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Using lead market factors to assess the potential for a sustainability transition

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ABSTRACT

This paper considers how the lead market concept can contribute towards analysing system transformation as described by the multi-level perspective (MLP). Lead market arguments for the export potential of eco-innovations can provide an argument for policy support for environmental niches. International policy diffusion and learning across countries on the level of niche–regime interaction can improve the legitimacy of supporting policies. We propose how eco-innovation can be framed within an integrated MLP-lead market approach. Eco-innovations address two classes of regimes (infrastructure and eco-efficiency), which are likely to follow different transition pathways. The use of indicators for lead market factors for empirically analysing the opportunities for system transformation in the MLP framework is assessed. Indicators for the lead market factors can be attributed to the MLP. However, some of the indicators are more general in nature and do only indirectly point towards system transformation towards eco-innovations.

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1. Introduction

Markets for environmental friendly products and services have been recognised as major areas of growth in modern economies. An important argument in the policy debate is that countries which develop eco-innovations will be well placed to export goods into the expanding international markets for clean intermediate and consumption goods, thus securing economic growth and new employment. Indeed, policy concepts such as the lead market initiative of the EU are based on such a rationale, and the same line of argument can be found under the heading of economic opportunities of eco-innovations. The recent evaluation of the lead market initiative (CSES and Oxford Research, 2011; Edler et al., 2012) points towards the importance of accurately assessing the potential for lead markets, and various lead market factors are analysed to do so.

The debate about systems transformation has been also intensified recently in both the political and academic arena. Slogans such as energy transformation, or moving towards a green economy, have been put forward at national and international levels. Within academics, a community has been developing around transition research, with the multiple level perspective (MLP) being an important part (Grin et al., 2010). It distinguishes landscape, regime and niches. The landscape represents the broader picture of the slow changing socioeconomic system, the socio-technical regime consists of the established paradigm. A radical alternative often arises in a niche, before it starts to compete with the established paradigm. New research challenges have been identified to enhance MLP: the role of specific forms of agency, such as power struggles, is underdeveloped, and the research focus should move from analysing single technological niches in historic case studies towards taking the regime level more directly into the focus (Smith et al., 2010; Markard et al., 2012; Weber and Rohrschacher, 2012). Coenen et al. (2012) and Quitzow et al. (2013) point out that the different perspectives of MLP (niche, regime and landscape) are explicitly not geographical in their nature; the geographic locus of developments in the transition process is not addressed in detail, and a systematic treatment of how differing national-level dynamics interact is lacking. From a methodological point of view, it is acknowledged that the empirical focus of MLP, which has been on single case studies, could also benefit from the application of other empirical methods (Geels, 2011).

The concept of lead markets and the MLP are both heavily influenced by evolutionary economics, among others. Thus, there seems to be a good starting point for integrating these approaches by looking into the potential of using lead market factors for assessing sustainability transformations within a MLP. In order to do so, we analyse three aspects, which also contribute to further development of the existing state of the conceptual background:

- First, on a conceptual level, whether the lead market concept can contribute towards analysing system transformation as described by MLP; this also addresses the shortcoming of MLP with regard to including agency and space.
- Second, how eco-innovation can be framed within an integrated MLP-lead market approach; this approach can address eco-innovation not only on the niche level, but also more directly on the regime level.
- Third, whether or not the measurement of lead market factors also contributes to empirically analysing the opportunities for system transformation with MLP; thus, we are also addressing how to supplement a case study oriented empirical approach with an indicator based approach.

The paper is organised as follows: Section 2 starts with an exploration of the concept of lead markets. Following definitions of lead markets and eco-innovation, the factors are explained which are vital for establishing such a position. Section 3 starts with highlighting the most important characteristics of innovation. Based on this, the lead market factors and eco-innovation are put into the context of a multi-level perspective. Section 4 looks at measurement issues of the lead market factors, and how they can contribute to analysis within MLP. It deals with assessing indicators, and also contains empirical examples on what kind of information can be extracted from them. Section 5 finally concludes with a reflection on the use of the lead market factors for assessing sustainability transitions and identifies some areas of future research.

2. Lead markets for eco-innovation and competitiveness

2.1. Definitions

Lead markets in a narrow sense denote the country in which a later globally successful innovation takes off (Beise, 2004). This perspective concentrates on the factors which make a later globally successful innovation happen first in a specific country (Quitzow et al., 2013). However, the concept of lead markets plays also an important role in policy: countries, but also regions such as the EU aim at identifying areas in which they can establish a lead market through policy action. Furthermore, these markets should offer a strong economic potential with regard to becoming an important supplier of the technology (Edler et al., 2012). Thus, this concept links the narrow lead market approach to competiveness. In this paper, we use the term lead markets according to such a definition which links the perspective of lead market also to lead supply (Quitzow et al., 2013).

If realising an economic potential is the focus of a policy, domestic suppliers of eco-innovations – and not foreign suppliers – must meet the demand. Taking the globalisation of markets into account, this requires establishing competence clusters which build on specific national competitive advantages and are difficult to transfer to other countries with lower production costs. These competence clusters must consist of high technological capabilities linked to a demand which is open to new innovations and horizontally and vertically integrated production structures (Meyer-Krahmer and Reger, 1999; Quitzow et al., 2013). However, this concept is only applicable to technologies with certain characteristics, which form obstacles to international relocation. Key prerequisite for the application of the concept is that competition is driven not so much by cost differentials and the resulting attractiveness of international production location alone, but also by quality and/or performance aspects. Thus, especially goods which can be characterised as knowledge-intensive and showing a high innovation dynamics can form the basis for long-lasting first-mover advantages. Empirical results indicate that under these conditions, unit labour costs play a lower role in determining exports (Amable and Verspagen, 1995; Wakelin, 1998). However, knowledge is necessary not only to create, but also to maintain export advantages (Andersson and Ejermo, 2008). Especially if knowledge has high tacit components, the acquisition of capabilities in the relocation of knowledge-intensive production is more difficult (Archibugi and Pietrobelli, 2004).

The introduction of any new or significantly improved product (good or service), process, organisational change or marketing solution, that reduces the use of natural resources (including materials, energy, water, and land), and decreases the release of harmful substances are called eco-innovations. Thus, the purpose of developing these innovations must not necessarily be environmental, but they must result in a reduction of the environmental burden regardless what the cause of their development has been (Eco-Innovation Observatory, 2010). Very often, energy technologies related to climate change mitigation are of prime concern in the literature of eco-innovations. However, a more systematic classification of eco-innovations has to take the most pressing environmental problems into account (see European Environment Agency, 2012). Thus, in addition to global warming, innovative technologies are especially needed to reduce environmental pressure related to eutrophication, acidification caused by air emissions, toxic contaminations with heavy metals and polycyclic aromatic hydrocarbons, water stress, and use of material resources. The conversion of primary energy resources to final energy carriers (energy supply), but also the demand for energy from final energy user sectors and from transportation are the main sources of emissions which contribute not only to global warming, but also to acidification and toxic contamination of air. Water use and sewage discharge contribute not only to water stress, but also to eutrophication and toxic contamination of water. Material efficiency technologies contribute towards reducing consumption of material and related emissions. Thus, even though there is no final list of fields of eco-innovation, technological delineations of eco-innovations typically encompass innovative technologies which relate to 5 different technology classes (ECORYS Research and Consulting, 2009; Walz and Eichhammer, 2012):

- green energy supply,
- energy efficiency,

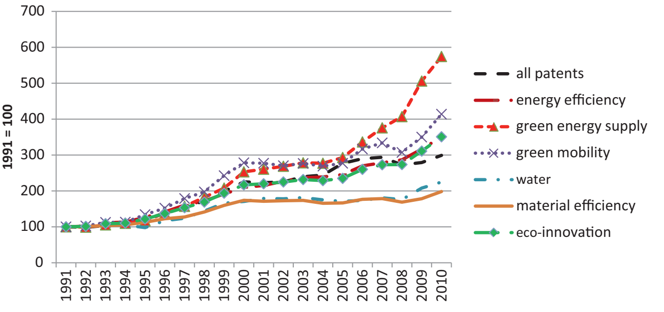

Fig. 1. Patent dynamics for fields of eco-innovations.
Source: calculations based on Fraunhofer ISI lead market database.

- green mobility,
- material efficiency (including handling of waste and recycling), and
- water related technologies.

Eco-innovations have been identified as a technology area where lead markets might be developed, going back to Porter and van der Linde (1995). Different empirical approaches show that eco-innovations are very likely to meet the characteristics which are necessary to establish a lead market position. A technological breakdown of eco-innovations shows that eco-innovations very often consist of technologies which are medium-to-high with regard to R&D intensity, or even high tech (Walz and Marscheider-Weidemann, 2011; Walz and Eichhammer, 2012). Technology forecasts, e.g. the Japanese Delphi study, the UK Foresight Programme or the German Foresight Process reveal that higher than average learning effects are expected for many of the eco-innovations. The patent dynamics for many eco-innovations are also impressive (Fig. 1). Thus, eco-innovations are a promising technology class for using indicators for capabilities and competitiveness to investigate the potential for lead markets.

