Innovations towards reaching natural resource related SDG – what are the starting positions?

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Abstract

Development along natural resources is linked to the SDG on economic, social, and also ecological dimensions. At the same time, economic and inclusive development requires that countries of the South increasingly develop their own capabilities. The GLOBELICS thematic report on natural resource development has taken up both requirements, and has pointed towards the potential of backward and forward linkages related to natural resources.

The paper addresses the extent to which innovation indicators indicate the level and development of competences with regard to providing linkage of natural resources to other fields important for development. We look at backward linkage to mining technologies, and forward linkages to metal production, renewable raw materials, and material efficiency. Patent and trade indicators reveal that the innovation dynamics in the relevant fields is about average. A heterogeneous picture emerges for the countries within a sample of 24 countries,. Some countries seem not to utilize linkage opportunities yet, others seem to be strong in establishing linkage in one area, other seem to even perform a more integrated approach along the value chain. However, in general, NICS are increasingly building competences especially in areas which are related to supply of natural resources. This increase in competences can be used to move closer to some of the SDGs related to natural resources. On the other hand, the traditional OECD countries are still in the lead especially with regard to the strategy of material efficiency, which is directed at reaching some other natural resource related SDG via a lowering of the demand for primary natural resources. This indicates the necessity of collaboration of North and South on the one hand. On the other, it shows that the different SDGs are not necessarily complementary, but that there will be trade-offs which require a careful balancing.

Keywords: sustainable development goals, natural resource based development, capabilities, forward and backward linkage, innovation indicators.

1 Introduction

After deciding on the Sustainable Development Goals (SDG) in the post Rio+20 process, and after the Paris Agreement, innovations to reach the SDG have gained in importance in policy debates. This paper concentrates on the SDG related to natural resource innovations. Recently, GLOBELICS has taking up the discussion about natural resource innovations and development in a thematic report (Andersen et al. 2015). The Globelics Thematic Report analysed the strategic options for various forms of integration. Economic and inclusive development requires that countries of the South increasingly develop their own capabilities. Innovation scholars did emphasize that development of technologies co-evolve with their socio-economic environment, and the GLOBELICS community, in particular, has pointed out the importance of building systems which enhance innovations, competence building and learning. However, what is the stage of development of building such systems? Will there be enough innovations generated to reach the natural resource related SDGs? And where will it be generated - are the innovations more likely to be coming from the North as in the past, or will we see a new pattern of generation of innovation with an increased or perhaps leading role of the South?

This paper takes the GLOBELICS thematic report as starting point and aims at carrying on research in two directions: The first aim is empirical. The Globelics thematic review on natural resource innovation highlighted the potential for inclusive development for developing and emerging economies by various forms of backward or forward integration. Thus we ask what we can learn from looking at the level and development of competences of single countries with regard to providing linkage of natural resources to other fields important for development. The second aim is more conceptual: The Globelics thematic report already pointed to the necessity of sustainable development. Using the SDG, we can see that natural resources are strongly embedded to the sustainability on various dimensions. Natural resource innovations are strongly linked to SDG 10 (Reducing Inequality) in an intergenerational aspect. Furthermore, they are related to economic and social dimension of sustainability, which show up in SDG 1 (no poverty), SDD 3 (Good Health and Well-Being), SDG 8 (Decent Work and Economic Growth), and SDG 9 (Industry and Innovation). However, natural resource innovations also relate to more environmentally driven SDGs: Reducing emissions from mining and industrial production (resulting from forward integration), for example, is related to SDG 6 (clean water) and SDG 13 (climate action). Finally, the use of resources, in particular resource efficiency, is at the heart of SDG 12 (consumptions patterns). This results also in including material efficiency and recycling – activities related more at the end of the value chain – as a potential target for forging linkages with natural resources. Thus, we also include this potential form of linkage into the empirical analysis.

The paper is organized as follows: Section 2 of this paper outlines the analytical background of the analysis. In section 3 we look on general empirical trends of build-up of competences. In section 4, we perform a country mapping of technological capabilities with regard to backward and forward linkages. We look at backward integration from mining, linkage towards renewable raw material production, forward integration of mining towards production of basic materials, and forward integration with material efficiency (the latter could perhaps also be portrayed as lateral integration). Finally, the summary and conclusions of the analysis will be presented in section 5.

2 Background

2.1 Conceptual background and aim of paper

The role of innovations in resource supply and use has been embedded in the debate on limits of growth early on. Raw materials are an important input into the economy. Thus, the first report "limits to Growth" indeed identified resource availability as a key bottleneck for growth, which emphasized the need for efficient use of natural resources. In general, geological scarcity of metals is seen less as a problem today (e.g. Poulton et al. 2013, Graedel et al. 2014). However, lower metal ore contents will make it likely that the costs of mining metals will increase in the long run (Humphreys 2014). Furthermore, the production and use of natural resources is strongly linked to environmental problems. Mining is a key source of pollution. There are emissions during operation of mining, but also from tailings leading to pollution of water and negative effects on biodiversity. The deposition of waste and tailings from mining has been increasing continuously; its volume has been increasing by a factor of ten during the last 30 years (Poulton et al. 2013). The environmental effects of mining are very substantial. This also can be seen from the latest report of Blacksmith Institutes (2013), which names among the ten most polluted places on earth also three which are characterised by mining (Kabwe, Sambia; Kalimantan, Indonesia; Norilsk, Russia). If the looks along the value chain of raw material, further emissions occur. Production of basic material is heavily responsible for energy consumption of industry, and also accounts for substantial industrial emissions of pollutants into air and water. The idea of industrial ecology and life cycle thinking finally puts the use of natural resources in products and their recycling into the focus. Environmental effects also happen during processing of raw materials along the value chain. Thus, reduction of material demand reduces the emissions along the value chains. In addition to energy related environmental targets, increase in material efficiency has become a prominent policy target. On a national, but also international level, policy strategies increasingly push towards reducing material demand, by calling for recycling and material efficiency strategies. To sum up the argument, environmental concerns will not only push towards employing less environmental harmful mining technologies, but will increasingly be tailored towards reducing the demand for raw materials per se.

The link of natural resource use and environmental effects also links natural resource development to the debate about economic development in the South in the context of the Environmental Kuznets Curve debate. According to the Environmental Kuznets Curve (EKC)-hypothesis, environmental pressure grows faster than income in a first stage of economic development. This is followed by a second stage in which environmental pressure still increases but slower than GDP. After a particular income level has been reached, environmental pressure declines despite continued income growth. Within the global environmental debate, it is argued that NICs do not necessarily have to follow the emissions path of the industrialized countries. An alternative development path has been labelled "tunnelling through the EKC" (Munashinghe 1999; Perkins 2003; Gallagher 2006). Put into the context of the strive for SDGs, this requires that development based on natural resources requires an environmentally friendly production and efficient use of these natural resources.

The Globelics community has pointed out early on that the conditions for such a tunneling are much more complex. The results of the research on technological development in the South and the factors which influence the build-up of their technological underlined the importance of absorptive capacity (Abramovitz 1986; Cohen and Levinthal 1990) and technological capabilities (Lall 1992; Bell and Pavitt 1993). Since the end of the 1980's, the concepts of Social or Absorptive Capacity (Abramovitz 1986; Cohen and Levinthal 1990) and technological capabilities (Lall 1992; Bell and Pavitt 1993) are widely known. The results of the research on technological development in NICs and the factors which influence the build-up of their technological capabilities (e.g. Fagerberg and Godinho 2005; Nelson 2007; Malerba and Nelson 2008, Lall 1998; Lee 2005; Lee and Lim 2005; Rasiah 2008) have underlined the importance of absorptive capacity and competence building. This challenge has to take into account the changing conditions for learning and knowledge acquisition. One aspect to consider is the tendency that the build-up of technological and production capabilities is increasingly separated (Bell and Pavitt 1993). Another aspect relates to the effect of globalization on the mechanisms for knowledge dissemination. Archibugi and Pietrobelli (2003) stress the point that importing technology has per se little impact on learning and call for policies to upgrade cooperation strategies towards technological partnering. Nelson (2007) highlights the changing legal environment and the fact that the scientific and technical communities have moved much closer together. Indeed, key Globelics activities such as the "BRICS-project" (Cassiolato and Vitorino 2009) and the "Catch-up project" (Malerba and Mani 2009) have been dealing with these issues. All these factors lead to the conclusion that domestic competences in sustainability related science and technology fields are increasingly a prerequisite for the successful absorption of green technologies in NICs.

There are some arguments which point towards sustainability innovations emerging also early on in the South (see Watson and Sauter 2011 on environmental leapfrogging). Studies using innovation indicators indicated that NICs have been increasing their capabilities substantially (Walz and Marscheider-Weidemann 2011). Within the Globelics community, considerable work has been done in performing numerous case studies on the build-up of domestic competences for sustainability innovations. Various case studies have been performed which look at the potential of natural raw materials (e.g. for biofuels) as an opportunity for development.

Recently, GLOBELICS has also taking up the discussion about natural resource innovations and development in a thematic report (Andersen et al. 2015). This paper takes this report as starting point and aims at carrying on research in two directions: The first is empirical: What can we learn from looking at the level and development of competences of single countries with regard to providing linkage of natural resources to other fields important for development. The second is more conceptual: The Globelics thematic report already pointed to the necessity of sustainable development. Using the SDG, which provide a wordwide accepted definition, we can see that natural resource are strongly embedded to the various dimensions of sustainability. In particular, this results also in including material efficiency and recycling – activities related more at the end of the value chain – as a potential target for forging linkages with natural resources.

