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Clean-tech Innovation in Emerging Economies: Transnational Dimensions in Technological Innovation System Formation

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ABSTRACT

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Keywords: Technological innovation system; clean-tech; emerging economies; changing global innovation

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Brief running title: Clean-tech Innovation in Emerging Economies

ABSTRACT

Emerging economies increasingly contribute to global clean-tech innovation. The 'Technological Innovation System' (TIS) framework and its system functions have become a popular analytical tool for clean-tech innovation. Its applicability to emerging economies is not entirely straightforward, however, because of two interconnected flaws. First, empirical TIS work has focused predominantly on advanced economies. Second, although TIS is theoretically understood to be a global phenomenon, empirical TIS work often uses national borders as system boundaries. Earlier perspectives on innovation in emerging economies have stressed the role of transnational linkages in (early) innovative activities in emerging economies. While implicitly acknowledged, the TIS literature lacks a systematic specification of these transnational linkages, how and under what conditions they form, and how they induce or hamper TIS formation. This paper draws on insights from the perspectives of National Learning Systems, International Technology Transfer, and Global Production Networks to elaborate on the transnational dimension of TIS formation in emerging economies. The insights these strand of literature offer on the challenges and opportunities of such transnational linkages may be accurately grasped by the seven TIS system functions, lending credence to further application of the TIS framework in emerging economy case studies.

KEYWORDS: Technological innovation system; clean-tech; emerging economies; changing global innovation

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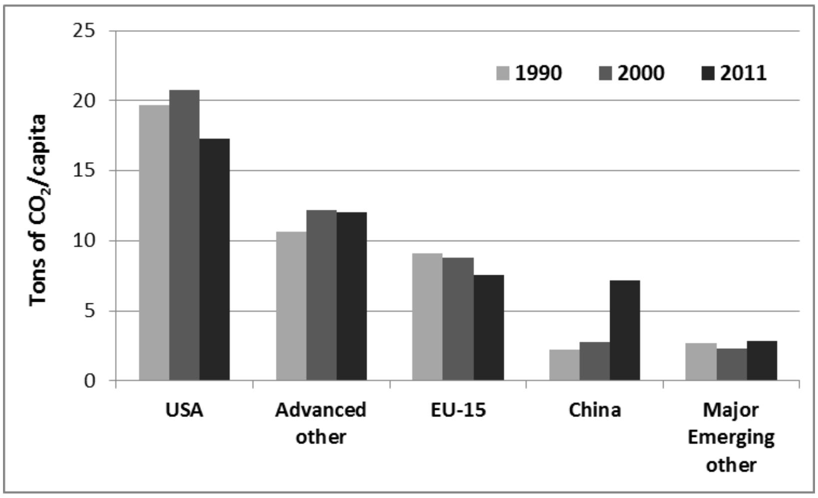
1. Introduction

Continuous development and wide-spread utilization of clean-tech is a key requirement to prevent and restore damage to stocks of natural resources and ecological systems upon which the welfare of current and future generations of mankind depend [1, 2]. The global climate is one of the planetary boundaries that is at risk from anthropogenic greenhouse gas (GHG) emissions [3]. The 'advanced economies'[1] carry the bulk of historical responsibility for GHG emissions, but rapid economic growth in the 'emerging economies'[1] has increased GHG emissions to a scale that these need to be addressed as well. China in particular stands out, having been the country with the largest GHG emissions since 2008 and current per capita emissions on par with that of the EU-15 (Figure 1).

Figure 1.Per capita GHG emissions, selected countries.



Notes: Per capita emissions in metric tons of CO_2-eq per year, includes emissions from fossil fuel use and cement production. Country grouping according to [4], see also footnote 1; emission data from [5].

