosch University relied on European funding and a German manufacture partner to develop the final product. The evolution in design during prototype development provides for a joint South Africa-German re-patent.

6.5.2.2. Heliostats

Innovation research in heliostats focuses on performance and price per surface area. Advances in both hardware and software include in wireless electrical linear activators and a self-supporting and self-positioning 'plonkable' heliostat pod that has no need for the building of foundations. The improvements in additional flux (energy intensity) include in 1.) the development of self-learning mirrors that allow for a higher quantity of mirrors in the array; 2.) higher optical performance; 3.) smaller size mirrors, which focus more light onto a smaller area of the tower receiver. These advances were ahead of their time in that they could not be commercialised until the CSP tower system could be developed further in order to accept the flux.

Design and manufacturing of key components is the main industrial opportunity, capturing 40-50% plant value with co-production of intellectual property which can earn royalty and licensing fees. Immediate opportunity lies in the heliostat field, comprising almost 40% of a tower plant capital cost, and offering the largest potential for tower cost breakthroughs. Engineers at the University of Stellenbosch have developed the patented Helio 100 modular heliostat system with a breakthrough low cost autonomous control system compared with standard control technology, and an indirect saving through compatibility with fields of smaller heliostats. Smaller heliostats can be less expensive, due to lower wind resistance requirement and easier transportation, among other factors. Heliostat field configurations containing large numbers of small heliostats support modularisation, standardisation and high- volume production. This will enable a local engineering company to design and manufacture linear actuators to dynamically adjust the facets as the sun moves. Drivetrains such as slew gearboxes and linear actuators currently account for approximately 50% of the cost of a heliostat. Most of the large international gear and drive manufacturers are adapting and designing products for CSP and PV trackers. There is no reason that South Africa cannot favourably compete, given its own satellite and telescope technology development. Future design-related opportunities outside the heliostat field include the development of alternative thermal storage solutions (i.e. using materials other than molten salt) and receivers (e.g. for direct generation, using John Thompson boilers).

6.5.2.3. Rock-bed heat storage systems

Rock-bed heat storage innovation investigated on how the piling of the rocks creates different pressure characteristics in 2 directions and in containing the rocks to 1.) provide thermal insulation, 2.) keep the environment out, 3.) pressurise it. Research is at the experimental stage, focusing on performance and cost optimisation. It has proven cost-ineffective to transport the rocks.

6.5.3. Influence on the direction of search

The development of a TIS depends on a range of firms and organization who chose to enter this space. These organizations, as well as their policies, resources and interests then guide the direction in which the technology develops (Bergek et al 2008).

The above- mentioned R&D clearly relies on joined sources and efforts within and outside South Africa. The conceptual development of the technologies results from decades of investment by the South African government (mainly) in the innovation systems. However, according to the research leader interviewees progress to the point of prototype development and commercialization relies on global partnerships and support and global supply networks.

Bergek states that TISs are generally global in character. So this was found to indeed be the case with all the STERG technologies. Even though the technologies have resulted from decades of investment by the South African government (mainly) in the innovation systems that have resulted in these three technologies getting to the stage they have, according to our interviewees, the entire TIS that will be involved, notably the commercialisation processes are involving global supply chains with a likely outcome of South African partners (mainly STERG) receiving license fees.

Thus, as to be expected, commercialization will probably rely on ongoing integration into global supply chains with local South African players providing specific roles depending on the location of comparative advantages for elements in the supply chains. These vary with technologies from in some cases being limiting to knowledge development and licensing through to others where there are factors providing advantages in manufacturing. The three technologies identified are still in the knowledge development phase.

The results of knowledge development are not necessarily fully retained by a research unit, or company or even country. For example, a patent registered by Stellenbosch University for ACC unique configuration design failed to gain local funding to develop further. The university secured a German manufacture partner with European funding that developed the concept to the point that the final product merits re-patent, which would be co-owned by the SA and German partners. Another is the Redstone CSP project. Continually delayed signing of a power purchase agreement, led to intellectual property for its molten rock energy storage being given away.

In the opinion of the research programme leaders, heliostat software and hardware innovations can be internationally competitive. Government is reportedly supportive in conversation yet lacked the 'belief' and 'boldness' to provide investment. Ten years into the STERG research programme, innovation has started to be relevant for commercialization. Potential applications for the new technology have started to materialise in the global market.