The GLOBELICS thematic report refers to the debate about a resource curse. Successful innovations based on natural resources require good framework conditions. The debate about natural resources as a base for development has been shaped by the discussion about the existence of a resource curse. There are two streams of argument: (e.g. Sachs und Warner 2001; Mehlum et al. 2006; Frankel 2010): The first focuses on increase in real exchange rates and crowding out of other export oriented industries, the second on the interplay between bad governance and rents from resources. Unless there is some level of sophistication reached with regard to good governance and corruption, specific strategies run the risk of becoming entrenched in the resource curse. Furthermore, the GLOBELICS thematic report put production of non-renewable raw materials by mining in the focus, and asked which integration strategies show promise of success. Combining the link of natural resources to environmental problems with their perspective for development, the following strategies evolve:

- Mining can build the basis for backward integration towards additional capabilities, which upgrade the mining technologies. These upgrading is necessary to increase productivity and to counter the lowering metal contents of ores on the one hand, but also to reduce the environmental burden of mining. This strategy builds on backward linkage of the value chain.

- Processing of ores from mining into basic goods can build the basis for forward integration. If we look at mining of metal ores, the first step of forward integration along the value chain would be the production of metals. This strategy also builds on a linkage from this first forward step along the value chain back towards competences in technologies which are necessary to perform processing.
- An efficient use of natural resources in the sense of material efficiency can also be interpreted as a specific form of integration. It is a forward integration, because the use of natural resources is further steps along the value chain of natural resources. Indeed, the disposal and recycling of materials belong to the last step of this value chain. It can also be argued that material efficiency strategies offer opportunities for lateral linkages of knowledge from primary raw material production. This is in particular the case for the production of secondary raw materials, which requires similar knowledge about material properties, and about technologies for separation of material from each other to the knowledge required at the beginning of the value chain.
- Production of renewable-resources can also build the basis for forward integration. If we look at renewable raw material, first step of forward integration would be the production of renewable materials as input into industrial production and of biofuels. This strategy also builds on a backward linkage from this first forward step along the value chain towards competences in technologies which are necessary to perform processing.

This papers aims at providing empirical evidence with regard to these four strategies of development based on natural resources. A national comparison of the capabilities of the major countries will provide indications about the form of linkages being developed. Furthermore, we will look to see indications that the build-up of competences is different for the different possible strategies.

2.2 Methodology

The general capabilities necessary for good governance in order to avoid resource curse are often characterized based on indices of corruption and good governance. We draw on the corruption perception index of Transparency International, which ranks countries based on how corrupt their public sector is perceived to be. It is a composite index which draws on corruption-indicators collected by a variety of institutions. The higher the index value, the less prevailing is corruption perceived. Furthermore, we look at data from Worldbank, which collects a dataset summarizing the views on the quality of governance provided by a large number of enterprise, citizen and expert survey respondents in industrial and developing countries. Based on these data, we build a composite governance index based on the average of the subset for the three areas “voice and accountability”, “political stability/no violence”, and “government effectiveness”.

In addition to general capabilities, specific competences for sustainability technologies are required. Measuring technological capabilities can draw on the experience with innovation indicators made over the last two decades (see Grupp 1999; Smith 2005; Freeman and Soete 2009). Patents are among the most used indicators in this kind of research. They belong to the intermediate output indicators of knowledge build-up and are directly related to technological capabilities. The choice of patent offices from which applications are taken is especially tricky for country comparisons, since patents also serve to protect markets, and it is therefore widely known that there are significant country biases in favour of domestic applicants which give highest priority to protect home markets. In order to account for country bias, the triadic patent approach has been developed in the 1990’s, which takes only patents into account which are applied for at the EPO, USPTO and JPO at the same time. Frietsch and Schmoch (2010) point to different methodological problems with this approach, especially with regard that this approach has problems to account for the effects of new players emerging on the international stage. Thus, Frietsch and Schmoch (2010) developed a transnational patent approach, which is also used for this paper. They count all PCT applications whether transferred to EPO or not, and all direct EPO applications without precursor PCT application. Thus, all patent families with at least a PCT application or an EPO application are taken into account. After testing and comparing different approaches, Frietsch and Schmoch (2010) conclude that this transnational approach provides larger samples than the Triadic approach for the analysis of specific fields, and is highly capable to grasp the relations between different countries more reliable. In this way, a method of mapping international patents is employed which does not target individual markets but is much more transnational in character. The patents identified in this way reveal those segments in which patent applicants are already taking a broader international perspective. The available data were retrieved from PATSTAT database. The latest year available for the analysis was 2013. Earlier periods for patents was used to describe the increase in patenting over the years.

In order to look at performance with regard to bringing innovation technologies to the market, we look at export data. International trade figures indicate the degree to which a country is able to compete internationally for specific technologies. The database UN-COMTRADE is referred to for trade figures. The classification of the technologies is using the Harmonized System (HS) 2002. This foreign trade classification allows more disaggregation and therefore a better targeting of the sustainability technologies compared with the older classifications common in international comparisons (Standard International Trade Classification SITC). The latest year available for the analysis was 2013. The trade data can be used to look on the performance of a country on the world market. On a more disaggregated level, it can be used to look into more detail how a country performs in trade with each other country. Both levels of analysis are taken within this paper. Especially dealing with the second research question requires country-to-country trade data.

For patents and world trade, the share of the selected countries at the world total was calculated (patent share, publications share, world trade share). Furthermore, the relative patent advantage (RPA) and the relative export activity (RXA) were calculated, in order to analyze whether or not the countries specialize on the sustainability technologies.

For every country i and every technology field j the Relative Patent Activity (RPA) is calculated according to: $RPA_{ij} = 100 * \tanh \ \ln [(p_{ij} / \sum_i p_{ij}) / (\sum_j p_{ij} / \sum_{ij} p_{ij})]$

i. e. the RPA relates the number of patents p for a given technology j in a country i to the worldwide patents for this technology. This ratio is then compared with the same ratio for al technologies.

The RXA is calculated in a similar way as the RPA, by substituting patents (p) by exports (x). All specialization indicators are normalized between +100 and –100 (see Grupp, 1999). Positive values indicate an above average specialization in the analyzed technology, a negative value shows that the country is more specializing on other technologies.

In order to focus on the four strategies pointed out above, the following approach is taken:

- The strategy of backward integration of mining to capabilities in mining is analysed by looking at the trade indicators for ores (success indicator for mining) and the patent indicator for mining (indicator for technological capability in mining technologies). Both indicators interpreted together give basis for analyzing the backward linkage.
- The strategy of forward integration from mining towards the next step along the value chain towards industrial production of basic materials is analysed by looking at the trade indicator

for ferrous and non-ferrous metals and the patent indicator for ferrous and non-ferrous metal production. In particular the latter also points towards capabilities of making basic metal production more energy efficient and environmentally friendly, and is important with regard to the link to the SDG.

- The strategy of forward integration of renewable resource availability is analysed by looking at the trade indicators for renewable resources and biofuels and the patent indicator for both fields. Both indicators interpreted together give basis for analyzing if the capabilities in the field of forward integration from agricultural production towards renewable resource production
- The strategy of circular economy is analysed by looking at the trade and patent indicator of technologies for recycling and material efficient production.

Especially with regard to patents, these technologies cannot be easily extracted from the database. Thus, for patents, we use an internal sustainability technology database, which also used specific key word based search strategies in order to derive patents for these technologies. With regard to trade data, there is a separate 6-digit level for some technologies. For some segments data, it was necessary to identify the key technological concepts and segments. They were transformed into specific search concepts for the publication, patent and trade data. This required substantial engineering skills. Furthermore, there is a dual use problem of the identified segments: the data only indicate that there is a technological capability which could be used for sustainability innovation – not necessarily that these technologies are already implemented in a way that the environmental burden is reduced.

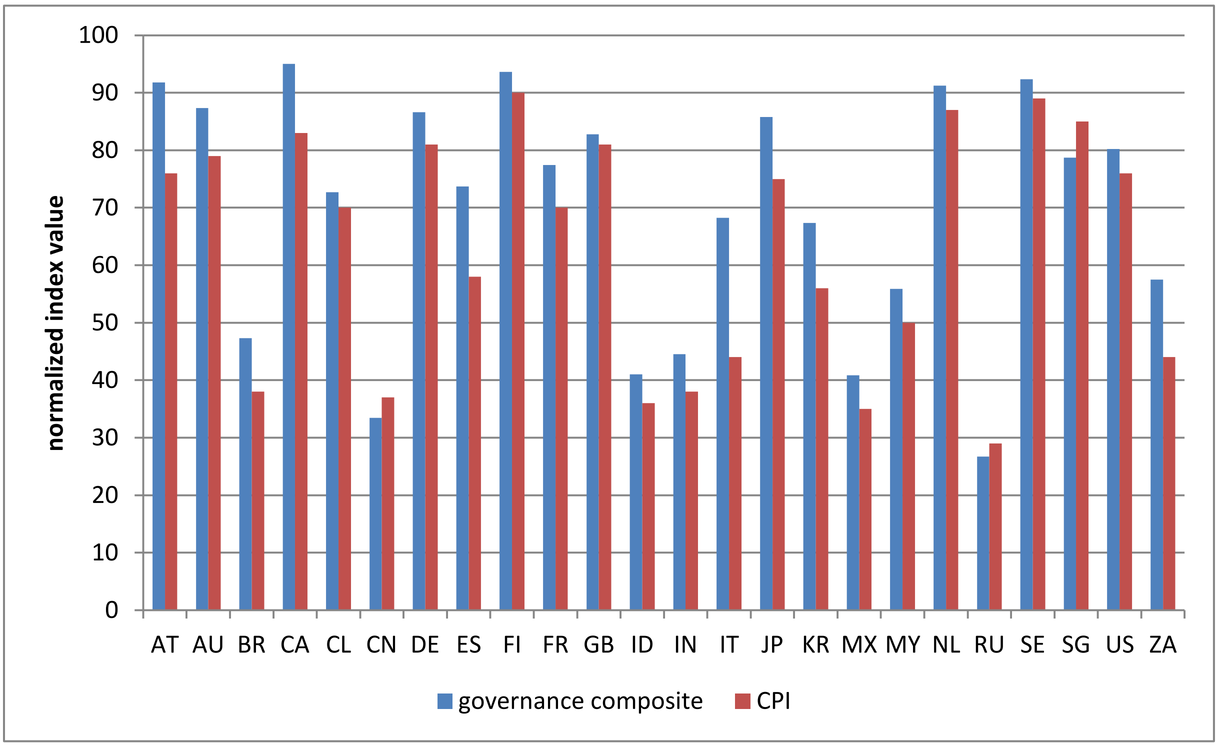
With regard to country coverage, we have selected a 24 country sample for performing the analysis. The sample consists of traditional OECD countries, typical emerging economies (BRICS plus Chile, Indonesia, Malaysia, Mexico), and also countries such as South Korea and Singapore, which are difficult to label as North or South. The rationale of this selection is also to look if we see patterns emerging, which support the hypothesis that linkages matter. Thus, we have chosen countries which already show a certain level of development. Developing countries, which often also natural resource availability, are not part of the country sample. However, by looking at the experience of the countries selected, we also want to gain further knowledge which might prove relevant for strategic positioning of developing countries.