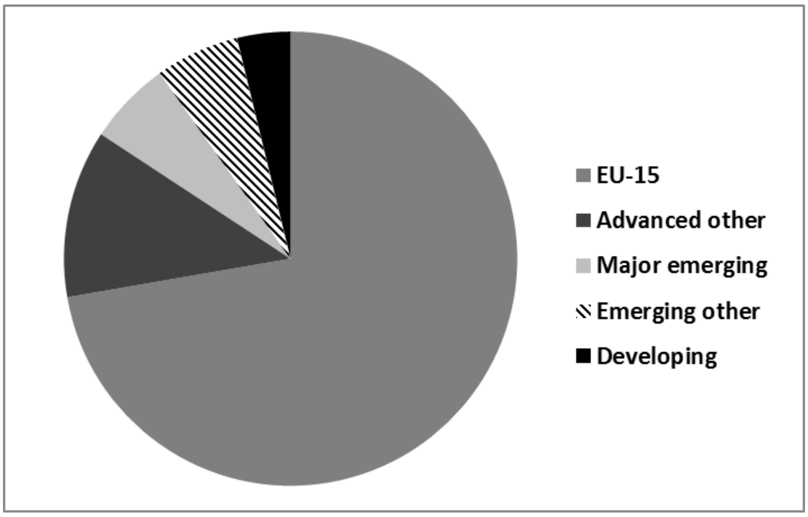
Preventing damage to the global climate system will require, amongst others, the widespread adoption of currently available renewable energy technologies as well as the development of new and improved generations thereof [6-8]. The capacity to utilize and especially develop technologies is intimately related with economic development. Lagging economic development is related with weaker technological capacity, whereas the successful emergence of an economy indicates increasing technological capacities [9-12]. Well-known success stories are that of the Asian 'Tiger Economies', that managed to very rapidly transform from technologically lagging, low cost manufacturing bases into new global hubs of innovation [10, 13, 14].

The original work on this technological 'catch-up' in the Asian Tiger Economies dealt with 'old' industries such as apparel, consumer electronics and cars, but emerging economies are currently increasingly involved in global clean-tech development [15], with especially clear evidence in renewable energy technologies [16, 17]. Brazil, China and India are in the global top ten in terms of investments in renewable energy as well as installed generation capacity for (non-hydro) renewable power, with China ranking first in both [17]. Of the global top ten wind turbine manufacturers (by annually installed capacity) five are from China and one from India [18], and China supplied sixty per cent of global demand for PV panels in 2011

[19]. The contribution of non-hydro renewables remains limited, however, at circa three per cent of total power consumption in China in 2011 [19, 20].

The concurrent advancement of utilization and development of technologies has often been studied with innovation systems concepts, with analysts of clean-tech recently favouring the 'Technological Innovation Systems' (TIS) framework [21, 22]. One of the attractive features of the TIS framework is the recent development of a list of 'system functions'; key processes to form or sustain a 'well-functioning' innovation system [23, 24], which may be used by analysts and policy makers to identify system weaknesses.
The bulk of TIS functions based analyses has been of innovation systems in advanced economies (Figure 2). The latecomer nature of innovative activity in emerging economies gives reason to assume that different formation mechanics are at work, especially in early phases of systems formation. The early phases of technological catch-up in the Tiger Economies were characterized by a strong reliance on foreign technologies and a highly export oriented industry complex, before a strong domestic market and innovation system developed. The capacity to absorb foreign technologies, the mechanisms involved as well as the conditions that frustrate or enable it, have been a major focus of the work on innovation in emerging economies [10, 11, 13, 25, 26]. The TIS literature, however, is rather ambiguous on the transnational linkages in TIS formation that are so crucial to initial system formation in Emerging Economies (more in section 2).

Figure 2.Geographical focus of TIS case studies



Note: based on 187 articles using the TIS system functions framework. We searched using Google Scholar, with search terms "Technological Innovation system", and either "influence on the direction of the search"[23] or "guidance of the search"[24]; names of the other functions are terms used in a much broader set of literature. Country grouping according to [4]; see also footnote 1.