2.2. Country factors for capability and competitiveness of eco-innovation

Following the literature on lead markets and first-mover-advantages, the following factors have to be taken into account when assessing the competitive advantage of countries with regard to global eco-innovation capabilities and competences (Meyer-Krahmer and Reger, 1999; Beise, 2004; Beise and Rennings, 2005; Walz, 2006; Quitzow et al., 2013):

- domestic market factors on the demand side,
- market factors on the supply side,
- innovation-friendly regulation in the country,
- technological capability of the country,
- structure of actors and competitiveness of related industry clusters in the country.

The importance of the market factors is emphasised by authors such as von Hippel (1988), Porter (1990) or Dosi et al. (1990). There are various market factors which influence the chances of a country developing a lead-market position. Beise (2004) and Beise and Rennings (2005) classify them in the categories demand and price advantage, market structure, and transfer and export advantage.

Among the market factors on the demand side, a growing domestic demand oriented towards innovations and readily supporting new technological solutions benefits a country in developing a lead-market position. One underlying mechanism is called price advantage. With growing demand, economies of scale drive the costs of the technology down. In the line of the work of von Hippel (1988) and Lundvall (1985), this effect is augmented by knowledge exchanged between users and producers during the use of the technology. This user-producer interaction leads to further innovations, which enable additional learning effects and further price advantages. The demand advantages focuses on the ability of a country to develop a market which takes up global demands earlier than others. It is linked to the concept of lead users, which are interested in novel approaches and willing to accept higher prices. Thus, quite often it is assumed that high income countries can support a higher percentage of new approaches. However, the situation might be different with regard to eco-innovations. They address a global societal need, which is much more triggered by societal concern and regulation than "normal" innovation. Thus, eco-innovations also open up the opportunity for other countries than the traditional high-income countries to establish a demand advantage.

The transfer and export advantages belong to market factors, which are on the supply side. The transfer advantage is based on a kind of demonstration effect (Beise, 2004). If countries show a high level of successful technological applications, they will find it easier to export their products. Thus, the transfer effect works in favour of countries which enjoy a high technological reputation. An export advantage results from the degree to which the preferences in one country are similar to the preferences on the world market (Beise, 2004). Thus, countries which are more open to the world will enjoy an export advantage compared to countries which are moving towards idiosyncratic solutions for their own market.

Regulation which at the same time is innovation-friendly and sets the example for other countries to follow the same regulatory path is another important factor (Beise and Rennings, 2005; Walz, 2007). This relates to different aspects: first, for eco-innovations, the demand depends very much on the extent by which regulation leads to a correction of the market failures which consists in the externality of the environmental problems (Rennings, 2000). Without such regulation, the demand will be much lower, and the various demand effects are less likely to be strong. Second, the national regulation should not lead to an idiosyncratic innovation, in other words an innovation that can be only applied under the very specific national regulatory regime. In contrast, the regulation should be open to diverse technical solutions, which increase the chance that they fit into the preferences of importing countries. Third, the national regulation should set the standard for the regulatory regime, which other countries are likely to adopt. Examples for this are product standards or testing procedures, which have to be fulfilled before a technology becomes classified as environmentally benign. If the procedure from the leading country is adopted in other countries, the national suppliers from the lead country have additional advantages on the world market, because they have adapted their technologies early on to pass the requirements of such a regulatory regime and have developed administrative capabilities how to deal with all the procedures. However, even though there has been some clarification of the mechanisms which make regulation an important parameter for a lead market, there is a lot of additional research necessary to develop a clear methodology on how to operationalise the empirical evaluation of an existing regulatory regime with regard to its innovation-friendliness.

The need for an innovation-friendly regulatory regime is especially strong for eco-innovations. They are very often applied in infrastructure fields such as energy, water or transportation, which are characterised by monopolistic bottlenecks. In these fields, the innovation-friendliness of the general regulatory regime, e.g. with regard to IPR or the supply of venture capital, must not only be accompanied by an innovation-friendly environmental regulation, but also by an economic sector regulation resulting in a triple regulatory challenge (Walz, 2007).

Since the Leontief Paradox and subsequent theories such as the Technology Gap Theory, it has become increasingly accepted that international trade performance depends on technological capabilities (for an overview see Dosi and Soete, 1988 or Fagerberg, 1995). Thus, the ability of a country to utilise a lead market for a first-mover advantage also depends on its comparative technological capability. If a country has a comparatively high knowledge base, it also has an additional advantage in developing and marketing future technologies.

Powerful economic actors, which drive future process and product development, are another success factor for establishing a lead market position. For developed markets, Beise (2004) points to the importance of a competitive market structure among the suppliers. However, it is more difficult to assess newly developing markets. There it is very often the existence of perhaps only a few actors at all, which indicate future innovation potential. The importance of social interactions and networks as basis for learning is also emphasised by the various concepts of innovations systems, which can be found on a national, sectoral or technological level. Interaction between enterprises and also between suppliers and users are an important element. Other important elements are interactions and networks between science and application, as well as integration into international value chains. It is widely held that innovation and economic success also depend on how a specific technology is embedded into other relevant industry clusters. Learning effects, expectations of the users of the technology and knowledge spillovers are more easily realised if the flow of (tacit) knowledge is facilitated by proximity and a common knowledge of language and institutions (Archibugi and Pietrobelli, 2004). Thus, the existence of strong domestic complementary sectors is another success factor. Indeed, there is strong empirical evidence that the international competitiveness of sectors and technologies is greatly influenced by the competitiveness of interlinked sectors (Fagerberg, 1995).

3. Factors for lead markets for eco-innovation in a multi level framework

3.1. Characteristics of the innovation process

The innovation process takes place in different phases. At the beginning of a radical innovation, a new configuration of the selection processes towards a dominant design are important, but also availability of diverse solutions to select from. In later phases, market formation and feedbacks between users and producers are becoming more important, and co-evolutionary processes in the societal subsystems (Safarzynska et al., 2012) supports further incremental innovations. However, these characteristics form a specific selection environment, which can support path dependencies and lock-ins (Smith and Raven, 2012; Foxon et al., 2013; for carbon lock-in, see Unruh, 2000).

Evolutionary thinking, and the notion of path-dependency and co-evolution are a feature of the multi-level perspective, which is advocated by scholars such as Kemp (1994), Geels (2002), Grin et al. (2010), and many others. The notion of co-evolution shows up at various levels of the multi level perspective (Fig. 2). It can be horizontal co-evolution within the regime between the established paradigm and institutions. Furthermore selection processes lead to an adaptation of strategies or routines of companies towards the paradigm. Co-evolution can also take place across vertical levels, e.g. the competition between the new and the established paradigm, with the latter using the surrounding institutions to fight the success of the new paradigm. However, it might also be that the landscape can support the growth of the niche.

Finally, if we look at ecological problems, we have also to consider that ecological systems and social systems also co-evolve (see Gual and Norgaard, 2010; Köhler, 2012). The state of the ecological system shows up in the landscape as environmental ethics and perceived importance of "nature" or "the environment". However, there are also physical interlinkages, with the regime and niche both having an impact on the ecological systems via emissions.

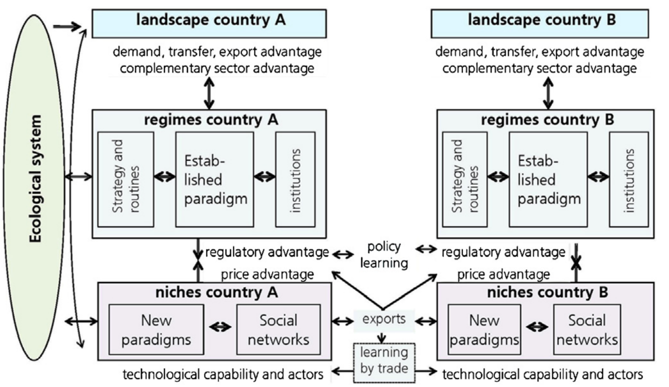

Fig. 2. Factors for capability and competitiveness for eco-innovation in a multi level perspective.

3.2. Lead market factors in the MLP framework

According to Geels (2002), niches gain momentum after a dominant design, powerful actors and networks have emerged. The concept of lead markets puts the focus at this process of gaining momentum. Thus, the development of lead markets can be interpreted as a specific phase of transition: the niche is growing, and starts to become an important economic component. It can be closely associated with empowerment, which Smith and Raven (2012) are advocating as a specific function of niches as protective space.

The MLP approach has been criticised in the past for being too functional, and not putting enough emphasis on power and actor aspects (Smith et al., 2005; Geels and Schot, 2007; Smith and Raven, 2012). Furthermore, it has been suggested that transition research needs to take space into consideration (Markard et al., 2012), and calls for integrating MLP with economics of geography are made. The concept of lead markets is related to both these aspects: the importance of power structures and political economy issues make green jobs an important part of the narrative supporting transition (Smith and Raven, 2012), and first mover advantages and export performance are a key factor in deciding whether or not net gains in employment are likely (Walz and Schleich, 2009; Walz, 2011). The lead market approach in our definition accounts for this, and in doing so simultaneously enlarges the scope towards different spatial entities. Thus, integrating the lead market concept into a MLP framework also adds to MLP with regard to accounting for political economy and the spatial dimension.