3 General empirical analysis of capabilities

3.1 General governance capabilities

The results of the indicators describes in section 2 indicate that newly industrializing countries, in general, have lower indicator values for both Worldbank governance and Transparency International Corruption Indicator (Figure 1). Thus, empirical data seems to indicate a higher vulnerability for resource course in the emerging economies.

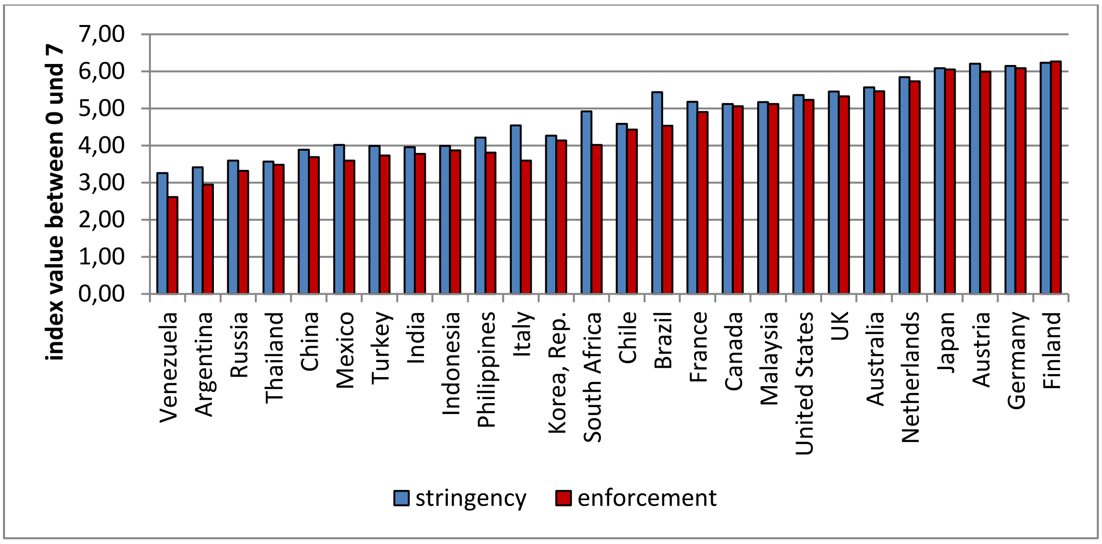
Figure 1 General innovation capability and technological readiness in selected countries



Source: Data from Wordbank and Transparency International 2015

Section 2 also indicated that natural resource based strategies are linked to environmentally related SDGs. Thus, the stringency with which the countries pursue environmental targets, and the enforcement of environmental policy, also act as indicator for successful demand stimulation within the innovation system. Various studies have shown that these factors are crucial for inducing innovation effects towards new or improved sustainability technologies. By and large, traditional OECD-countries still show a higher stringency and higher level of enforcement of environmental policy than NICs (Figure 2).

Figure 2 Stringency and enforcement of environmental policies



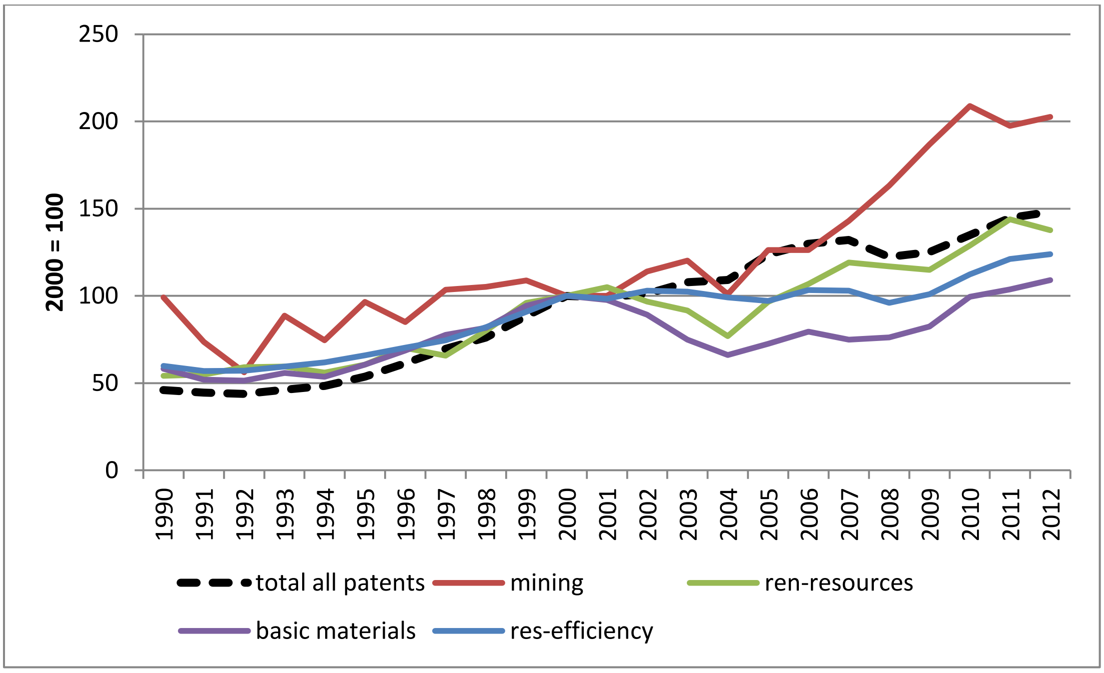
Source: Data from WEF 2015

3.2 Dynamics of capability for linkage areas of natural resource based development

We look at patents as main indicator for dynamics of technological capability (Figure 3). Only the dynamics for mining has been surpassing the general patent dynamics. The dynamics for the supply side of raw materials (mining and renewable raw materials) become stronger after the mid 2000s. For production processes of basic materials and resource efficiency, however, the dynamics actually slowed down in the first half of the 2000s and only keeps the same pace as the general development afterwards.

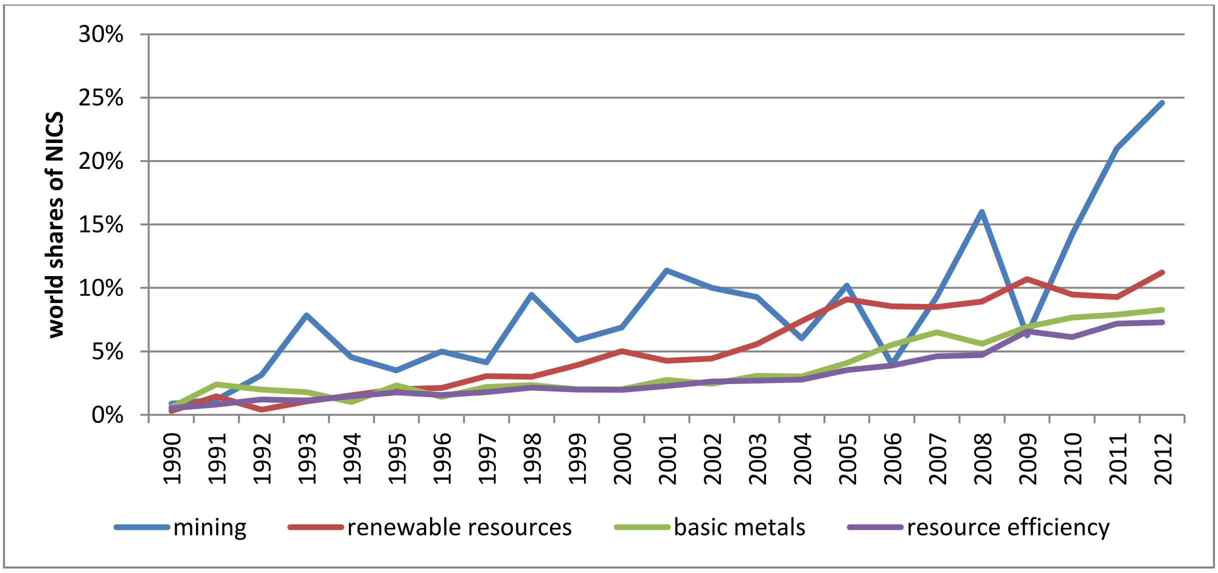
The accumulated shares of the NICs at the worldwide patents for the four fields for which we compiled patent data are shown inFigure 4. In each field, the share of NICs has been growing. Most impressive is the growth in patents in mining, with about 25 % of all patents originating in NICs in 2012. This gives credit to the claim that especially backward linkages show a promising perspective for natural resource based strategies. However, the data also shows fluctuations, and it has to be seen, if the increase, which has been most impressive only recently, will stabilize.