The objective of this paper is to suggest adaptations to the TIS functions framework that improve its applicability to the study of clean-tech innovation in emerging economies, by specifically incorporating international lag and transnational linkages in system formation. Theoretically, we will draw from related strands of research that have more explicitly incorporated geographical dimensions into the study of innovation, i.e. the literature on 'National Learning Systems', 'International Technology Transfer' and 'Global Networks of

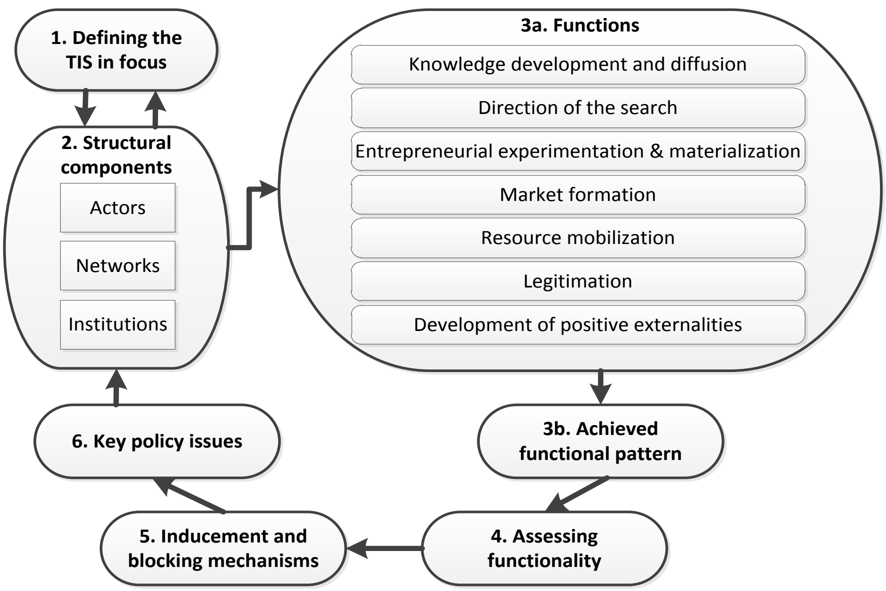
Production'. Empirically, we will illustrate with examples from the Chinese renewable energy sectors throughout the text. Further empirical testing of the framework we introduce here will be done in two subsequent articles on China's renewable energy industries.
The rest of this paper is structured as follows. In section 2 we elaborate on the current lack of attention for international lag and transnational linkages in TIS formation, and the need to incorporate these when studying emerging economy cases. In section 3 we review the TIS functions framework. For each step of the framework we work out what the existence of international lag and transnational linkages in innovation systems implies for the focus in empirical application in emerging economy case studies. In section 4 we close with a discussion and suggestions for further research.

2. The lack and need for transnational linkages in TIS

2.1. The Technological Innovation System framework

Technological Innovation systems are defined as 'dynamic networks of agents interacting [..] under a particular institutional infrastructure and involved in the generation, diffusion, and utilization of technology' [12: p94]. An important question for both academics and policy makers is what influences innovation system functioning, i.e. how well a specific system spurs the generation, diffusion and utilization of technologies. Much of the recent TIS work has revolved around the analysis of 'system functions'; processes that determine the overall performance of the innovation system [23]. This list of functions helps operationalize the rather complex TIS concept in analyses of system weaknesses and in drafting policy recommendations to reduce these. A number of different lists of functions has been suggested, but differences have been converging on more or less the same [27]. We choose to start our argument using TIS functions framework as suggested by Bergek and colleagues [23] (see Figure 3).

Figure 3.The TIS scheme of analysis



Source: [23]

2.2. The lack of transnational linkages in TIS

Our criticism of the TIS framework for neglecting transnational dimensions might appear paradoxical, as the TIS concept has originally been suggested as an alternative to innovation system concepts that employed rigid geographic boundaries [22, 23]. The original work on innovation systems mostly used the national level as the scope for analysis [14, 26]. Later contributions highlighted subnational regions or 'hubs of excellence' as important geographical units in innovation [28, 29], although these regions are understood to be nodes in a globalizing economy with connections across national borders [30]. Other analysts have argued that innovation systems are best delineated at the level of industrial sectors, that are usually spread out over many countries [31]. The Technological Innovation System approach suggests that innovation is best studied at the level of a single technology. The TIS and sectoral approach share the notion that national borders do not confine technologies, stating that TIS ' may have a geographical dimension, but are often international in dimension' [23: p409]. With increasingly globalized world markets and economic production, innovation systems may stretch the entire globe [12, 22]. This does not necessarily imply, however, that all corners of the globe contribute to or benefit from the generation, diffusion and utilization of technology to an equal extent.