The starting point for our integration of the lead market approach into the MLP is the different lead market factors and the potential advantages discussed above. Fig. 2 describes how the factors at a country level can be related to the MLP framework:

- The price advantage describes the innovation and diffusion driven reduction in costs of technology; it depends on the speed of diffusion, and the functioning of the technological innovation system of the niche. Thus, this factor can be located at the interplay of the regime and niche, because it enables the niche to compete more effectively with the regime and move to a phase where diffusion accelerates.
- The demand advantage focuses on the ability of a country to develop a market which takes up global demands earlier than others. This also reflects a general perception in a country that sustainability characteristics are an important feature of technologies. In the context of the multi-level framework, this ability can be attributed to the landscape level.
- The transfer advantage works in favour of countries which enjoy a high technological reputation. With many options which are in their early phases, these aspects are typically not specific for a single niche alone, but are of a more general nature. Thus, they are more likely to be located also on the landscape level. However, with increasing experience with the technologies constituting the niche, it is more likely that the transfer and export advantage is determined by the performance of the niche technologies (e.g. demonstration that these technologies are working). These advantages would then be associated with the niche level.
- The regulatory advantage depends very much on sector and technology specific policies. They directly influence the niche, but are the key factors the regime can use to slow down the growth of the niche. Thus, they are the key factors in the interplay between niche and regime.
- The technological capability shows the level of competences the new paradigm has been able to develop. It describes the innovation performance of the niche.
- The development of actors and networks describes the level of development of key components of the innovation system of the niche. Thus, this factor can be located at the niche level.
- The strength of complementary sectors also adds to the technological capability and export advantage factors. However, it is located on the landscape perspective: it is rather slow to change, and is not directly influenced from the niche.

The widening of the lead market perspective to include innovation and first mover related export success also leads to interlinkages between the niches in different countries. The lower part of Fig. 2 illustrates this relationship: it is assumed that in country A and B the same niche is developing. The legitimacy of policies supporting niche development in country A increases, if similar policies are taken

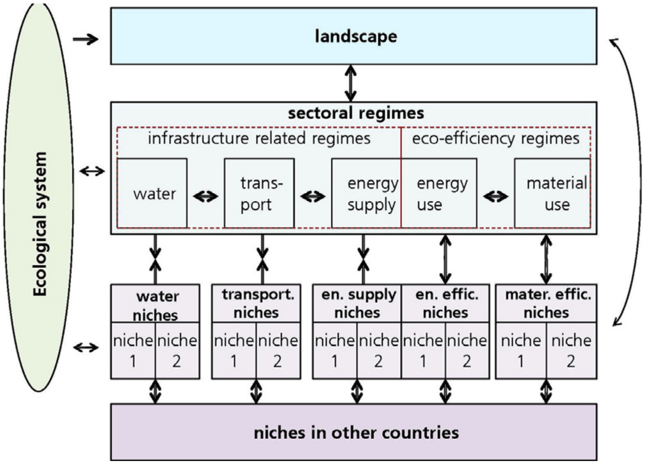

Fig. 3. Eco-innovation in MLP framework.

in other countries, e.g. in country B, and vice versa. Political scientists point towards policy learning between countries taking place, which leads to adoption of similar policies (Jänicke, 2005). Such a policy learning can be interpreted as a link between the interplay of niche and regime in one country to other countries, which influences the regulatory advantage in the other countries. Thus, looking at Fig. 2, country A might benefit from the experiences country B has already made with policies to foster a niche and to influence the regime, and vice versa. Diffusion of the niche in another country also leads to increase in technology demand, which is a prerequisite for export success of the first mover country. Thus, if country B follows country A in developing the niche, there will be increasing demand for the niche technology. If country A enjoys a lead supplier position, this increase in demand offers the potential for export success, which justifies the costs of domestic policies in country A to foster the niche. Exports from country A to B give further rise to the price advantage of country A versus country B. Furthermore, exporting leads to additional learning effects, which increase the technological capability of country A (for an overview of the literature on learning by exporting see for example Saggi, 2002; Keller, 2004; Wagner, 2007; Wei et al., 2008; Melitz and Trefler, 2012). Thus, the niche in country A will be strengthened, which will enhance its development versus the established regime. However, the interplay between the countries can also lead to obstacles to domestic niche development: if country B is successfully developing the niche, and at the same time is able to improve the competitiveness of its domestic suppliers of the niche technology, the lead market advantages of country A might erode. The likelihood of such a development depends on many factors, among them the ability of country B to absorb new technology and to build up skills (see for example Keller, 2004; Griffith et al., 2004; Kneller, 2005, Fagerberg et al., 2007; Fagerberg, 2010), and constitutes a research topic on its own which is beyond the scope of this paper. Nevertheless, if technology exports from country A are shrinking, or if even country A starts to import niche technologies from country B to support further development of the niche, the economic argument in favour of niche development in country A becomes weaker. Thus, with increasing niche development in other countries, it is more likely that new competitors will arise to the suppliers from the first mover country. Such a development can undermine the political rationale of a first mover advantage, and can strengthen the resistance of the regime.

3.3. Eco-innovations in a MLP framework: infrastructure and eco-efficiency sectors

Our definition of eco-innovation in Section 2.1 pointed towards a broad definition of eco-innovations, which, however, are related to different classes of technologies. Eco-innovations relate to the MLP schemes in two ways: first, single technologies form the core of a niche; second, the class to which they are related addresses the core of socio-technical regimes (Fig. 3). We also argue that there are common features of all the eco-innovation sectors which justify distinguishing them from other technologies. Eco-innovations share the double externality problem described by Rennings (2000). In addition to the regulation of protection of knowledge and R&D, which is classified by Rennings (2000) as the first regulatory challenge, eco-innovations in addition also face the externality of environmental costs. There is not much demand for eco-innovation, unless some form of environmental regulation leads to a level playing field between new and old, environmentally more harmful innovations. Thus, demand is highly policy driven, and policies such as standards, emissions trading systems, feed-in-tariffs or quota systems are simultaneously both environmental and demand led innovation policies. Furthermore, changes on the landscape level such as increasing environmental awareness, changing perceptions of man-environment relationships, or development of a political system more adept to green issues effect all the eco-innovation technologies. Thus, the different regimes and niches of eco-innovations are all affected by the same specific changes on the landscape level.

We propose that eco-innovations address two classes of regimes: infrastructure related regimes and eco-efficiency related. The specificities within each class leads to similar selection environments. Furthermore, Geels and Schot (2007) have been proposing that depending on the state of development and the timing of transformations taking place, the interplay between niche and regime can lead to different transition pathways. We also argue that the transition pathway within each of these two classes is likely to be similar, but different between infrastructure related regimes and eco-efficiency. Following Geels (2011), who points towards influences from other regimes on the focal regime being an understudied but promising topic, we expect to see that there are positive influences from one regime to the other within each of these two classes.

The first class relates to the more infrastructure related regimes in the left-hand side of Fig. 3. These regimes and related technologies share the following specificities:

- Asset durability: a lot of the infrastructure related technologies are characterised by a very long lifetime (e.g. power stations, investments in related infrastructure such as electricity or water grids, roads and rail). Thus, the high asset durability limits the opportunity for reinvestments. Furthermore, the investments in infrastructure related technologies tend to be very capital intensive (Markard, 2010). Thus, it would be very costly to substitute them before they have reached their end-of-life. Both factors support “technical path dependency” and technological lock in.
- Technical systemness of physical networks: if the technologies are physically connected with each other, via a grid, technical systemness (Markard, 2010) increases path dependency. Problems of integration of renewable electricity supply, for example, can arise from a grid structure which is optimised towards the existing carbon intensive power system. If the grid structure is not suited, even large investments in low carbon electricity supply do not necessarily increase the market share of low carbon alternatives, unless they are supported by vast investments into a new grid structure. Thus, the specific features of technical systemness lead to a comparatively high level of path dependency.
- Cultural significance: access to energy, water and transportation are all related to basic needs, which shows up, for example, in their prominence among the future global challenges.
- Monopolistic bottleneck: despite the call for deregulation and liberalisation, it is still acknowledged that monopolistic bottlenecks characterised by both sunk cost and natural monopoly cost functions should be regulated. Clearly, infrastructure systems based on physical networks such as electricity/gas, water supply and sewage treatment, or railways include such a monopolistic bottleneck. Even potentially competitive stages, in general, require access to the monopolistic bottlenecks. This also holds for power produced by independent power producers, e.g. the operators of renewable energy, or railway operators. However, the way of economic sector regulation also influences the speed and direction of related technology innovations. From the point of view of innovation, these infrastructure sectors pose a third regulatory challenge (Walz, 2007).
- Actor structure and political economy: infrastructure innovation systems are characterised by a specific structure of actors. The incumbents which drive the existing regime, such as public utilities or multinational energy companies, are typically very powerful and sometimes influence government. Many of the actors which drive the niches, however, are small and medium enterprises, and are often newcomers. However, in addition to this actor constellation – which can also be found for

other innovation systems – there are also community based groups and NGO-type actors, which are among the key proponents for eco-innovation niches. This reflects the characteristic of infrastructure systems as a social need, which cannot put to individual market based decisions alone. To sum up the argument, important actors in infrastructure innovation systems are different from the typical actors in other innovation systems. Thus, it can be expected that their behaviour also differs. Furthermore, the regime-niche constellation can be characterised as an arena with a very uneven power structure: large companies, which profit from existing lock in, sometimes directly linked to government, versus drivers of eco-innovation, which very often are not part of the established innovation system, and do neither possess capital reserves nor experience in upscaling innovation.