Figure 3 Patent dynamics for selected fields



Source: own calculation

Figure 4 Accumulated world share of NICs at patents for selected fields



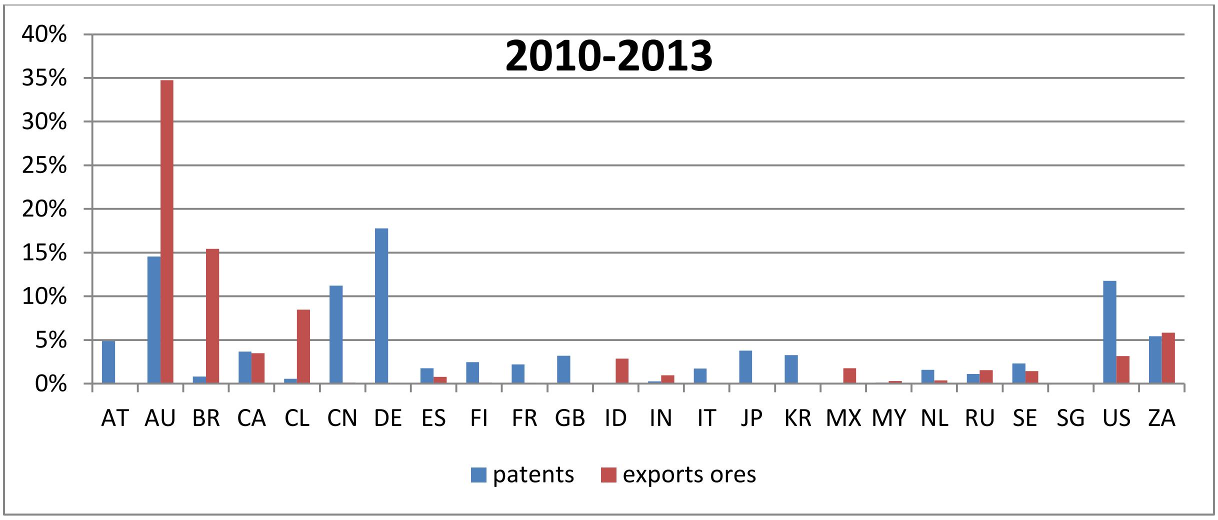
Source: own calculation

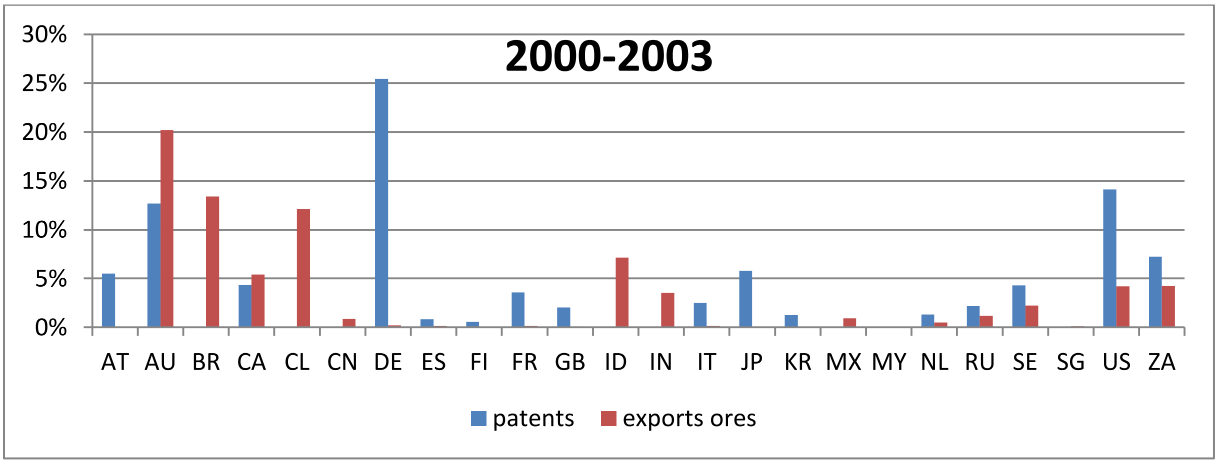
4 Mapping of specific technological capabilities

4.1 Backward linkage from mining ores to mining technologies

The main exporters of ores from mining are Australia, followed by the NICs Brazil, Chile and South Africa (Figure 5). Among traditional OECD countries, Canada, the US and Sweden can be mentioned. Additional countries from the NICs also play a role, such as Mexico, Indonesia and India. Major player with regard to patents is Germany, which is a low exporter and producer of ores. Australia is second, which underlines a strategy of backward linkage. China and the US follow. Additional countries with significant mining activities, which show considerable activities in mining technologies patenting, are Austria, Sweden, and South Africa. On the other hand, there are also countries which are not known for their mining activities which show considerable activities in mining technologies, e.g. Japan, Korea, and the Netherlands. A comparison between the lower and upper part of Figure 5 shows that the pattern of exporters has not changing much. The rise of NICs overall percentage can be explained mainly by the development of China. By and large, the share of South Africa has remained constant for both patents and exports.

Figure 5: World shares in metal ore exports and mining patents

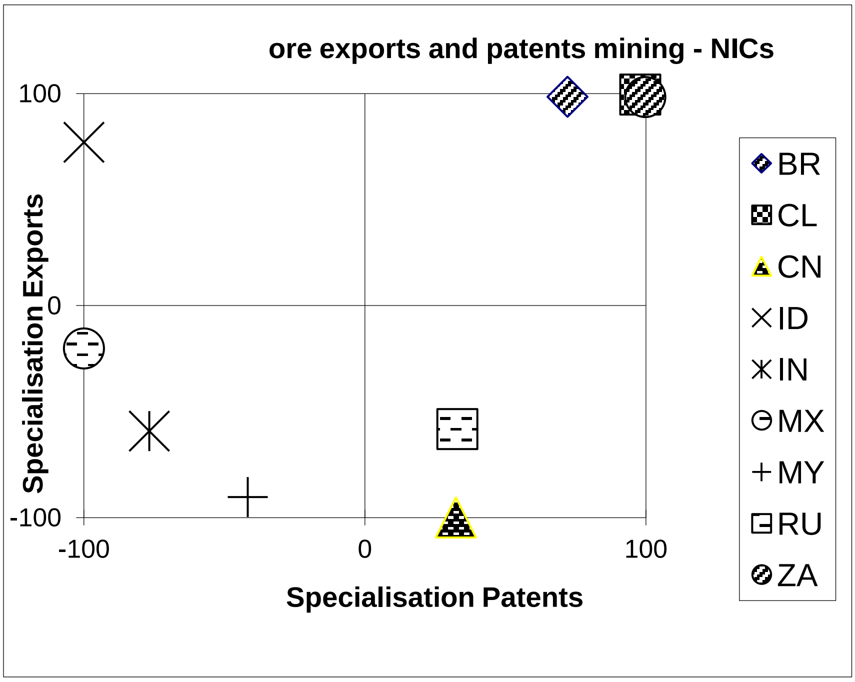




Source: own calculation

Looking at the size and development of shares hides the fact that these values are also influenced by size and general development of countries. Specialisation indicators are used which show the pattern of specialisation within the countries. Figure 6 shows the specialisation for mining patents and ore exports for the most important NICs and traditional OECD countries. Among NICs, the data for South Africa, Chile, and Brazil show a strong specialization for both ore exports and mining patents, which indicates a strong backward linkage. The results for Mexico, India and Malaysia are also in line with the argument about backward integration as a growth strategy: All three countries show negative specialisation with regard of ore exports, which is accompanied by negative mining specialisation. Russia and China both show a negative trade but positive patent specialisation. This can perhaps be interpreted with a combination of backward and forwards integration: Both countries utilize backward linkages, and at the same time integrate forward. Therefore they do not specialise on exporting ores, but on processed products (see section 4.3). Indonesia is a country which seems not to utilize on backward integration yet. It combines a strong specialisation in exports of ores with almost no level of patenting in mining companies.

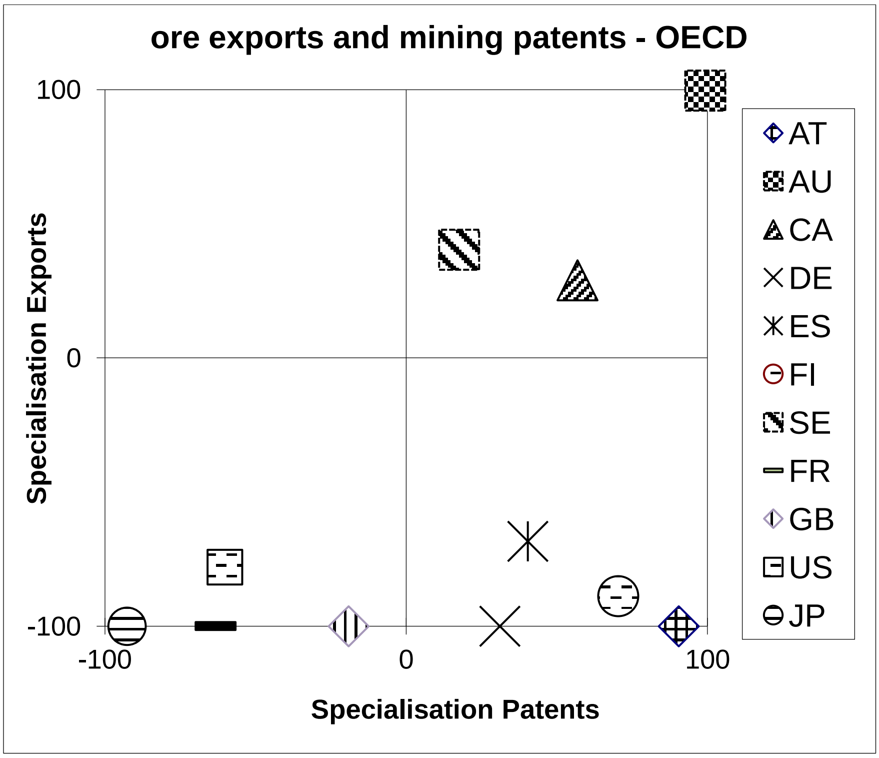
Figure 6: Specialisation profile for ore exports and mining patents for selected NICs



Source: own calculation

The traditional OECD countries also show a distinct pattern (Figure 7). The positioning of Australia, but also of Sweden and Canada fits the notion of backward integration very well. On we other hand, this notion can also explain that negative ore export specialisation goes hand in hand with negative mining patenting for Japan, France, and to a lower extent the UK and the US. More difficult to explain are the results for the counties with negative trade and positive patent specialisation. For Austria and Finland, the argument that they have both backward and forward integration seems to hold. For Germany and Japan, which show lower activity in domestic mining, it might be path dependency from past backward integration (Germany), or perhaps lateral integration from other areas of competences such as machinery, which also benefit mining technologies.