Global inequalities in innovation are apparent in comparative case studies, where successful system formation in one country is contrasted with formation mechanics in relatively less successful countries. For instance, analysts have been keen on identifying the factors that have led Denmark to become a leading nation in the global wind power industry, in spite of competing initiatives from the earliest phases of wind power industry development in Germany and the US [32, 33]. Comparisons of successful and less successful nations have helped in drafting and testing the TIS' functional dynamics scheme, in the identification of commonly occurring weaknesses and of generally successful policy interventions [34-36].

Conceptually, however, the analysis of innovation systems at the national level is at odds with the premise that TIS boundaries should be set at the level of a technology, not a geographic unit. This is a problem mostly because this flawed approach has become standard operating procedure in empirical application. TIS case studies have virtually exclusively set system boundaries at the national level and largely sought to explain TIS formation as the result of processes occurring within those borders, i.e. interaction between domestic actors under a national level institutional infrastructure. Few analysts have explicitly incorporated processes at the supranational or global level [37-39].

There are five justifications for choosing system boundaries at the national level, especially for clean-tech:

1. A number of important technological, institutional, economic and political factors are strongly dependent on the country in which the case study is performed [39, 40]. For Clean-tech in particular, national governments remain crucial in setting the size of research funds and their direction of investigation, fiscal (dis)incentives for sustainable versus conventional alternatives and market sizes [21, 41];
2. Policy support for clean-tech may come from both environmental and industrial policies [42]. Environmental policy may seek to induce cleaner production, e.g. growth in renewable power consumption, but the preferred means to that end from an industrial policy perspective is with equipment from domestic manufacturers.

3. The TIS framework is aimed at studying innovation from technological concept to market maturity, but analysts have focused on (very) early phases of TIS formation [43]. This is connected with the preference of studying system formation in the advanced economies, the usual loci of early technological advancement. Initial phases of system formation involve only a small number of actors. Early technological concepts require testing in experiments and niche applications, which are still highly localized. Initial market demand as well as guidance to the further development of the technology, is strongly dependent on government support in the form of subsidies or RD&D programmes [44, 45]. The smaller size and higher degree of localization of actor-networks in early phases make it more likely that national borders, however significant or confining they are, encompass all the elements that comprise the innovation system.
4. It is methodologically difficult to study TIS at the supranational or even global scale. This implies an 'explosion of scale' and complexity of analysis [46]. The analysis of all individual actors in all countries of the world, their relationships, all global experiments and policy support measures simultaneously would be an enormous task.
5. As long as actors or activities abroad do not significantly influence innovation dynamics within the country of study, then the selection of national borders as the system boundaries will not significantly affect the explanatory power of the systems analysis. Something that does not affect the system, is not part of the system [22].

In contrast with the last three arguments, TIS analysts have noted factors of influence originating from outside of the national system boundaries. Initially localized TIS are likely to become international phenomena when they reach a certain growth phase [22, 23, 38]. Exemplary is the treatment of these by one author that states 'couplings with other nations or international developments' to influence domestic system dynamics, but includes these under 'external factors' [46]. Comparable treatment of transnational linkages pervades most of the empirical TIS work. Such linkages are recognized, but considered to add high complexity yet limited additional explanatory power when studying TIS in early formation stages. The omission is recognized as an imperfection but accepted for pragmatic reasons. They are included when and where deemed suitable, but remain underspecified in analytical frameworks.

2.3. Need for international lag and linkages in emerging economy TIS

The analysis of TIS formation in emerging economies would be seriously flawed when using a purely national focus. Innovation systems may be highly localized during initial stages of system formation in advanced economies, but these are likely to have matured to globalized systems by the time emerging economies commence domestic innovative activities for the technology.