These specificities of infrastructure technologies point towards the regime being rather strong. This leads us to expect that a transition pathway which Geels and Schot (2007) have called "technological substitution", will emerge more often: radical innovations have developed in niches, but remain stuck because the regime is stable and entrenched. Only after strong disruptive changes in the landscape the regime will be challenged. Strong growth of the niche, brought forward by policy measures, might prove to be expensive, which again reduces the legitimacy of further growth of the niche. In such instances, the narrative of transition typically points towards future cost degression of the niche technologies (Smith and Raven, 2012). The link to niche growth in other countries can strengthen such a narrative: export success in the radical new technologies becomes an important argument to counterbalance the critique of rising economic costs. If the niche technologies promise to reduce or even to phase monopolistic bottlenecks, this can also add to further bolster up the transition narrative.

Energy efficiency and material efficiency niche–regime relations form a second class, which typically differs from the case of infrastructure. Especially with regard to costs, there is a significant untapped potential of low cost energy and material efficiency, which has been named no-regret potential in the policy debate. Evolutionary economics point out that decisions within companies are the result of a complex process, which is characterised by multifunctional network structures with differing objective functions, spillovers between the individual sectors, limited information processing abilities and bounded rationality. As a consequence, there is the possibility to bring about substantial efficiency improvements. There are arguments that these inefficiencies are particularly pronounced in energy and material efficiency (Walz and Schleich, 2009). The specific selection environment is shaped by consumers putting more emphasis on the amount of the purchase price, and less on total cost of ownership. Such behaviour is supported by information asymmetries, and by energy and materials being a derived demand, which is hidden behind the functionality of product features. The routines for energy and material decisions are only slowly changing: many decisions with regard to energy and material still reflect the framework conditions of the 1990s, which has shown declining energy and raw material prices, and the complexity of issues such as long-term development of energy and raw material prices, which are also heavily influenced by policy making, make adaptation of routines more difficult.

Innovations, which increase the energy or material efficiency of existing technologies, or lead to new process steps, leave many of the existing technologies or products intact. High efficient lighting and insulation of houses, for example, do neither phase out suppliers of technologies, nor change the constructing business altogether. The relationship between niche and regime is much more symbiotic, and transition pathways are likely to follow much more often transition pathways which Geels and Schot (2007) have labelled as either "transformative" or "reconfiguration".

4. Meso-level measurement of factors for lead market

In Section 3, we have argued that lead markets can be an important element in the political debate about policies supporting a regime shift. However, this requires that the opportunities for each country, to benefit from a lead market position, can be backed up with evidence based analysis. Thus, the issue of measurement of lead market factors becomes a crucial point for utilising a lead market argument in the political economy. Given the logic of the lead market argument, such a measurement must be comparative in nature between different countries. Furthermore, we have shown in Section 3 how the different factors integrate into a MLP approach. Thus, by measuring lead market factors we might also gather information which relate to comparing countries with regard to state and opportunities for niche growth and regime shift.

So far, empirical analysis with MLP has focused on case studies, with the niche being very often in the focus of delineation of the system (Smith et al., 2005; Genus and Coles, 2008; Geels, 2011). The lead market approach has been used for case studies of single technologies, too. However, it has also applied indicators (Beise and Rennings, 2005; Walz, 2006; Quitzow et al., 2013), and the focus of analysis has also been shifting towards more aggregated classes of technology, such as in the European lead market initiative. Thus, the experience made in building innovation indicators on that level (Grupp, 1999; Freeman and Soete, 2009) can also be used for our purpose. Furthermore, the political debate on the economic benefits of technologies is more likely to unfold on the level of aggregate technology niches related to a regime shift, than on a single technology niche. Thus, the measurement of lead market factors on an intermediate level becomes important. Therefore we look in this section on the following aspects:

- Availability of indicators: for which lead market factors are indicators available? Do we have evidence on their robustness? Can we extract the development of indicator values over time?
- What is the level of aggregation of these indicators: are they directed to a larger set of technologies than eco-innovations, to the aggregate of all eco-innovations, to the level of one of the regimes, or even to a very disaggregated level of single technology?
- Relation to MLP: are the indicators directly measuring growth of the niche or regime shift, or is the relation more indirect, by measuring the opportunities to establish lead markets which benefits the political economy towards niche supportive policies?

In addition, we illustrate the results of available empirical material, in order to figure out what picture about which countries are more likely to develop lead markets in eco-innovation fields emerges from the available data. The countries chosen for this illustration reflect the most important countries with regard to the indicator values for both OECD countries and emerging economies. The abbreviations used refer to standard ISO country codes.

4.1. Domestic market factors on the demand side

The price advantage indicates the extent to which an increase in demand drives down costs and enables suppliers to reduce prices. A typical approach to assess the reduction in costs as a function of increasing demand, are learning curves. However, the values are very technology specific. Overviews on renewable energy technologies show already substantial differences within this one segment of eco-innovations (see McDonald and Schrattenholzer, 2001; Berglund and Söderholm, 2006; Köhler et al., 2006; Uyterlinde et al., 2007). Typically, learning rates between 10% and 30% are assumed, which lead to a vast difference especially for technologies in their earlier phase of development. However, it is also criticised that learning curves systematically underestimate the learning rates for established technologies (Pan and Köhler, 2007; Jamasb and Köhler, 2008). To sum up the argument, it is difficult to assess the price advantage already for a single technology, and given the differences between technologies, it not possible to assess it for the aggregate level of eco-innovations.

The demand advantage is attributed to countries where society and markets are more open than others towards future challenges. Eco-innovations are tackling a global need: reducing the environmental burden to strive towards sustainability. Thus, countries forging ahead with regard to taking sustainability issues into account can be ajudged in general to have a demand advantage. In Section 3.2, we have related this to the landscape level. However, there are still problems in assigning which countries are forging ahead. The measurement has to take into account the perception of the population. This requires the use of surveys. Typically, surveys are conducted either as population survey or as expert survey. The latter claim a higher level of information among those surveyed. Furthermore, expert surveys might allow for more intensive communication about goals and definitions of the items surveyed, due to smaller numbers of people to be surveyed. Well known among the expert surveys of the importance of environmental concern are the data from the World Economic Forum (WEF, 2008). This data shows the general consideration of social and environmental criteria by the actors

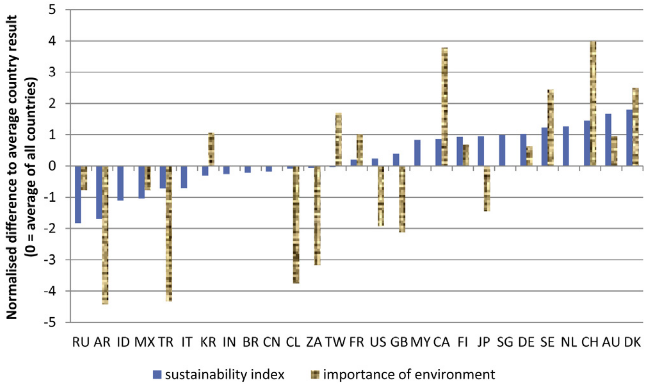

Fig. 4. Sustainability index.
Source: normalised data from Peuckert (2011) and Smith (2013).

within their decision processes, i.e. the societal anchoring of the sustainability concept as a leading principle in the technological development process. However, it has to be kept in mind that basis for these results are subjective estimations of the interviewed experts. Thus, the robustness of this data also depends on the reliability of the chosen design for sampling the raw data. Relying on this data, Peuckert (2011) has constructed an index. For this index, 55 countries are taken into account, comprising OECD countries as well as NICs, and a few developing countries for which the indicator values are available. The index values are normalised in a way that a value of zero indicates that the general innovation capabilities of a country are estimated to be at the average of all 55 countries included in the survey. Fig. 4 shows the resulting values for selected countries. Based on this approach, countries such as Denmark or Austria could be assigned a certain demand advantage.

In general, population surveys about the importance of environmental issues in countries, confirm, that wealthier countries express higher concern for environmental issues (Gelissen, 2007; Franzen and Meyer, 2010). Results from NORC (2013), for example, show the same tendency, with Canada, Switzerland and Scandinavian countries showing the highest concern for environmental problems. The differences in the importance of environmental problems between the countries (normalised between −5 and +5) is also shown in Fig. 4. Compared to the results of expert surveys (sustainability index), there are significant differences between the ranking of countries resulting from population surveys. Chile and South Africa, but also the US and Great Britain, show weaker importance in the population survey, compared to the expert survey. These differences clearly point towards the limitations in the robustness of these indicators.