Figure 7: Specialisation profile for ore exports and mining patents for selected OECD countries

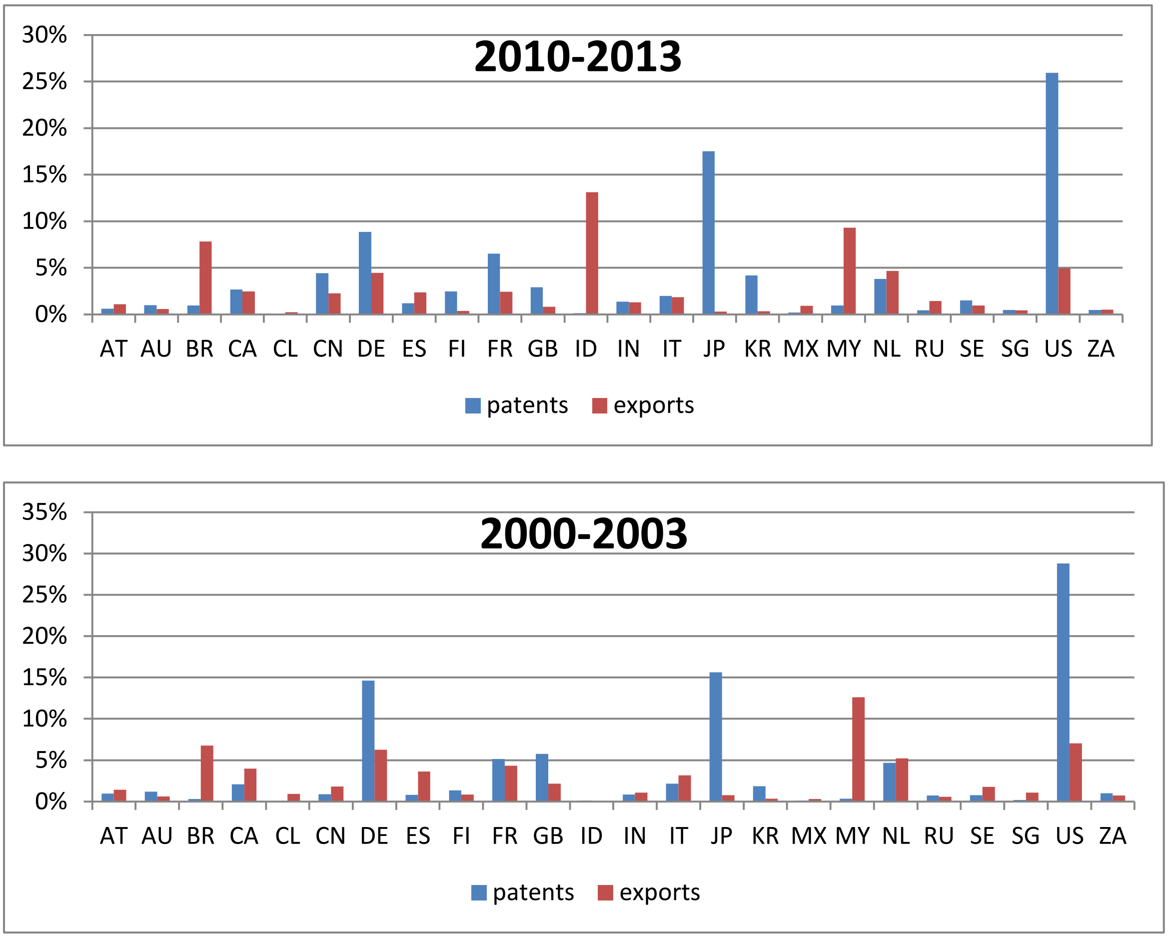


Source: own calculation

4.2 Linkage from production of renewable raw materials to natural resource technologies

The main exporters of natural raw materials (including biofuels) are from NICs (Figure 8). Indonesia, Malaysia and Brazil are accounting for about one third of world exports in this field. Exporters from traditional OECD countries are the US, Germany, and the Netherlands. With regard to patents, the US and Japan, followed by Germany and France, are the leading countries. Korea and China as countries with a South background follow. The data for the early 2000s does not show a much different pattern for exports (no data for Indonesia is available prior 2010). With regard to patents, most important seems to be the increase for China, Korea, but also – less obvious – for Brazil and Malaysia.

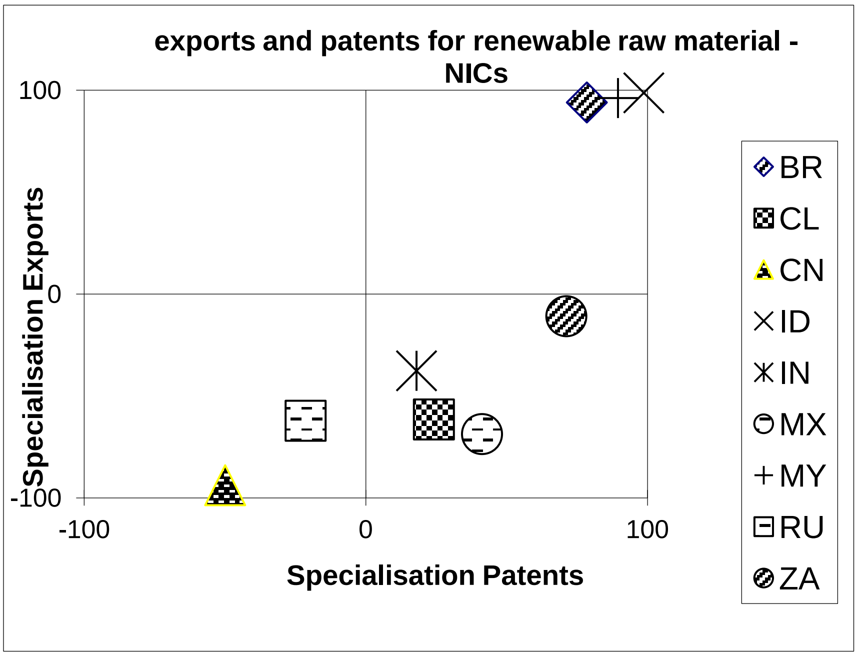
Figure 8: World shares in renewable raw materials exports and related process patents



Source: own calculation

Figure 9 shows the specialisation for exports of and for technologies relevant for renewable raw materials for the most important NICs. Among NICs, the data for Indonesia, Malaysia and also Brazil show a strong specialization for both exports and patents, which indicates a strong backward linkage. The results for China and to a lower extent Russia are also in line with the argument about backward integration as a growth strategy: Both countries show negative specialisation with regard to exports and technologies. The positioning of the other countries is more difficult to explain. The positive patent specialisation for India is mainly related to biofuels. For Chile, the results should be interpreted with caution, as the overall number of patents is not that high. For South Africa, an additional explanation could be path dependency originating as a legacy of the Apartheid regime, which had been driving technologies to make South Africa more independent from oil, and had resulted in technological paths towards coal and biomass to liquid.

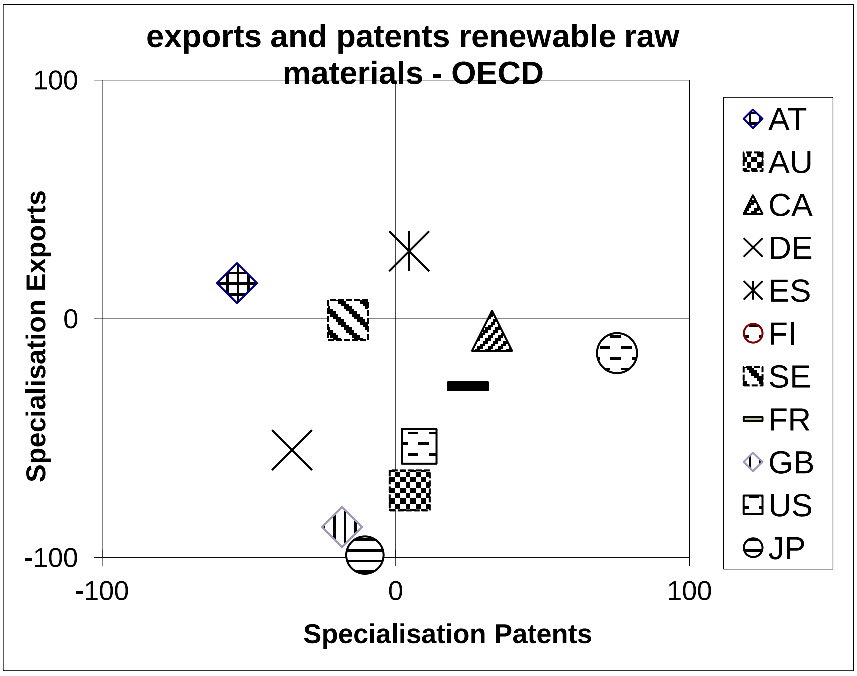
Figure 9: Specialisation profile for natural raw materials exports and patents for selected NICs



Source: own calculation

The specialisation profile of OECD countries, by and large, shows a rather negative specialisation profile for exports. This might be explained by environmental policies in these countries, which try to foster the use of raw materials, and which results in attractive home markets so that not much renewable resources are exported to other countries. With regard to patents, most countries show an average specialisation. Perhaps this can be interpreted as follows: Renewable resources might be an important policy topic and seen as a future field, but there are no strong backward linkages yet, and the activities rely more on lateral linkages. Finland could be seen perhaps as an exception, with the high availability of natural resources (biomass) as a driver for patenting activities in this field.