For example, the first grid-connected wind turbine in China was installed in 1985 [47]. By that time, the collective experiences with wind power in Denmark had already resulted in the presence of several Danish turbine manufacturers, whose collective sales captured 80 per cent of the global market [32]. China's first grid connected turbine was imported from Denmark, as were many of the turbines in later years [47, 48]. Many of these turbines were (co-)financed by foreign government agencies, and often accompanied with training programmes for maintenance or the setting up of domestic turbine production lines. As such, these imported turbines were not only the first to deliver wind power to the Chinese grid, their further study boosted domestic scientists, engineers and later manufacturers' understanding of turbine design and wind power grid integration [47, 48].

Up until recently, many Chinese turbine manufacturers, including the two leading Chinese firms, Sinovel and Goldwind, have worked on the basis of licenses from or joint ventures with foreign design firms [49]. Further, around seventy per cent of installed wind power capacity in China receives funding through the CDM mechanism [20, 50], and the World Bank recently finished a project that encouraged and co-financed further knowledge exchange between Chinese and foreign industry partners [51]. More recently, China has adopted a string of policy initiatives in order to realize 'indigenous innovation' in the renewable energy industry, and has labelled it a 'strategic emerging industry' in which it 'aims to occupy a competitive position in future global markets' [51-54].

This short recap highlights the significance of transnational linkages in stimulating advancements, from very early system formation onwards. It also indicates an ambition to transform the relationship between the domestic and the global with the emergence and maturation of the domestic innovation system.

2.4. Inspiration from related frameworks

The complexity of TIS formation mechanics gives sufficient reason to expect that the transnational linkages involved will also be of a certain complexity. It is not necessary, however, to rely entirely on new TIS based empirical research to describe them. There are a number of related strands of literature that have investigated the mechanisms through which innovative activity in emerging economies may benefit from foreign advancement.

First, innovative activity in emerging economies has been a major focus in the earliest work on National Innovation Systems [14, 55]. Those analysts dealt with late-comer industrialization in the 'Asian Tigers'. Analysts have argued that economic progress depended on how well these countries were able to incorporate foreign technologies into the national system, and have analysed how this 'absorptive capacity' could be improved [10, 56]. To highlight the difference in mechanisms for progress when compared with advanced economies, these systems have also been labelled National Learning Systems [10].

Second, the literature on international technology transfer may provide insight on the institutions governing transnational linkages. This strand of literature has often dealt with the global diffusion of 'environmentally sound technologies', and incorporated a strong focus on institutions and the role of government, much like as in TIS [57, 58]. This institutional focus includes how governments of emerging economies may improve domestic circumstances to draw in innovative activity from abroad, as well as how governments of technologically leading countries may spur the outward diffusion of clean-tech to emerging economies [58, 59].

Third, we may draw insights into innovative capacity at the level of the firm from the literature on Global Production Networks. The central premise of this strand of literature is that economic production is seldom organized within the confines of a single firm, but rather in increasingly globalized networks of suppliers [60, 61]. Firms in emerging economies may benefit from the inclusion in such networks if the interaction with more technology intensive firms allows them to learn about and engage in increasingly complex and more value added production steps, a process labelled 'industrial upgrading'[60, 61].

Compared with TIS, however, the above strands of literature lack the analytical structuring that the TIS functions offer. The literature on international technology transfer focuses on the utilization of technologies by economies with especially weak technological capacities and loses much of its explanatory power for phases of more advanced domestic capacity formation [57]. The literature on National Learning Systems and Global Production Networks are stronger in that phase, but have focused on industries with an existing market demand. The TIS framework has more attention for policy created markets, often a prerequisite for clean-tech demand.

3. Integrating transnational linkages in TIS analyses

In our suggestions for the integration of transnational linkages, below, we will follow the six steps of the analytical framework as suggested by Bergek and colleagues [23] (see also Figure 3).

3.1. Step 1: Defining the TIS in focus

The first step of any TIS evaluation is to delineate the system. It is important to communicate the specific technological delineation [23]. This could be as broad as 'bio-power', or as specific as 'co-generation in combined cycle power plants with integrated gasification of forest biomass'.

Important in our contribution is the spatial delineation. We would not suggest a global analytical scale, for reasons mentioned in section 2.2, i.e. mostly the enormous scale of such an analysis and the realization that not everything in the global system will affect innovative activity in a specific domestic system.