4.2. *Market factors on the supply side*

The transfer advantage depicts a demonstration effect and also depends on the technological reputation of the country. If countries are assigned a high technological reputation, they also have a transfer advantage. The expert opinion surveys of the World Economic Forum (WEF, 2008) also contain questions, which point towards technological reputation. Using factor analysis, Peuckert (2011) constructed an index which condenses the results for the different questions. According to his results, Germany and Finland could be assigned a certain transfer advantage. Furthermore, he analysed the robustness of the indicator and derived highly significant correlation between similar indexes such as the World Economic Forum's Innovation Factor and the Global Innovation Summary Index. These indicator approaches, however, do not exclusively look at eco-innovations, but are directed to other high-tech innovations as well. Thus, their value for explaining specifically opportunities for eco-innovation is limited, and they cannot contribute to indicating whether or not there is pressure on the landscape towards a regime shift (Fig. 5).

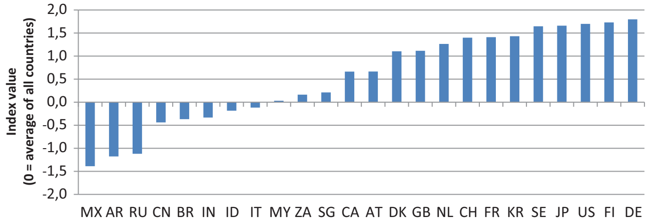

Fig. 5. Indicators for transfer advantage: index of technical competence.
Source: Peuckert (2011).

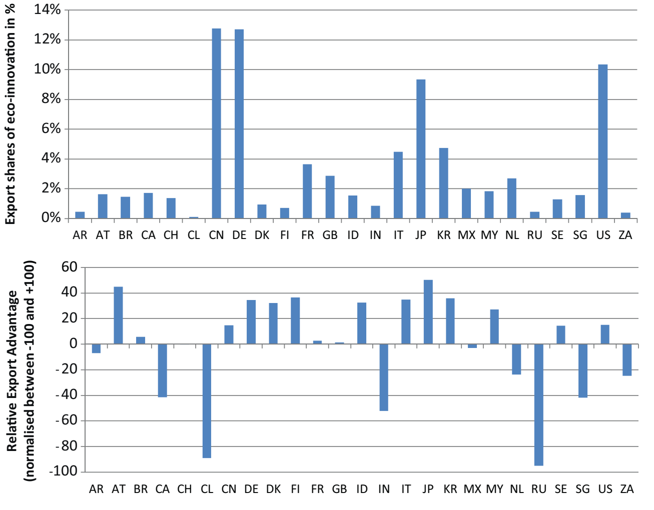

Fig. 6. Indicators for transfer advantage of eco innovations: trade figures.
Source: calculation based on Fraunhofer ISI lead market data base.

A more specific indicator is the use of trade statistics. If there is already significant trade in the analysed technology classes, the demonstration effects also shows up in the amount of technology exports each country is achieving. Thus, the share of exports at world exports is also used as an indicator for the transfer advantage. A classification of eco-innovations in the trade statistics has been developed and builds an important piece of the Fraunhofer ISI lead market database (Walz, 2010 and Walz and Marscheider-Weidemann, 2011). The classification allows an analytical level on the 6-digit level of the HS system. Using this classification, we derive indicator values for various levels of aggregation. Fig. 6 shows the aggregated export shares for the countries for the aggregate of eco-innovation. Germany and China are leading, closely followed by Japan and the US. However, looking only at export shares results in a large country bias. Therefore typically specialisation measures such as the Relative Export Advantage (RXA) are used in addition.[2] A positive value indicates that a country is specialising on eco-innovations. Thus, eco-innovations have already achieved an above average importance, which gives them a higher weight in the political economy shaped debate. Among the countries with the highest export shares, Germany and Japan have been also specialising on eco-innovation, which is not the case for China and the US. A more detailed analysis of the 5 technology classes, which are related to the 5 socio-technical regimes important for eco-innovations, indicate that there are some differences in the

[2] For every country i and every technology field j the Relative Export Advantage (RXA) is calculated according to: $RXA_{ij} = 100 \times \tanh \ln[(x_{ij}/\sum_i x_{ij})/(\sum_j x_{ij}/\sum_{ij} x_{ij})]$.

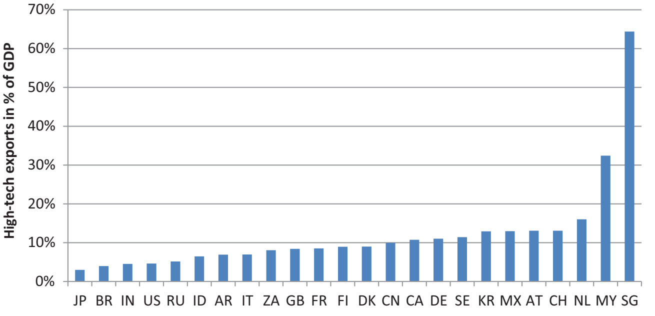

Fig. 7. Percentage of high-tech exports at GDP.
Source: calculations based on UN-comtrade data.

specialisation pattern of a country with regard to technology class (see Table A1 in Annex). However, a number of countries have been specialising in all of the analysed fields.

The export advantage describes the advantages of a country due to its openness. Trade data is used to present an indicator based perspective on this factor (Fig. 7). The share of R&D intensive exports at the GDP of the countries is used as an indicator. The higher this value, the stronger is the economy shaped by the demands from abroad. However, there is also a small country bias in such an indicator: smaller countries tend to specialise more on single sectors than large countries, which offer a wider export portfolio. Thus, it is not surprising to see that rather smaller countries are among the leading countries with regard to this indicator.

Another indicator has been proposed by Cleff and Rennings (2013). They argue that the concentration of export markets might be an important indicator for the export advantage. If a country exports mainly to a few other countries, it takes only a small variation of the worldwide preferences into account. Thus, a high concentration of export markets for a country points towards a lower export advantage. So far, there has been made only limited use of this indicator. However, using the classification scheme mentioned above, the construction of such an indicator is also feasible.

4.3. *Innovation-friendly regulation*

Consistent development of eco-innovations must also be supported by innovation-friendly regulation. Expert opinion about the innovation-friendliness of regulation typically measure the hindering effect of regulation on innovation processes, e.g. with regard to bureaucratic procedures (WEF, 2008). However, eco-innovations clearly differ here from normal innovations. Due to the externality problem and – for grid based systems – the problem of monopolistic bottlenecks, which increase the power of established players which constitute the regime, regulation becomes a key prerequisite for eco-innovation (see Section 2.2). However, there seems to be no easy indication about what constitutes an innovation-friendly regulation. Soft context factors play an important role (Jänicke, 2005). The results on the influence of policy instrument choice is rather inconclusive: econometric estimations either indicate contradicting results depending on the technology or the innovation phase (Johnstone et al., 2010), or point towards small and not very significant influence at all (Walz et al., 2011). To sum up, innovation-friendly regulation typically is assessed on a technology specific case study level, but no reliable quantitative indicator is available on a more aggregated level.

4.4. *Technological capabilities*

Measuring technological capabilities can draw on the experience with innovation indicators made over the last two decades (see e.g. Freeman and Soete, 2009). Despite all the problems and caveats associated with measuring technological capabilities, patent indicators are among the most widely used indicators. The empirical importance of these indicators for trade patterns, which was already concluded in the 1990s (Dosi et al., 1990; Fagerberg, 1995), is also supported by more recent empirical research (e.g. Sanyal, 2004; Lachenmaier and Wößmann, 2006; Madsen, 2008). Madsen (2008) underlines the importance especially of transnational patents.

Recently, progress has been made in applying patent indicators also for eco-innovations, and they have been added to the Fraunhofer lead market database (Walz, 2010; Walz and Marscheider-Weidemann, 2011). The approach draws on patent applications at the World Intellectual Property Organisation and thus transnational patents (for the concept see Frietsch and Schmoch, 2010). 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 classification of eco-innovations uses patent classes and a search word based strategy to come up with patents in the 5 classes of eco-innovations. We use this concept in order to derive data for the years 2003–2007, which were chosen as the period of study so that a statistically more reliable population is achieved in which random fluctuations in individual years are evened out.

There are various aspects how the technological capability can be measured by patents. If one looks at the overall technological capability within the field, the share of patents can be used. Clearly big countries have an advantage here over small ones. In order to make the different countries comparable, patent intensities can be used. They normalise the number of transnational eco-innovation patents with regard to inhabitants or GDP. Fig. 8 shows the results if the number of transnational eco-innovation patents is related to GDP.

Furthermore, the specialisation within a country is important. If a country is specialising on a technology, it can be assumed that it is easier for this technology to attract capital and the best human resources. Thus, the specialisation also gives some indication about the future prospects. Typically the Relative Patent Activity (RPA) is used as an indicator to measure patent specialisation.[3] Fig. 8 indicates, that no clear pattern between countries of the OECD and emerging economies exists. Table 1 in the Annex gives the specialisation for the sum of eco-innovation, as well as for each of the 5 regime oriented technology classes. The differences within each country also indicate that the technological capability within the countries differs between the various eco-innovation technologies.

4.5. Actors and complementary sectors

Without capable actors, outgrowing a niche is not possible. However, the manifold aspects which describe a capable actor make it difficult to come up with a quantitative indicator. Also it is difficult to interpret the data. The interpretation of the number of companies active in a niche, for example, depends very much on the size and capability of each country. In the same way, the number and size of networks does not provide information about the intensity of communication and knowledge exchange in each of them.