Figure 10: Specialisation profile for natural raw materials exports and patents for selected OECD countries



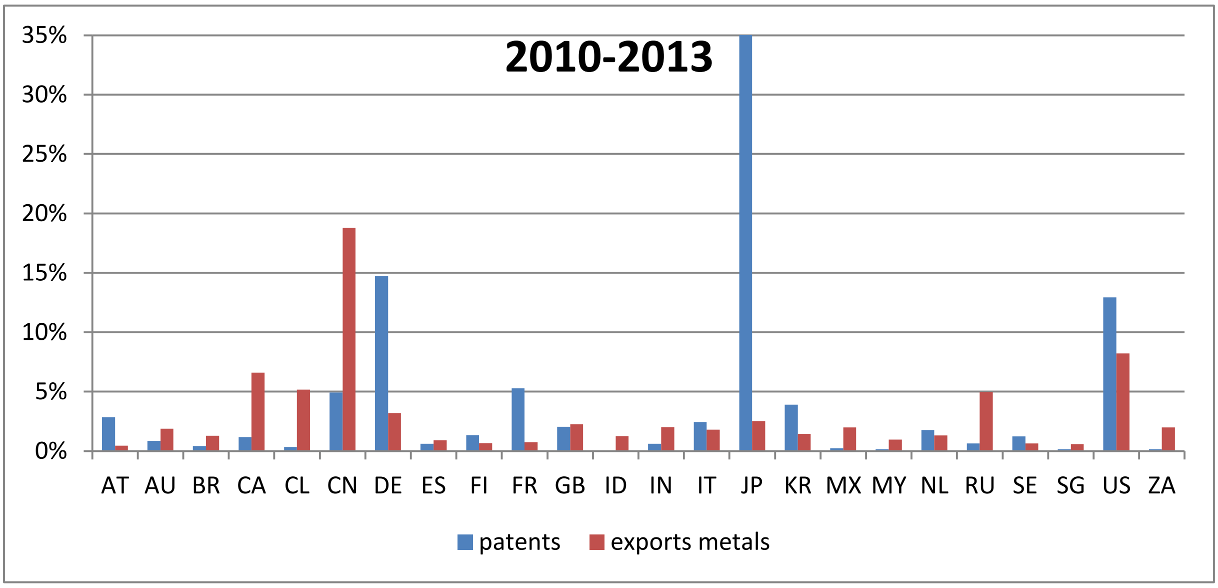
Source: own calculation

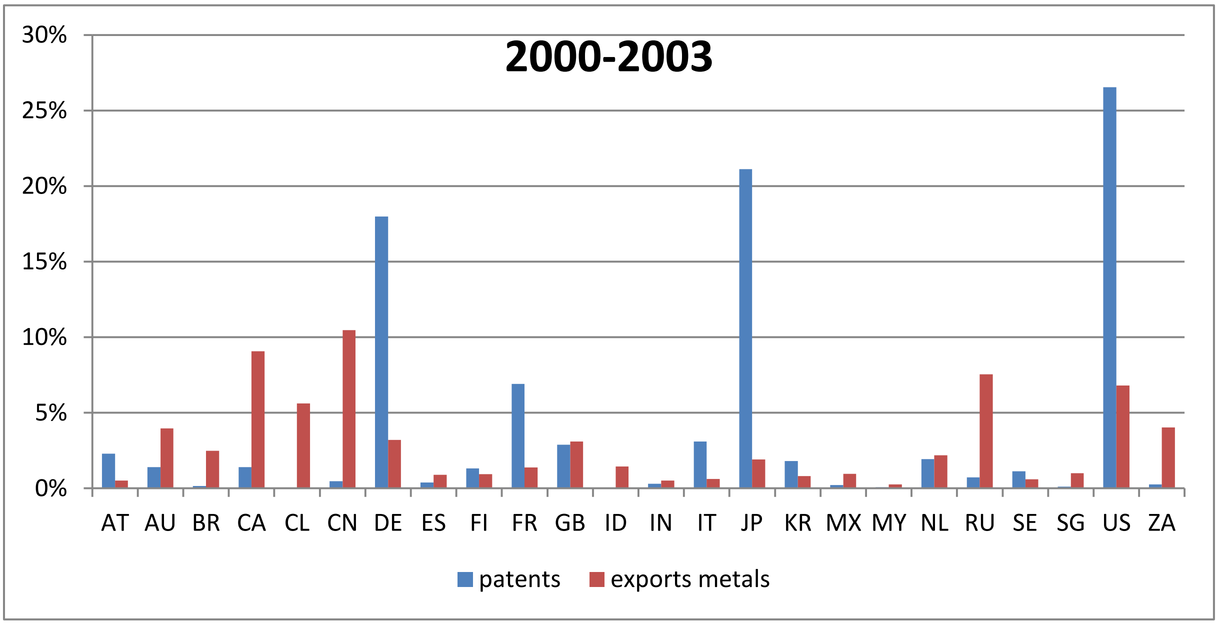
4.3 Linkage from production of basic metals to metal process technologies

The main exporters of ferrous and non-ferrous metals are China, followed by the US and Canada (Figure 11). Chile and Russia are additional countries among the NICs, which show a substantial share at world exports. Especially steel production has been diffusing internationally. Nevertheless, there a severe differences within process efficiency (Figure 12). The position of the countries is partly influenced by the share of electric steel production which uses less energy than the blast furnace route. The vertical distance from the red line which represents a mix of the most efficient blast furnace process (BOF, based mainly on iron ore) and electric arc process (EAF, based on scrap) shows the distance of a given country with the same process mix to the benchmark set by the most efficient processes. With a comparable process share a factor 2 - 4 with respect to the benchmark can also be observed here. Among the sample of countries, Venezuela, Russia, India, and South Africa are in particular positioned very far away from the benchmark. Some other newly industrializing countries, such as Chile or Turkey, have been moving towards the benchmark. Moving from the left-hand side of the diagram to larger share of EAF steel may also present an improvement in energy efficiency but this is more difficult to realize in some countries. Many NICs tend to have a stronger focus on electric steel processes because they represent smaller units which can be more easily managed and financed. On the other hand scrap, which is necessary as input for EAF steelmaking, is less easily available. This explains the position of countries such as China or Brazil more to the left-hand side.

With regard to patents, the traditional OECD countries Japan, US and Germany show the highest share. Around 60 % of all patents originated from these countries. They are followed by France, China and Korea. The most notable change over 10 years has been the rise of Japan to the very top, the increase of patents from China, which has been accompanied by a reduction of patent share from the US and Germany.

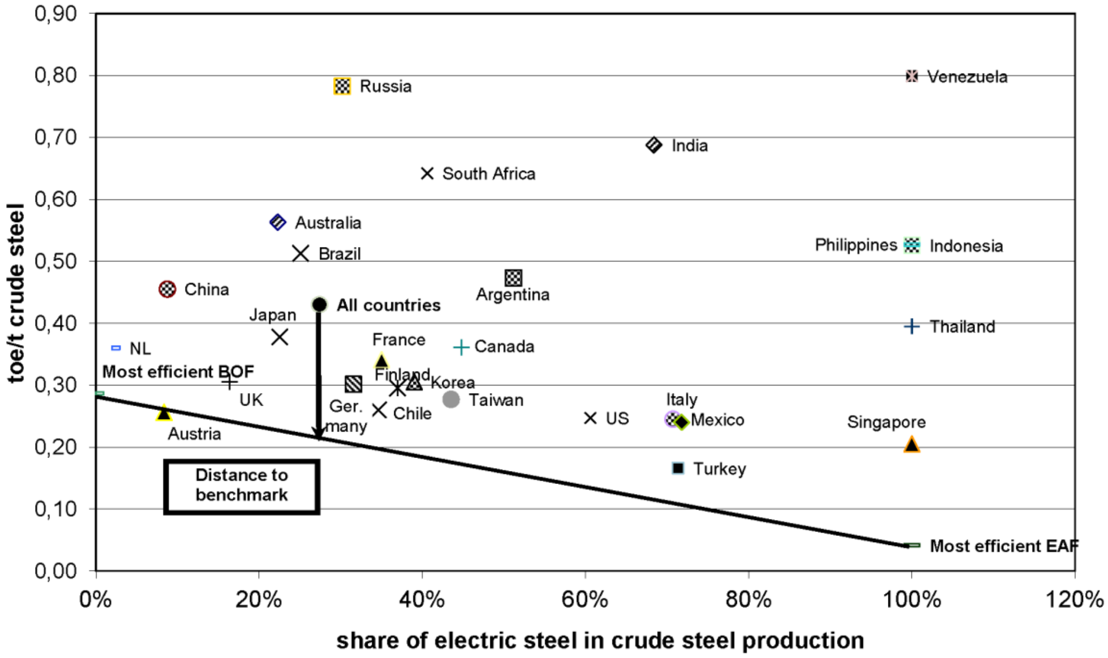
Figure 11: World shares in basic metal exports and related process patents