Rather, we would suggest a multi-scalar conceptualization of national systems as constituents of the global system [confer e.g. 62, 63, 64]. Such a delineation would uphold the notion that the national scale remains important because many conditions that exist at this level, including the policies for which we seek recommendations, remain important explanatory factors for the systems' functioning. Concurrently, such delineation highlights that innovative activities are part of an increasingly globalized economic system. Transnational linkages may influence system formation in emerging economies especially, and nationally determined policies may or may not have influence over such international linkages.

3.2. Step 2: Identifying structural components

The second step in a TIS analysis is the identification of structural components, which are the actors, the networks that connect these actors, and the institutions that govern the relationships in these networks [23]. Actors at the centre of the development of technologies include universities, research institutes as well as firms. Other actors within this economic process include e.g. the suppliers of credit or RD&D funds and consumers. Some actors are part of the system mostly because they seek to influence the institutions governing them, e.g. government agencies, interest groups from industry or civil society, standard setting organizations etc. [23]. Examples of networks that may be formed are production chains, university-industry links and producer-consumer relationships. Institutions include formal laws, standards and regulations, as well as less formal norms, routines and culture [23].

Compared with nationally framed TIS studies, two additional structural components are relevant in analyses of trans-nationally linked TIS. First, ‘Global Production Networks’ of firms that seek to utilize the competitive benefits that exist in different national territories (section 3.2.1); secondly, (formal) supranational or global institutions that govern international trade and, for clean-tech specifically, international cooperation on environmental issues (section 3.2.2).

Some foreign actors may fulfil very specific roles (functions) in the domestic system, and to prevent repetition we will deal with this in the section on functioning (section 3.3).

3.2.1. Firms and global production networks

The production of technological products seldom occurs within the confines of a single firm, especially not if we consider this process to include product development (RD&D) as well as manufacturing, marketing, distribution, maintenance etc. [61, 65]. Firms may perform production processes cooperatively, in value chains in which each firm performs the production steps for which it has the highest levels of competitiveness, resulting in the most competitive solution for the whole of the process [66].

Such value chains are recognized in the TIS framework [23, 24]. There are, however, unique characteristics of such production networks when connections are formed between firms in advanced and emerging economies, because of the potential for international knowledge spill-overs [61, 66]. Global Production Networks (GPN) are typically conceptualized as being orchestrated by a lead firm (or ‘flagship firm’ [66]), that developed the intellectual property involved. The lead firm is typically based in an advanced economy, where it derives its competency for product development from the comparative availability of highly skilled labour and well developed clusters of technology intensive collaboration between firms, universities and research institutes [60, 61]. Lead firms will seek to outsource labour intensive production steps, whilst firms based in emerging economies may use their advantageous access to low-cost labour to compete for those production steps in the GPN.

Lead firms are very protective of their intellectual property but have to accept some dispersion of knowledge along the value chain [60]. Even when the less sophisticated production steps are outsourced, suppliers will at the very least need to know how to manufacture it, and to what technical quality requirements it should accord. Supplier firms will be better capable of fulfilling those requirements when the lead firm transfers technical and managerial knowledge on the production process [66]. Furthermore, competition amongst suppliers is high, and suppliers in emerging economies are aware of the competitive advantages that may come from investment in managerial capabilities and workforce training [67]. Over time, a build-up of knowledge, skills and experience in the supplier firm allows it to perform increasingly complex production steps and perform a bigger and more profitable share of the value chain [68]. Over longer periods of time, such ‘industrial upgrading’ has consequences for national economic development, with increased and more profitable firm activity, as well as increased demand for skilled, better paid labour [60, 61, 67].

Such industrial upgrading has been witnessed in the ‘Asian Tigers’. In the seventies and eighties of last century, these attracted much of the outsourced assembly and manufacturing of e.g. consumer electronics and auto parts, but now have globally successful industries for electronics, automobiles etc. [69-71]. Similar upgrading is underway in the Chinese wind industry. During the nineties, wind farm operators in China imported complete turbines, with only the turbine base and towers produced domestically [72, 73]. In the first half of last decade, Chinese nameplate turbines were mostly assembled from imported components [73, 74]. More recently, China's wind turbine industry has begun to specialize, with numerous domestic manufacturers of blades, structural bearings, gearboxes, and generators, reducing the demand for imports to only highly specialized components such as converters, spindles and gearbox bearings [75, 76].