It is widely held that innovation and economic success also depend on how a specific technology is embedded into other relevant industry clusters. There is strong empirical evidence that the international competitiveness of sectors and technologies is greatly influenced by the competitiveness of interlinked sectors measured by the Revealed Comparative Advantage (RCA) (Fagerberg, 1995). In order to give an overview about the empirical situation, we use the RCA of R&D-intensive goods (Fig. 9).[4] The numbers indicate which countries have advantages with regard to the interlinkage of eco-innovations to complementary sectors.

The robustness of this indicator hinges on the assumption that high tech sectors are important complementary sectors. Eco-innovations are very much about handling natural resource and energy flows. Thus, it can be also argued that especially the machinery sector is a highly complementary sector. Fig. 9 shows the RCA for the machinery sector of the countries involved. Indeed there are

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

[4] The RCA takes also the imports m into account and is calculated according to: $RCA_{ij} = 100 \times \tanh \ln[(x_{ij}/m_{ij})/(\sum_j x_{ij}/\sum_j m_{ij})]$.

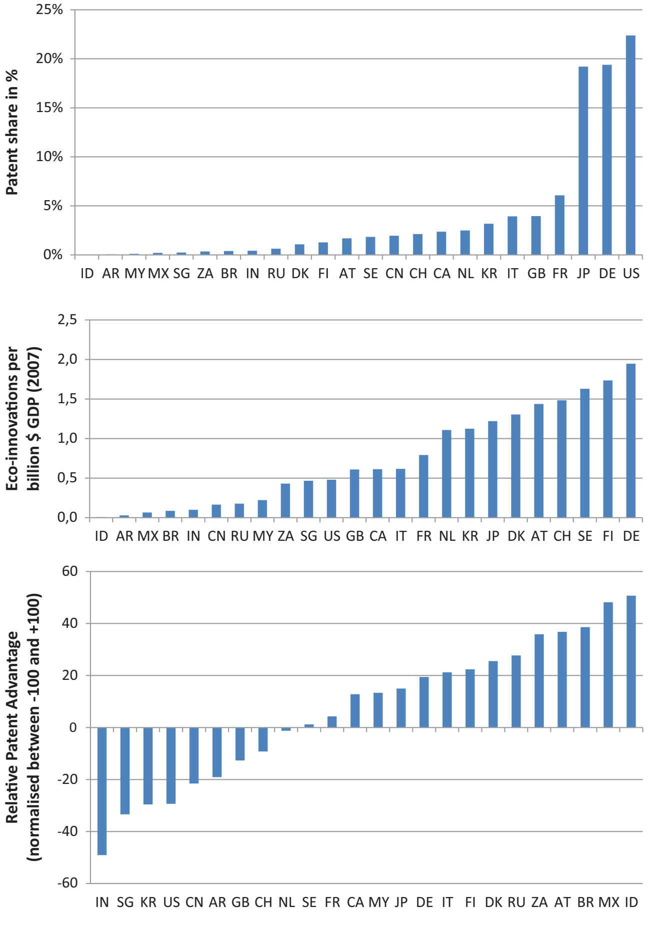

Fig. 8. Patent indicators for eco-innovations.
Source: calculations based on Fraunhofer ISI lead market database.

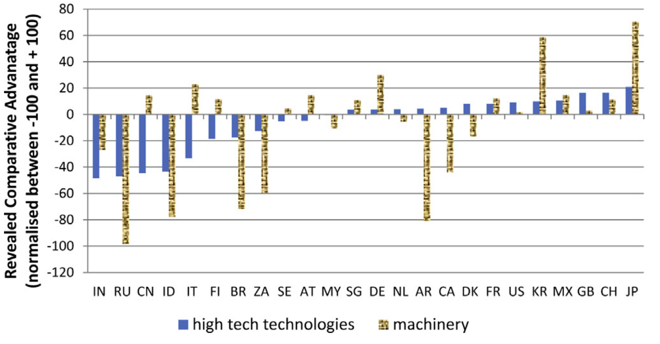

Fig. 9. Revealed Comparative Advantage (RCA) of high-tech technologies and machinery sector.
Source: calculations based on UN-Comtrade data.

Table 1
Classification of indicators for assessing lead market potential of countries for eco-innovations.

Lead market factor	Indicator and its empirical basis	Level for which quantitative indicator is available	Development over time available	Problems for robustness	Relation to MLP: indication for system transformation
Price advantage	Learning curve (techno-economic data)	Only niche technology level	Yes	Learning rate; data on diffusion of technology	Yes (speed of increasing competitiveness of niche)
Demand advantage	Awareness sustainability (survey data)	Eco-innovation level	Systematic and reproducible time series difficult	Country bias may inhibit comparison between countries	Yes (level of disruptive change)
Transfer advantage	Technology index (survey date or composite of technical figures)	Only all technologies	Systematic and reproducible time series difficult	Bias of survey participants	No
	Trade figures (statistics)	Niche, regime, eco-innovation level	Available	Classification on 6-digit level	Yes (political economy argument; level of learning by exporting)
Export advantage	% of high tech exports at GDP (statistics)	Only all technologies	Available		No
	Spatial distribution of exports (statistics)	Niche, regime, eco-innovation level	Available	Classification on 6-digit level	No
Technological capability	Patent data (statistics)	Niche, regime, eco-innovation level	Available	Different propensity to patent; capability not showing in patents	Yes (development level of niches)
Regulation	Stability	No eco-innovation specific indicator available yet	Systematic and reproducible time series will be difficult		Yes: evaluation of policy support
	Long-term targets	No eco-innovation specific indicator available yet	Systematic and reproducible time series will be difficult		Yes: evaluation of policy support
	Instrument	No eco-innovation specific indicator available yet	Systematic and reproducible time series will be difficult		No
Actors	Availability of capable actors and networks	No indicator available yet	Systematic and reproducible time series will be difficult		Yes (strength of niche)
Complementary sectors	RCA high tech (statistics)	Only all technologies	Available	Classification as complementary sector	No
	RCA machinery (Statistics)	Only all technologies	Available	Classification as complementary sector	No

some deviations for a couple of countries. One advantage of the data, however, is that time series are available which can show a change of the situation over time.

4.6. Discussion of indicators

The previous sections have presented a perspective on available proxy indicators for the different lead market factors. A methodological reflection about the availability and the nature of the available indicators reveals the following aspects:

- Availability of indicators on different aggregation levels: no quantitative indicators are available for regulatory advantage and for the actor advantage. For the price advantage, available indicators are only meaningful on the level of single niches. On the other hand, the indicators for transfer, export and complementary sector advantage are not directed to eco-innovations, but apply for other technologies as well. The indicators using trade and patent data (technological capability, part of transfer and export advantage) offer the advantage that they can be flexibly tailored to the level of eco-innovations, regime-related or niche specific aggregation level.
- Availability over time: in principle, time series can be built for all indicators. However, this requires a database which covers these time spans. For the indicators investigated, this is, in general, more often the case for the indicators which are based on statistical data. Survey based data tend to be more ad hoc, and often the specific framing of the surveys change over time.
- Robustness of indicators: the specific problems of the survey based indicators relate to representativeness of those surveyed, and country bias due to different understanding and cultural setting of answers to the common questions. A problem of the statistics based indicators is the classification of eco-innovations. Especially the trade statistics has its shortcomings, because even using a 6-digit level in trade statistics which builds a technological based classification scheme, cannot overcome all shortcomings related to using a predefined and fixed 6-digit classification (Walz and Marscheider-Weidemann, 2011). Patent statistics are insofar more robust, as the use of key words allow to redefine the predefined classification into patent classes. The robustness of the price advantage depends crucially on the assumed learning rate for new technologies, and on the robustness of data for diffusion of technology. There might be difficulties with regard to the latter, because eco-efficiency technologies are very often integrated into other technologies.
- Contribution to indicating level of system transformation: in Section 3, we have attributed the lead market factors to the different levels within MLP. However, not all of the lead market factors do also indicate a direct level of pressure towards system change. The transfer and export advantage as such are more remote. The indicator for demand advantage – importance of sustainability in the society – is an indication of the level of disruptive change on the landscape level. Other indicators point to the degree of maturing of niches; their aggregate on the intermediate level (sum of niches related to a regime) makes challenging the regime more likely. Thus, there is indeed a potential that some of the lead market indicators can also contribute towards assessing the probability that regime shift might occur in different countries. However, these indicators provide only a snapshot picture. They cannot substitute for a detailed analysis which takes causal feedback loops into account.

The results obtained with the available indicators show that traditional OECD countries still seem to have the best starting points for developing lead markets in the field of eco-innovation. Among the large traditional technology suppliers, the indicators show favourable positions for Germany and Japan especially with regard to supply side market factors, technological capability, and strength of complementary sectors. The U.S., in contrast, does not show up as one of the leading countries. Some smaller European countries, especially the Scandinavian countries in the EU and Switzerland, enjoy favourable starting points with regard to demand advantage and the normalised technological capability indicators. Even more interesting, however, is that some of the Newly Industrialising Countries seem to be advancing in these respects. China and South Korea been have moving up in the market factors of the supply side and technological capability; Brazil, Mexico and South Africa show a positive specialisation pattern in their patent activities. Nevertheless, it has to be kept in mind that not all factors could be assessed. Especially the factors of regulation, which is linked to the environmental policy making, and the factors regarding economic players are missing. Furthermore, the indicator values provide only a snapshot, they cannot tell the story how the different indicators influence each other, and what dynamic is developing from that in the various countries.