6.5.4. Resource mobilization, market formation and legitimation

These TIS functions are intrinsically related. For the domestic market, in the highly regulated energy sector, the CSP technology depends on the REIPPP to create a market for the diffusion of the technologies. Successful technological diffusion and innovation depend on the successful mobilization of resources from both public and private actors. The successful deployment of the technology then adds to the legitimation function, as the government will only be able to support the technology if it is generally socially accepted or at least not opposed.

However, as previously mentioned the three identified technologies could be competitive in integrated global supply chains and thus the local TIS would play specific roles in those chains depending on the process in which the technologies are commercialized and then the choices over manufacturing locations. There is no specific link between the location research activities, commercialization, manufacturing and installation/deployment.

Media plays a strong role in legitimation for renewable energy in South Africa, despite the problem that media reports confuse CSP with PV technology. Industry bodies have also played a role in leveraging industry, for example in round one of the competitive bidding for supply contracts under the REIPPPP, there were no winning PV technology bids. Air-cooled condenser technology is legitimated by water shortages and South Africa's need to carefully manage water resources.

However, within the contact of global supply chains, state and investors' confidence in CSP innovation appears to be affected by prospects for local manufacture and local markets. The Department of Science and Technology (DST) reportedly would provide funding if South Africa has strong local component in the product development. The Technology Innovation Energy (TIA) the state institute tasked to bridge the divide between research and development provides funding provided there is a strong co-partner for the pipeline of the project. In terms of the timing for the innovation process, in the first ten years the research unit established itself and identified and carried out research that would make a difference, and the goal of the following 5 years would be to commercialise the technologies. In terms of the funding, the timing was mentioned as being important, for example that in hindsight TIA funding had been premature.

The changes in public belief in CSP technology over the last five to ten years were described as incredible, and largely related to legitimation in the media. While falling CSP electricity production costs improve financial feasibility of CSP projects, this confidence is slow to be reflected in energy planning. Proponents and 'champions' of all technologies vie to be considered by state energy planners. High levels of uncertainty around predicted costs and lobbying play key roles. Previously solar photovoltaic technology was promoted on the basis of being cheaper, more recently CSP technology has grown more attractive because of growing capacity for energy storage. In terms of belief in the international CSP TIS, ambitious research goals have been set in Europe and the USA. Evidence of growing belief in CSP innovation is apparent from the more bullish projections for CSP by the South African Centre for Scientific and Industrial Research (CSIR), one of SA's leading public research units. Previously it favoured PV over CSP.

Stellenbosch University researchers argued that the CSP technology innovation system would benefit from firm decision to provide a national commitment to support building a specified number of plants over time (for example as was done to stimulate the automotive industry. National commitment to a long-term strategy has been shown to be beneficial, for example the persistence shown in the pursuit of coal to liquid fuel technology development, which came under threat and was voted on in parliament in the 1960's to continue the R&D despite explosions and deaths. The interviewees emphasized that commitment and continuity were essential and in the context of changing governments, ideally policy makers should be less impacted by the politics of the day and make decisions on strategy long-term goals (personal communications). Policy makers should reduce uncertainty and communicate what the policy is so that R&D can align with the strategy. One way to implement this is to maintain consistency in research themes of funding of student bursaries.

6.5.5. Entrepreneurial experimentation

Entrepreneurial experimentation refers to the considerable uncertainties in technologies, their applications and markets (Bergek et al 2008). Renewable energy learning curves forecasts have proved unreliable in the past and should be treated with caution. For example, previous forecasts of PV costs for South African failed to capture the major (downward) cost drivers of the renewable energy incentive program. The steep learning in PV was associated with innovation in total project costs, involving all links in project chain, not only technology/manufacturing costs. The support for entrepreneurial experimentation in CSP technology is a real threat to its success, also in terms of policy uncertainty, as funding is not underpinned by a committed energy plan for renewable energy. The absence of commitment to medium to long-term plans and associated inconsistency in funding add the main risks and uncertainties to the current CSP innovation in the country, as opposed to technological risks.

The interviews reflected that the technology innovation takes place in the global rather than the regional space, and that for South Africa the scale of the CSP market is limited in terms of opportunities for new entrants. The importance of timing was noted. This applies to technology innovation to be implemented without need for further development to other components and funding to focus on a specific component.