Source: own calculation

Figure 12: Unit consumption per ton of steel as a function of the share of electric arc furnace (EAF) steel in total crude steel production (2007)

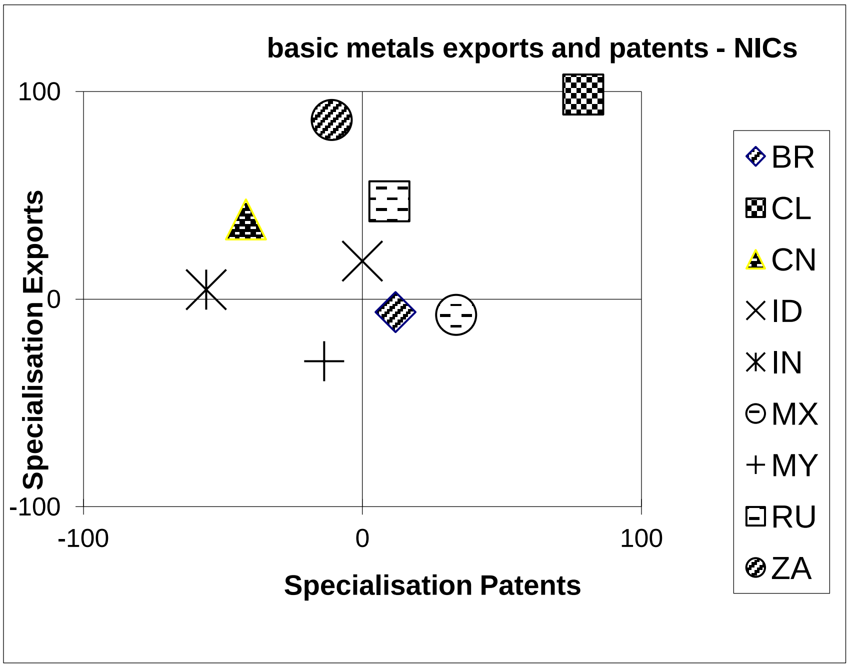


Source: adapted from Walz & Eichhammer 2012, based on Data from ENERDATA Global Energy & CO_2 Data (2015) Indeed, a look at the worlds efficiency in steel production shows that Indeed,

Figure 13 shows the specialisation profile for basic metal exports and patents for newly industrialising countries. Chile shows a pattern which indicates, that the forward link towards metal exports is also backed by process capabilities. South Africa, Russia, and China show considerable positive export specialisation. Their linkage to process technology competences is not pronounced. Thus, the position of South Africa, China and Russia, which show considerable strength in mining technologies, but not ore exports (see section 4.1) might be explained by success in forward integration (from mining to metal production), however without acquiring a strong backward link from metal production to related process technology competence.

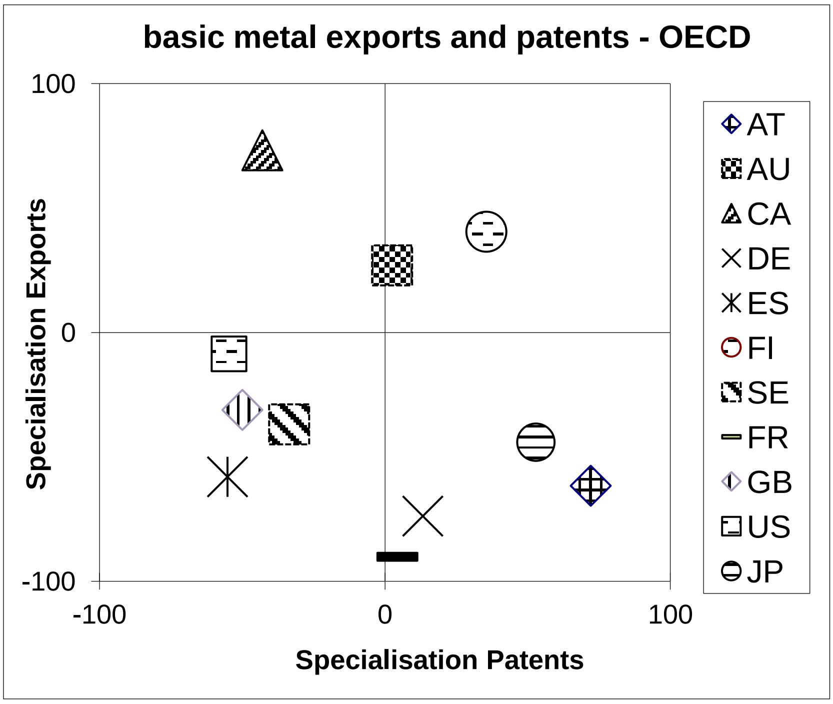
Among OECD countries, only Finland shows a positive specialisation in exports and process technologies. Thus, the positioning of Finland can be explained along the same lines as for Chile. Canada shows a very strong specialisation in exports. At the same time, it is experiencing a negative patent specialisation in metal process technologies. Thus, the positioning of Canada might be explained along the same lines as for South Africa, China, and Russia. In contrast, Austria and (to a lower extent) Germany show negative trade specialisation, but positive process technology specialisation. In particular the positioning of Austria, but also Germany and Japan, might be explained by a combination of backward integration into mining technologies with forward integration, which goes beyond the first steps of the value chain and focuses on further downstream activities (therefore negative exports of metals).

Figure 13: Specialisation profile for basic metals exports and related process technology's patents for selected NICs



Source: own calculation

Figure 14: Specialisation profile for basic metals exports and related process technology's patents for selected OECD countries

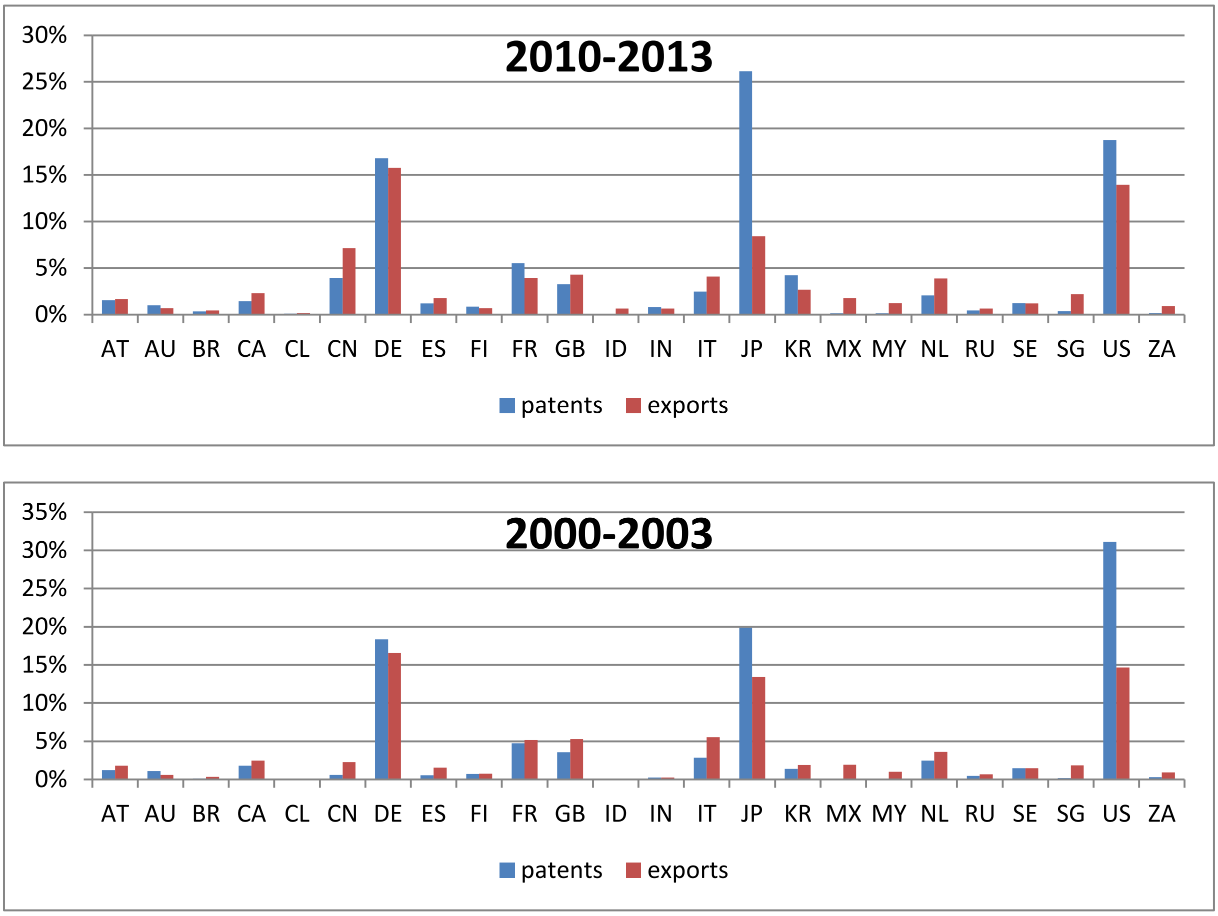


Source: own calculation

4.4 Linkage to material efficiency

This sections looks at indicators for the last step in the value chains: the efficient use of materials in production processes, products, and end-of-life. Patents and – to a lower extent – exports of technologies related to material efficiency are originating mostly in traditional OECD countries, especially Germany, Japan, and the US (Figure 15). Even though NICs have been increasing their share somewhat, material efficiency is still the field in which the distance between NICs and OECD is the biggest.