5. Conclusions

The concept of lead markets and the MLP are both heavily influenced by evolutionary economics. Thus, there is a good starting point for integrating them, despite the other influences on these concepts. Our first goal has been to analyse if lead markets can contribute towards analysing system transformation as described by the MLP. We have found two different points for integration. The first is a political economy argument: the growth of eco-innovation niches and socio-technical regime change requires most often policy support. The incumbent regime, however, has typically developed superior ties to government, which makes political support more difficult. The perspective of economic opportunities of an export potential of the niche technologies can offer an opportunity for balancing the disadvantages on the political arena. However, such an argument only carries weight if it assumes a critical mass of jobs to be gained. Thus, such a debate is more likely to develop on a more aggregated level than a single technological niche. The second point relates to feedback loops between niches and regimes in different countries. International policy diffusion and learning on the level of niche–regime interaction can improve the legitimacy of supporting policies. Learning by exporting and realising scale effects in the niche technology both work towards maturing of the niches, making it more likely that they can challenge the regime.

Eco-innovation has been targeted as a field for lead market initiatives. Thus, our second goal has been to investigate how to relate eco-innovation to system transformation by framing it within an integrated MLP-lead market approach. We argue that an aggregated analysis of eco-innovations is too broad: MLP calls for specifics of the regime–niche interplay to be taken into account. Thus, eco-innovation has to be broken down in order to be studied with regard to system transformation. Five areas of eco-innovations can be identified, which relate to specific regimes. Three of these regimes are infrastructure related (energy supply, water, transport), two of them (energy and material efficiency) make up the class of eco-efficiency. Thus, eco-innovations can be interpreted as forming the basis of technological niches which relate to one of these socio-technical regimes. Furthermore, we propose that there is co-evolution between the development of the regimes. Due to common specificities, we expect these co-evolutions to be especially strong within the class of infrastructure related regimes, and within the eco-efficiency regimes. However, the current data base does not allow this proposition to be tested: we expect this co-evolution to show up especially in the policies and regulations influencing niche–regime interaction, but it is especially the regulatory advantage for which an indicator approach is missing and still has to be developed.

MLP analysis has been predominantly performed on a qualitative case study level. There are various lead market analysis on this level, too. However, the use of indicators for identifying and assessing lead market positions has also been an important methodology. Thus, our third goal has been to analyse whether or not the measurement of lead market factors can also contribute to empirically analysing the opportunities for system transformation with MLP. Indeed, the indicators for the lead market factors can be attributed to the different levels of MLP. However, an assessment of the indicators provides a mixed picture: some of the indicators are more general in nature and do not specifically point towards eco-innovations. Indicators are not available for all lead market factors and there are various technical problems of indicator building with regard to robustness and availability of data over time. Finally, such an indicator approach does not tell the whole story. It only provides a snapshot, and cannot substitute for an analysis of causal relationship within each system, which takes the dynamic nature and the feedbacks into account.

Our results call for additional research in various areas: indicators for regulation, but also for describing the actor structure are a key priority. Refining social network indicators might provide a useful approach here. The importance of political economy as an explanation for supportive policies for regime shift should be studied by case studies, by taking also into account the role of economic opportunities which are attributed to an export potential of the niche technologies. In this context it will be also helpful to look more in detail on the role of space, which seems to matter with regard to both the political economy and integration of national niches into global value chains. Finally, we could envisage that the study of causal relationships, which so far has been predominantly performed on qualitative case study basis, should be extended towards looking in the possibilities for modelling system transformation. This certainly is a huge challenge with many caveats and a long way to go. However, the indicators we were looking at and the integration of lead market factors into a MLP framework, might help to move into that direction.

Acknowledgements

This paper was developed within the context of a research project entitled “Lead Market Strategies: First Mover, Early Follower and Late Follower”. The financial contribution of the Germany Ministry of Education and Research is gratefully acknowledged.

Appendix A.

Table A1
RXA and RPA values for aggregate of eco-innovation and for regime levels.

Country	Eco-innovation aggregate		Infrastructure related						Eco-efficiency			
			Water		Green mobility		Green energy supply		Energy efficiency		Material efficiency	
	RXA	RPA	RXA	RPA	RXA	RPA	RXA	RPA	RXA	RPA	RXA	RPA
AR	−7	−19	−68	−90	−76	−81	−97	23	−75	−10	64	−4
AT	45	37	42	8	58	43	31	5	54	42	39	40
BR	6	39	−59	56	0	−22	−88	22	−42	47	56	82
CA	−42	13	−34	42	−45	0	−72	30	−51	2	−22	29
CH	0	−9	22	−18	−76	−31	33	11	13	−12	9	1
CL	−89	11	−94	15	−91	−60	−100	−68	−99	25	−68	86
CN	15	−22	12	−3	41	−65	47	−11	39	−6	−59	5
DE	35	19	51	5	17	33	39	6	51	20	30	1
DK	32	26	69	64	−37	−50	34	72	64	3	29	41
FI	37	22	22	10	40	−75	35	−14	73	54	18	28
FR	3	4	10	−14	1	35	5	−2	14	−10	−4	−18
GB	1	−13	14	0	−12	−17	−12	6	−5	−31	14	13
ID	32	51	−93	96	−41	−86	−61	5	−88	67	83	75
IN	−52	−49	−60	34	−37	−75	−49	−43	−70	−57	−58	−9
IT	35	21	79	9	−8	18	5	6	73	25	14	40
JP	50	15	22	−21	69	47	46	4	28	8	46	−4
KR	36	−30	−28	4	85	−84	13	−38	−48	1	−40	−46
MX	−3	48	6	70	−6	−25	26	47	37	58	−45	75
MY	27	13	−75	−3	−86	−86	32	53	−53	8	74	82
NL	−24	−1	−39	−9	−51	−78	−50	18	−48	18	15	5
RU	−95	28	−97	39	−91	8	−98	46	−96	14	−94	49
SE	15	1	39	−14	−4	4	5	−3	29	0	16	−8
SG	−42	−33	−55	26	−80	−83	−4	−17	−61	−30	−26	5
US	15	−29	24	−18	−30	−45	4	−22	8	−28	40	−21
ZA	−25	36	−66	69	−56	−59	−86	64	−66	31	36	50

Source: Calculations based on Fraunhofer ISI lead market database.

References

Amable, B., Verspagen, B., 1995. The role of technology in market shares dynamics. Applied Economics 27, 197–204.

Andersson, M., Ejermo, O., 2008. Technology specialization and the magnitude and quality of exports. Economics of Innovation and New Technology 17, 355–375.

Archibugi, D., Pietrobelli, C., 2004. The globalisation of technology and its implications for developing countries – windows of opportunity or further burden? Technological Forecasting and Social Change 70, 861–883.