The development of niche markets for a range of potential applications for the heliostat innovation has become a real possibility. The interviewees named the main markets as the electricity market, and high temperature process heat for industry and mineral processing including preheating metals prior to smelter. Niche markets include high temperature reactors for hydrogen production and desalination. Some small-scale applications already exist. The interviewees' perceptions were that in the formative stage of the market one would find companies that would develop whole application systems, and that specialisation in specific components occurs with growing market maturity.

6.5.6. Development of positive externalities

The development of positive externalities is an important process for the growth of TIS where innovation and diffusion processes enable each other. Entry of new firms in to the TIS are central to this function (Bergek et al 2008).

The South African TIS has not shown significant new entries in the market, but its innovations may be outgoing into global markets. At the same time, there has been momentum for industry players to shape up into coalitions in response to Eskom resistance to the REIPPPP programme. The delays in signing the power purchase agreements in 2018 led to increased participation in the industry body SASTELLA. The influence of SASTELLA is attributed with the growing success of solar energy bids. Advocacy coalitions have grown in importance and have driven the formation of a new industry association SOSTASTA. Participation in industry associations appears to have promoted industry participation in conference and symposia activity attendance.

6.6. Conclusions

The analysis found that there is an emerging TIS in South Africa with potential to innovate and commercialise three identified technologies. The uncertainty in the policy environment made the TIS vulnerable and dependent on international funding sources and partners, which may increase the risk of losing patents and innovation rents.

The extent of the dedicated TIS arranged around these CSP-related technologies, at STERG and elsewhere was not anticipated. Global markets remain important drivers. For South Africa the most likely potential for exports is for the local TIS and technology to develop as elements in global supply chains. The absence of knowledge production to the point of commercialisation suggests the TIS would benefit from stronger links between industry and academia.

6.7. Addendum A - Expert 'manual' patent analysis

There are in excess of 80 million patents registered globally. These are typically categorised according to a Patent Classification (PC) code that relates to the field of activity for which the patent is described. The selection of relevant PCs to filter relevant patents is described in the patent literature as a crucial strategy for patent analysis.

Interviewees at the Solar Thermal Energy Research Group (STERG), the first university research group in South Africa to focus on solar thermal energy research, provided a list of CSP technology patents registered with at least one inventor based at STERG. All the patents related to CSP and some of the patents had additional application outside of CSP. Following Montecchi *et al* (2013) methodology for using PC codes for searching relevant patents for analysis, we examined each of the STERG patents on World Intellectual Property Organization WIPO PatentScope database and identified their PC codes as F01, F03, F22, F24, F28. These codes are for applications in Mechanical engineering: heat exchange, steam generation, machines, production of heat, and in Electricity: basic electric elements. We assume that these are the codes would identify most CSP related innovation.

A search of the (WIPO) PatentScope database yielded 93 patents with the aforementioned PCs registered for inventors in South Africa for the period 2012 to 2018. A comprehensive scan of each patent description and claim identified the inventor's proposed application. Of the patents, 16 were registered for CSP application, including among others heliostat tubular pylon and hinge arrangement, water collection trough assembly, and splash grids for rain. The remaining 77 patents applications included water heater and solar water heating (19), water and or wind energy (15), co-generation or combined heat and power (6) and domestic solar applications (4).

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7. ADDENDUM: Future prospects for wind energy in Brazilian climate policy

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7.1. Introduction

The political-economic crisis and resulting recession have led to a halt in new energy project procurement between 2016 and 2017, negatively impacting wind power expansion. In fact, in light of lower prospects for energy demand for the coming years, Decree 9019 from March 2017, allowed the revocation of energy contracts previously set. Through the prediction of a competitive mechanism operating under a similar logic of contracting bids, an auction held on August 2017 led to the cancellation of 183.2 average MW (from which 16 wind farms and 9 photovoltaic plants), and the reimbursement of R$105.9 million for a Reserve Energy Account (CONER), (Costa, 2017).

Yet, a new tender took place in April 2018, evidencing that prospects for wind energy in Brazil remain strong. New wind projects summed 114.4 MW, with average tariffs of 67.6 R$/MWh, against 97 R$/MWh in 2017. This section discusses future prospects for wind energy in Brazil, focusing on financing and trade possibilities, technological development and the role of wind in meeting the Brazilian NDC goals.