Figure 15: World shares in exports and patents related to material efficiency

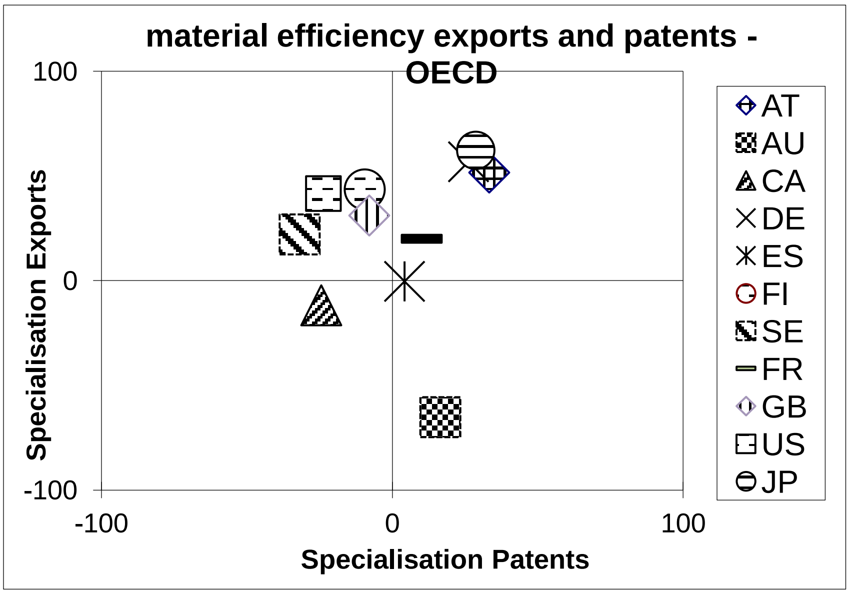


Source: own calculation

This pattern becomes even more obvious by looking at the specialisation profiles. There is no country from the NICs with positive trade and patent specialisation. Indeed, only one country (Chile) has a positive patent, another one (South Africa) a positive trade specialisation. Clearly material efficiency is not the focus of NICs yet.

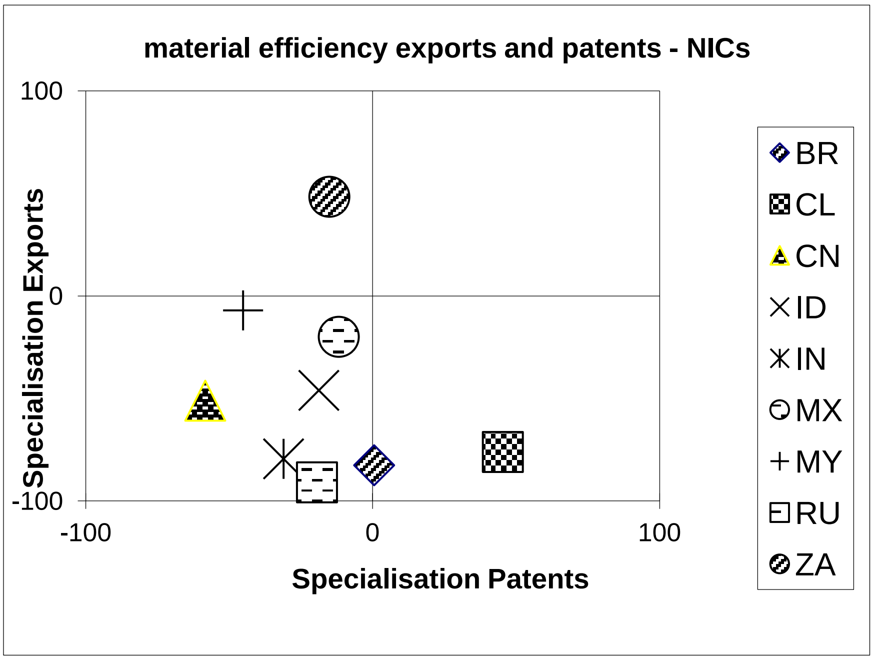
The situation is different for the OECD countries. Japan, Austria and Germany show positive specialisations for both patents and trade in this field. Interestingly it is exactly the three countries which were assigned a substantial forward integration beyond the first steps down the value chain in section 4.3. Thus, their position might be explained that the forward linkages reach even towards the end of the value chain. Furthermore, for Austria and Germany, this positioning is in line with lateral linkage of knowledge related to mining and mining technologies to the supply of secondary resources from recycling. With the exception of Australia, the other OECD countries show a lower specialisation. Australia is characterized by a low trade specialisation. If lateral linkage is important, Australia has not used its potential for building competences in material efficiency yet.

Figure 16 Specialisation profile for material efficiency exports and related patents for selected OECD countries



Source: own calculation

Figure 17: Specialisation profile for material efficiency exports and related patents for selected NICs



Source: own calculation

5 Interpretation of results and conclusion

The previous empirical sections have looked how the capabilities of different countries with regard to forming linkages between natural resource availability and innovations via different linkages have been evolving. In general, the NICs have been increasing their capabilities substantially. Especially with regard to mining technologies, NICs hold a world share at patent in the order of magnitude of 25 %. On the other hand, there is still a substantial difference in the ranking of NICs and traditional OECD countries in the governance indicators analysed. However, it remains unclear how much that poses a specific risk for natural resource based innovations. Indeed, it can be also argued that problems with regard to governance inhibit all forms of innovation which aim at development. The best innovation strategy cannot work if the political system does not accommodate it.

The bulk of the empirical work has been devoted to analyse capabilities with regard to the four forms of linkages which were identified:

- backward linkage of the value chain from performing mining to capabilities in coming up with new mining technologies;
- forward linkage down the value chain towards processing metal ores into metals, including the linkage from processing to capabilities in coming up with new process technologies;
- forward linkage to material efficiency, which is located at the end of the value chain, and which includes also the supply of secondary materials via recycling, plus the linkage towards capabilities in coming up with new technologies related to material efficiency;
- forward linkage of renewable natural resources towards processing renewable raw materials, including the linkage from processing to capabilities in coming up with new process technologies.

Looking at the empirical results, a heterogeneous picture emerges for the different countries: Some countries seem not to utilize linkage opportunities yet, others seem to be strong in establishing linkage in one area, some other countries seem to even perform a more integrated approach along the value chain. The following picture emerges for the most important countries:

country	Indication backward linkages non-renewable materials	Indication of forward linkage basic materials	Indication of linkage renewable materials
		NICS	
Brazil	Strong	No indication	Strong
Chile	Strong	Strong, linkage to process technologies	Unclear
China	Substantial, extends forward	Strong forward linkage to basic materials, but not to process technologies	No strong basis in renewable materials
Indonesia	No strong mining basis	No strong mining basis	Strong
India	No strong mining basis	No strong mining basis	partially
Mexico	No strong mining basis	No strong mining basis	Unclear
Malaysia	No strong mining basis	No strong mining basis	Strong
Russia	Substantial, extends forward	Strong, but not to process technologies	No strong basis in renewable materials
South Africa	Strong	Strong, but not to process	Unclear

		technologies	
Traditional OECD countries			
Austria	Substantial, extends forward	Strong forward linkage down to material efficiency, also to process technologies	No clear indication
Australia	Strong	Moderate, No linkage further down the value chain;	No clear indication
Canada	Strong	Strong forward linkage to basic materials, but not to process technologies	No clear indication
Germany	Unclear	Strong forward linkage down to material efficiency, also to process technologies	No clear indication
Spain	Unclear	No indication	No clear indication
Finland	Substantial, extends forward	Strong forward to basic materials, linkage to process technology	Strong
France	No strong mining basis	Weak indication for linkage to process technologies	No clear indication
Great Britain	No strong mining basis	No indication	No clear indication
Japan	No strong mining basis	linkage to process technologies and further down the value chain	No clear indication
Sweden	Strong	No indication	No clear indication
US	No strong mining basis	No indication	No clear indication

Perhaps the following general pattern is the most obvious:

- Among the NICs, Brazil, Indonesia and Malaysia seem to be able to form linkages from availability of renewable resources towards to process technologies.
- Among NICs, especially Chile seems to be able to span a set of linkage from backward to mining technologies until forward to metals and process technologies. Other countries, for which some forward and backward linkages are indicated, are China, Russia, and South Africa.
- Among NICs, the indicators do not reveal an indication that the linkage extends already until the end of the value chain and the supply of secondary resources.
- Among the traditional OECD countries, the linkages for renewable natural resources seem to be rather unclear. This indicates that other mechanisms are likely to dominate the specialisation patterns.
- Especially Austria and Germany seem to be OECD countries, which span a wide range of backward and forward linkages. Given that Austria is a small country itself, this points towards that even small countries can build such wide ranging linkages.
- OECD countries rich in non-renewable Resources, such as Australia, Canada, or Sweden typically show strong backward linkages.

In our interpretation, we have assumed that the respective pair of indicators point towards an existence of strong linkage if their respective values are both strongly positive. However, the interpretation of these results should be taken with caution, because these correlations do not necessarily translate in causation. Thus, additional interpretation about the background and framework conditions of countries, but also at interpreting the set of indicator value from a systemic perspective is necessary.

This also points toward the methodological conclusions, that indicator based analysis in this field should not be interpreted as stand-alone research results, but should form the basis for additional analysis. Clearly it will be necessary to back up the hypothesis emerging from the empirical results by further case study analysis of countries. Such an analysis has to unveil the perspective of different actors within the innovations systems of the countries, and should be able to look into additional drivers and barriers for establishing linkages.

However, even given all the uncertainties about interpretation of the data, it seems to be a robust conclusion that NICS are increasingly building competences especially in areas which are related to supply of natural resources. This increase in competences can be used to move closer to some of the SDGs related to natural resources. On the other hand, the traditional OECD countries are still in the lead especially with regard to the strategy of material efficiency, which is directed at reaching some other natural resource related SDG via a lowering of the demand for primary natural resources. This indicates the necessity of collaboration of North and South on the one hand. On the other, it shows that the different SDGs are not necessarily complementary, but that there will be trade-offs which require a careful balancing.

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