Beise, M., 2004. Lead markets: country specific drivers of the global diffusion of innovations. Research Policy 33, 997–1028.
Beise, M., Rennings, K., 2005. Lead markets and regulation: a framework for analysing the international diffusion of environmental innovations. Ecological Economics 52 (1), 5–17.
Berglund, C., Söderholm, P., 2006. Modeling technical change in energy system analysis: analysing the introduction of learning-by-doing in bottom-up energy models. Energy Policy 34, 1344–1356.
Cleff, T., Rennings, K., 2013. Are there any first mover advantages for pioneering firms? Lead market oriented business strategies for environmental innovation. European Journal of Innovation Management 15 (4), 491–513.
Coenen, L., Benneworth, P., Truffer, B., 2012. Toward a spatial perspective on sustainability transitions. Research Policy 41, 968–979.
CSES and Oxford Research, 2011. Final Evaluation of the Lead Market Initiative, Final Report. Publications Office of the European Union, Luxembourg.
Dosi, G., Pavitt, K., Soete, L., 1990. The Economics of Technical Change and International Trade. New York University Press, New York.
Dosi, G., Soete, L., 1988. Technical change and international trade. In: Dosi, G., et al. (Eds.), Technical Change and Economic Theory. Pinter, London.
Eco-Innovation Observatory, 2010. The Eco-Innovation Challenge. Pathways to a resource efficient Europe. Report of Eco-innovation observatory, Brussels/Wuppertal.
ECORYS Research and Consulting, 2009. Technologisk Institute and Cambridge Econometrics Study on the Competitiveness of the EU Eco-industry. Final report, Brussels, October.
Edler, J., Georghiou, L., Blind, K., Uyarra, E., 2012. Evaluating the demand side: new challenges for evaluation. Research Evaluation 21, 33–47.
European Environment Agency, 2012. Environmental Indicator Report 2012. EEA, Copenhagen.
Fagerberg, J., 1995. Technology and competitiveness. Oxford Review of Economic Policy 12 (3), 39–51.
Fagerberg, J., Srholec, M., Knell, M., 2007. The competitiveness of nations: why some countries prosper while others fall behind? World Development 35, 1595–1620.
Fagerberg, J., 2010. The changing global economic landscape: the factors that matter. In: Solow, R.M., Touffut, J.-P. (Eds.), The Shape of the Division of Labour: Nations, Industries and Households. Edward Elgar, Cheltenham, pp. 6–31.
Foxon, T., Pearson, P.J.G., Arapostathis, S., Carlsson-Hyslop, A., Thornton, J., 2013. Branching points for transition pathways: assessing responses of actors to challenges on pathways to a low carbon future. Energy Policy 52, 146–158.
Franzen, A., Meyer, R., 2010. Environmental attitudes in cross-national perspective: a multilevel analysis of the ISSP 1993 and 2000. European Sociological Review 26, 219–234.
Freeman, C., Soete, L., 2009. Developing science and technology indicators: what can we learn from the past? Research Policy 38 (4), 583–589.
Frietsch, R., Schmoch, U., 2010. Transnational patents and international markets. Scientometrics 82, 185–200.
Geels, F., 2011. The multi-level perspective on sustainability transitions: responses to seven criticisms. Environmental Innovation and Societal Transitions 1, 24–40.
Geels, F., Schot, J., 2007. Typology of sociotechnical transition pathways. Research Policy 36, 399–417.
Geels, F.W., 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Research Policy 31 (8/9), 1257–1274.
Gelissen, J., 2007. Explaining popular support for environmental protection: a multilevel analysis of 50 nations. Environment and Behavior 39, 392–415.
Genus, A., Coles, A.-M., 2008. Rethinking the multi-level perspective of technological transitions. Research Policy 37, 1436–1445.
Griffith, R., Redding, S., van Reenen, J., 2004. Mapping the two faces of R&D: productivity growth in a panel of OECD industries. The Review of Economics and Statistics 86 (4), 883–895.
Grin, J., Rotmans, J., Schot, J.W., 2010. Transitions to Sustainable Development. Routledge, New York.
Grupp, H., 1999. Foundations of the Economics of Innovation: Theory, Measurement, and Practice. Edward Elgar, Cheltenham.
Gual, M.A., Norgaard, R., 2010. Bridging ecological and social systems coevolution: a review and proposal. Ecological Economics 69, 707–717.
Jamasb, T., Köhler, J., 2008. Learning curves for energy technologies: a critical assessment. In: Grubb, M., et al. (Eds.), Delivering a Low-Carbon Electricity System. Technologies, Economies, Policy, Cambridge, pp. 314–332.
Jänicke, M., 2005. Trend-setters in environmental policy: the character and role of pioneer countries. European Environment 15 (2), 129–142.
Johnstone, N., Haščič, I., Popp, D., 2010. Renewable energy policies and technological innovation: evidence based on patent counts. Environmental and Resource Economics 45 (1), 133–155.
Keller, W., 2004. International technology diffusion. Journal of Economic Literature 42, 752–782.
Kemp, R., 1994. Technology and the transition to environmental sustainability: the problem of technological regime shifts. Futures 26 (10), 1023–1046.
Kneller, R., 2005. Frontier technology, absorptive capacity and distance. Oxford Bulletin of Economics and Statistics 67 (1), 1–23.
Köhler, J., 2012. A comparison of the neo-Schumpeterian theory of Kondratiev waves and the multi-level perspective on transitions. Environmental Innovation and Societal Transitions 3, 1–15.
Köhler, J., Grubb, M., Popp, D., Edenhofer, O., 2006. The transition to endogenous technical change in climate-economy models: a technical overview to the innovation modeling comparison project. The Energy Journal SPEC. ISS. MAR., Endogenous Technological Change and the Economics of Atmospheric Stabilization 27, 17–55.
Lachenmaier, S., Wößmann, L., 2006. Does innovation cause exports? Evidence from exogenous innovation impulses and obstacles using German micro data. Oxford Economic Papers 58, 317–350.
Lundvall, B.-A., 1985. Product Innovation and User-Producer Interaction Industrial Development Research Series No. 31. Aalborg University Press, Aalborg.
Madsen, J.B., 2008. Innovations and manufacturing export performance in the OECD countries. Oxford Economic Papers 60, 143–167.

Markard, J., Raven, R., Truffer, B., 2012. Sustainability transitions: an emerging field of research and its prospects Research Policy 41, 955–967.
Markard, J., 2010. Transformation of Infrastructures: Sector Characteristics and Implications for Fundamental Change, June. Eawag – Swiss Federal Institute of Aquatic Science and Technology, Zürich, Switzerland.
McDonald, A., Schrattenholzer, L., 2001. Learning rates for energy technologies. Energy Policy 29, 255–261.
Melitz, M.J., Trefler, D., 2012. Gains from trade when firms matter. Journal of Economic Perspectives 26, 91–118.
Meyer-Krahmer, F., Reger, G., 1999. New perspectives on the innovation strategies of multinational enterprises: lessons for technology policy in Europe. Research Policy 28, 751–776.
Pan, H., Köhler, J., 2007. Technological change in energy systems: learning curves, logistic curves, and input–output coefficients. Ecological Economics 63, 749–758.
Peuckert, J., 2011. Assessment of the social capabilities for catching-up through sustainability innovations. International Journal Technology and Globalisation 5, 190–211.
Porter, M.E., 1990. The Competitive Advantage of Nations. The Free Press, New York.
Porter, M.E., van der Linde, C., 1995. Toward a new conception of the environment-competitiveness relationship. Journal of Economic Perspectives 9 (4), 97–118.
Quitzow, R., Walz, R., Köhler, J., Rennings, K., 2013. The concept of "lead market" revisited: contribution to environmental innovation theory. Environmental Innovation and Societal Transitions, http://dx.doi.org/10.1016/j.eist.2013.11.002.
Rennings, K., 2000. Redefining innovation – eco-innovation research and the contribution from ecological economics. Ecological Economics 32, 319–332.
Safarzynska, K., Frenken, K., van den Bergh, J.C.J.M., 2012. Evolutionary theorizing and modeling of sustainability transitions. Research Policy 41, 1011–1024.
Saggi, K., 2002. Trade, foreign direct investment and international technology transfer: a survey. The World Bank Research Observer 17 (2), 191–235.
Sanyal, P., 2004. The role of innovation and opportunity in bilateral OECD trade performance. Review of World Economics 140 (4), 634–664.
Smith, A., Voß, J.P., Grin, J., 2010. Innovation studies and sustainability transitions: the allure of the multi-level perspective and its challenges. Research Policy 39, 435–448.
Smith, A., Stirling, A., Berkhout, F., 2005. The governance of sustainable socio-technical transitions. Research Policy 34, 1491–1510.
Smith, A., Raven, R., 2012. What is protective space? Reconsidering niches in transitions to sustainability. Research Policy 41, 1025–1036.
Smith, T., 2013. Public Attitudes towards Climate Change & Other Environmental Issues across Time and Countries, 1993–2010. NORC at the University of Chicago, Chicago.
Unruh, G.C., 2000. Understanding carbon lock-in. Energy Policy 28, 817–830.
Uyterlinde, M.A., Junginger, M., de Vries, H.J., Faaij, A.P.C., Turkenburg, W.C., 2007. Implications of technological learning on the prospects for renewable energy technologies in Europe. Energy Policy 35, 4072–4087.
von Hippel, E., 1988. Sources of Innovation, New York.
Wagner, J., 2007. Exports and productivity: a survey of the evidence from firm-level data. The World Economy 30, 817–838.
Wakelin, K., 1998. The role of innovation in bilateral OECD trade performance. Applied Economics 30, 1335–1346.
Walz, R., 2006. Impact of strategies to increase RES in Europe on employment and competitiveness. Energy & Environment 17 (6), 951–975.
Walz, R., 2010. Competences for green development and leapfrogging in newly industrializing countries. International Economics and Economic Policy 7 (2–3), 245–265.
Walz, R., et al., 2011. Regulation, innovation and wind power technologies – an empirical analysis for OECD countries. In: Paper Prepared for the DIME Final Conference, Maastricht http://final.dime-eu.org/files/Walz_C5.pdf
Walz, R., 2007. The role of regulation for sustainable infrastructure innovations: the case of wind energy. International Journal of Public Policy 2 (1/2), 57–88.
Walz, R., 2011. Employment and structural impacts of material efficiency strategies: results from 5 case studies. Journal of Cleaner Production 19, 805–815.
Walz, R., Eichhammer, W., 2012. Benchmarking green innovation. Mineral Economics 24 (1), 79–101.
Walz, R., Marscheider-Weidemann, F., 2011. Technology-specific absorptive capacities for green technologies in newly industrializing countries. International Journal of Technology and Globalisation 5 (3–4), 212–229.
Walz, R., Schleich, J., 2009. The Economics of Climate Policy: Macroeconomic Effects, Structural Adjustments and Technical Change. Physica/Springer, Heidelberg.
Weber, M., Rohrschacher, H., 2012. Legitimizing research, technology and innovation policies for transformative change. Combining insights from innovation systems and multi-level perspective in a comprehensive 'failures' framework. Research Policy 41, 1037–1047.
2008. The Global Competitiveness Report 2008–2009. World Economic Forum, Geneva.
Wei Yingqi, Y., Xiaming Liu, X., Wang, C., 2008. Mutual productivity spillovers between foreign and local firms in China. Cambridge Journal of Economics 32, 609–631.