7.2. Expansion of wind markets in Latin America

Wind turbine component manufacturers currently operating in Brazil add up to 4 GW of annual production capacity. Domestic electricity supply depends mainly on public auctions, and national production exceeds demand, so that exports prospects are underlying for business sustainability. Currently, Brazil exports more than types of 15 components, which summed BRL 1 billion in 2014 (Apex-Brasil).

In 2015, US$ 428 million in wind equipment were exported to Canada, USA and Europe by Tecsis alone. The company invested over BRL 200 million to expand its annual production from 2,700 to 7,500 blades, whereas Aeris plans to increase its production from 1,550 to 1,800 blades per year.

Apart from traditional markets, the increase of renewable energy bids in the Southern Cone, creates new possibilities for the Brazilian industry. Argentina, Chile and Uruguay have very underdeveloped wind industries, setting Brazil as a prominent regional exporter.

Three main factors place the Brazilian industry as the main exporter to Southern Cone partners:

- the very low degree (or even the inexistence) of development of local wind manufacturers in these countries;
- production capacity of the Brazilian wind industry, which exceeds the domestic market;
- financing conditions at competitive costs in international markets, with BNDES being one of the few long-term financiers in Latin America.

Apart from funding domestic production at mild conditions, BNDES finances several infrastructure projects in Latin America. Most importantly, it offers Brazilian companies specific export financing lines, such as 'Exim Pre-Shipment'[55] (to finance production destined to foreign markets) and 'Post-Shipment'[56] (to finance the commercialization of products abroad). However, as Gaylord (2017) points out, recent changes on BNDES´s financing schemes, now closer to market conditions, may affect investors´ decisions. Higher interest rates are likely to raise manufacturing costs, especially if LCR remain unchanged. Gaylord (2017) advocates that these conditions should be given more flexibility (e.g. on mandatory costly pieces), assuring competitiveness for exports and reasonable domestic prices in energy auctions.

Chinese Goldwind, currently launching its activities in Brazil, for example, should prescind from BNDES´ financing. The company claims that the bank´s LCR conditions do not match its global operation goals, which require a diversified production. In addition, Goldwind can rely on other promotion agencies, such as China Development Bank and Exim Bank (Canal Energia, 2017).

7.3. Synergies between offshore wind generation and the oil and gas sector

Brazil figures among countries with high offshore wind potential, alongside China, the United States and Australia (IEA, 2018). Preliminary assessments estimated total offshore wind potential at 606 GW, approximately 12 times higher than the country´s onshore potential (Ortiz and Kampel, 2011).

Offshore wind farms can benefit from better quality wind resources, pushing up capacity factors. In Brazil, they could supply electricity for the various large demand centres located along the coast, with lower interference with the population compared to onshore sites. Competition to other land uses could also be softened, even though issues related to fishery and navigation activities may arise.

The offshore wind sector in Brazil can profit from ongoing international developments, namely in the North Sea. According to the IEA (2018), the height of commercially available turbines has increased from just over 100m (corresponding to 3 MW of installed capacity) to more than 200m (8 MW) between 2010 and 2016. In Brazil, three offshore wind farm projects are currently under development (environmental licensing phase), adding up to 30 MW of installed capacity (4C Offshore, 2018; E&P Brasil, 2018). Projects can be installed at greater distance from shore, possibly in deeper waters (more than 40 m), where better wind quality can be assured.

Despite higher capital costs associated to turbine sizes and foundations, offshore projects usually provide gains in operation and maintenance and better performance, leading to lower overall costs. The levelized costs of electricity (LCOE) for offshore wind in Brazil were estimated by Medeiros (2014) as varying between 97.1 US$/MWh and 350.3 US$/MWh, whereas onshore wind costs range between 85.5 US$/MWh and 398.2 US$/MWh.

In particular, the oil and gas sector, in which LCR are also required, is fairly developed in Brazil, offering a series of synergies that can be explored with the integration of offshore wind and the hydrocarbons sector. The IEA (2018) identifies interlinkages in three major areas, as discussed below.

Competencies required to operate offshore facilities could be transferred from O&G supply chain´s sector expertise, including the construction of turbine foundations, substations and cables. A variety of equipment and support services can also be adapted to wind generation. The application of meteorological and oceanographic data, maintenance and inspection services, and environmental assessment and licensing activities could also be of great use.