3.2.2. Institutions

National policies are a crucial part of the domestic set of institutions for innovation, especially for clean-tech. At the same time, the 'emerging international economic order is a rules-based system whereby more and more previously domestic policies become the subject of international regulations' [77: p433]. The most relevant supranational institutions to clean-tech innovation are those governing international trade and of intellectual property rights, and those governing global efforts for environmental sustainability.

3.2.2.1. Institutions governing trade and intellectual property rights

Successful clean-tech innovation system formation requires government intervention in the form of e.g. the creation of protected 'niche' markets, subsidies on consumption and/or R&D, or government procurement that promotes environmental alternatives [23, 78].

In the design of such stimulus measures, member nations of the World Trade Organization (and virtually all countries are) may not discriminate between domestic and foreign products [79]. It is, for example, not allowed to create niche markets for domestically produced wind turbines by levying taxes on imported goods and services (border tax adjustments, or tariffs), nor is it allowed to introduce non-tariff barriers to trade, such as import quota. Industrial subsidies are also prohibited when exports disturb foreign markets (dumping), and in the strictest sense of the WTO it is not allowed to provide RD&D grants, if these are available only to domestic firms [79].

These restrictions may be more relevant for emerging economies, as these join the competition in global innovation systems in later phases. The more matured industries in advanced economies are likely less dependent on government support than the more embryonic industries in emerging economies. More matured global systems furthermore have larger market sizes with increased economic significance. This likely leads to increased international scrutiny on government stimulus measures, and this may limit the set of policies available to emerging economy governments to promote emerging domestic innovation systems.

There are, however, four important nuances to the restrictions as laid out by the WTO agreements.

First, many emerging economies have not been WTO member for very long, and new member nations are granted a transition period to comply with WTO rules. China became a WTO member in 2001, but was required to comply with trade barrier rules by 2005, and broader economic adjustments were evaluated annually for an eight year period [80].

Secondly, although the aim of the WTO is a complete removal of trade barriers between member nations, this is an unfinished process. Membership requirements for China were to reduce tariffs on industrial goods to 'an average of 9 per cent' [80]. The expected differences in benefits of full trade liberalization between advanced and emerging or developing economies are a focal point of the debate [81].

Third, some forms of government support are allowed ('non-sanctionable'). Government support can be provided for industrial research and pre-competitive development activities [79].

Fourth, the WTO has an agreement on government procurement, but few Emerging Economies, including China, are signatories to this separate agreement and cannot be sanctioned for non-compliance.

WTO members are automatically signatories to the agreement on 'Trade Related aspects of Intellectual Property rightS' (TRIPS). TRIPS stipulates minimum requirements for IPR regulation in member countries, including that foreign firms may register ownership over a patent or industrial design, and that their exclusive ownership will be protected for a period of 20 years (patents) or 10 years (industrial designs) [82].

3.2.2.2. Institutions governing environmental sustainability

Because of its societal value (environmental benefits) but limited potential for private financial gain, the development and utilization of clean-tech have received support from the governments worldwide. Part of that agenda is the diffusion of such technologies to countries with lesser technological and economic capabilities.

The most widely recognized in this regard are probably the UN's 'Agenda 21', which promotes global sustainable development, and the UNFCCC, which promotes climate change mitigation efforts. Both documents urge the transfer of environmentally sound technologies to developing parties as well as technological capacity-building and cooperation [2, 83]. Both speak of creating 'favourable access to' and allocation of funds to facilitate technology transfers.

The most formal institution for such technology transfers is the 'Clean Development Mechanism' (CDM). Under the CDM, 'Annex 1 parties' (circa the advanced economies) may fulfil part of their domestic GHG emission reduction obligations by carrying out reduction projects in non-Annex 1 parties. These projects are required to be 'additional' in the sense that they either introduce technologies that were either not previously employed in the projects host country, and/or that would be financially unattractive for private investment [84]. Far more bilateral/multilateral cooperation programmes for environmental sustainability exist, but we cannot give an exhaustive overview of these here.