55 Exim Pré-Embarque
56 Pós-Embarque

The opportunity to electrify offshore oil and gas operations could reduce the need of on-site fossil-fired generation. Possibilities include pumps for extraction and injection, compressors for transportation, needs related to living facilities (lighting, heating, etc.), among others.

According to the National Oil Agency, 54% of Brazilian offshore facilities are operating for 25 years or longer (ABIMAQ, 2017), therefore, close to decommissioning. Deactivated platforms could provide offshore bases for operation and maintenance of wind farms. New uses for existing infrastructure (e.g. cables and pipelines) can be considered as alternatives to full decommissioning, lowering overall costs. Such synergies can potentially boost the interest of companies belonging to the oil & gas sector or supply chain for investing in renewables, accelerating the energy transition (Schaffel, Westin and La Rovere, 2017).

The integration of offshore platforms and wind generation could bring a series of benefits, from reduced costs to improved environmental performance, reaching cost-competitiveness and unlocking the Brazilian offshore wind potential.

7.4. Wind energy as a lever for achieving NDC goals

Positive prospects for wind energy are likely to act as an enabling factor for achieving goals set in Nationally Determined Contributions (NDCs) under the scope of the Paris Agreement, both in Brazil and its trade partners. The Brazilian NDC (Brazil, 2015) establishes an increase in sustainable use of renewable sources, excluding hydropower, to at least 23% of electricity generation by 2030.

Estimates from the ten-year energy expansion governmental plan (PDE 2026) from EPE (2017), show that wind development is likely to surpass NDC goals, even in a lower economic activity scenario. The table below compares PDE 2026 prospects with the Brazilian NDC intermediary goal for 2025. It is worthy to mention that the latter considered high economic growth rates (hence higher demand for energy), which explains the lower share of wind in the electricity mix compared to PDE 2026 figures.

Table 7-1: Wind energy generation in 2025

	NDC	PDE 2026
Installed capacity	24 GW 11% of total electricity mix	27 GW 14% of total electricity mix
Electricity generation	92 TWh 11% of total electricity mix	104 TWh 12% of total electricity mix

Source: Adapted from EPE (2016).

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Conclusion

Complying with the NDCs and moving along a ‘well below 2°C’/1.5°C pathway implies a substantial increase in the global uptake of low-carbon technologies. In this report we quantify countries who have specialised in exporting and inventing in 14 low-carbon technologies.

We find that almost all of the analysed countries (EU28, EEA, G20, and Israel) have a revealed comparative advantage in at least one low-carbon technology. Furthermore, based on the individual countries’ strength in related sectors and developments in similar countries, we would expect that all countries may potentially increase export specialisation in specific low-carbon exports.

The same holds true for innovation. The data shows that patent and export specialisation patterns are correlated. All the countries have specialised in patenting at least one low-carbon technology. Based on the individual countries’ strength in related technologies and developments in similar countries, we would expect that all countries may potentially increase patenting specialisation in specific low-carbon technologies.

Consequently, all countries might contribute to provide the investment goods needed to move along a ‘well below 2°C’/1.5°C pathway. Four case studies support this point – but also highlight the importance which policy plays in enabling a local industry in low-carbon technologies.

The case of Brazil indicates that local content provisions – a tool often seen sceptical by trade economists – may have played a role in the relatively successful development of the Brazilian wind industry.

The case of China’s PV sector is intriguing, as China does not only try to translate superior innovation activity into exporting strength but also aims to move from mass-manufacturing to a more innovation-based growth model.

The case of Italy shows that a country who has a proud history of manufacturing vehicles does not necessarily manage to become a world leader in electric vehicle and batteries technology. However, it also shows that regional developments may matter more than general trends.

The case of South Africa shows that continued public support to a technology in which the country arguably has some potential – concentrated solar power – may enable a self-sustaining comparative advantage in this sector.

Overall, the report provides an in-depth overview of the current state of export and technological specialization in low-carbon technologies. Based on a network analysis of trade and patent data, we are able to display (unused) export and technological potential of countries in certain low-carbon technologies. The case studies show the importance of specific policies and public support. However, they also indicate that there is no single viable solution which can be applied universally. Every country and region have to find their own way to successfully develop an advantage in low-carbon technology.