3.2.2.3. Other supranational or global institutions

A few additional global institutions related to innovation deserve mention here. The Bretton Woods institutions (World Bank and IMF) often supply finance as well as technical assistance for projects that promote the use of clean-tech in developing and emerging economies [61]. The private banking and investment industry is highly internationalized and can provide capital necessary for business and projects. Quality control and certification of technological equipment can be performed by organizations such as TÜV, originally a German organization, but now a globally recognized institution for such services.

3.3. Step 3: Mapping the functional pattern

In this section we elaborate how transnational linkages may influence the functioning of domestic innovation systems. We separately deal with each of the seven systems functions; 'Knowledge development and diffusion' in 3.3.1, 'Influence on the direction of search' in 3.3.2, 'Entrepreneurial experimentation and materialization' in 3.3.3, 'Market formation' in 3.3.4, 'Resource mobilization' in 3.3.5, 'Legitimation' in 3.3.6, and 'Development of positive externalities' in 3.3.7. Table 1, at the end of section 3.3 gives an overview of the transnational linkages in the seven system functions.

3.3.1. Knowledge development and diffusion

In system approaches to innovation, the development of new knowledge is regarded to be central to the process of economic change [24]. Knowledge generation is understood to include basic research and the R&D stage of the technological lifecycle [85, 86]. It can be measured by analysing the number, quality and orientation of scientific publications, patents and R&D projects [23]. The literature on innovation in developing and emerging economies often points to the development of knowledge as a weaker system function, making it the basis for the notion of international technology transfer [7, 57].

The diffusion of knowledge in the TIS framework is defined as interaction within networks, where actors from different backgrounds, i.e. academics, firms, government, and markets exchange information about the innovation [24]. Examples are how policy makers may seek to be informed of the latest technological insights before defining standards and appropriately ambitious targets, user-producer interactions etc. [24]. In national level TIS analyses, there is some recognition of transnational diffusion of knowledge, in for instance scientific and industry association exchanges that are often organized on an international level.

There is less focus in the TIS framework on firm-to-firm exchanges of R&D products in the form of designs, licenses or patents. Initial manufacturing activity in certain technological fields in technologically lagging countries typically seeks to offer lower-cost alternatives of existing manufacture. The knowledge to initiate or improve production may come from such R&D products, or even from the manufacture itself ('reverse engineering'). Firms therefore make careful considerations in what knowledge, and how, they are willing to transfer, as these products form the basis for their competitiveness and too much transfers would induce the risk of creating new competitors [25, 73]. When entering markets in developing or emerging economies, a weaker intellectual property rights regime adds to the reluctance to transfer knowledge [87].

The firm itself may also act as the vessel through which knowledge is conveyed over national borders [88-90]. A firm has a range of possible strategies to enter a foreign market. This may be realized by market expansion, but the firm may also choose to be more strongly connected organizationally. This can be realized though either foreign direct investment, a subsidiary firm, the creation of supplier networks, joint ventures with a domestic partner or relocation decisions of manufacturing and/or R&D activities [88, 91, 92], although most corporate R&D is performed in the home nation even after having internationalized their business [93]. Such firm cooperation increases organizational proximity, which may be as important to providing opportunities for knowledge spill-overs as is geographical proximity in technology clusters, or 'regional innovation systems' [94, 95].

Emerging economy governments may encourage transnational firm-to-firm cooperation and knowledge exchange through tax breaks for certain forms of cooperation, better IP protection, or even by demanding certain transfers as a condition for market entry. They also have a key role in making the most out of the opportunities for technological cooperation and assistance for clean-tech offered by multilateral or global institutions. This includes the selection or promotion of preferred technologies or cooperation mechanisms, and setting up agencies that perform technological needs assessments and act as the domestic counterpart in the management of technology transfer projects [57, 58, 96, 97].

A more recent trend in knowledge transfers from advanced to emerging economies is the merger with or acquisition of knowledge intensive firms in advanced economies by firms from emerging economies, a trend that challenges the usual power distribution as suggested by the 'flagship plus suppliers' model that dominates the literature on Global Production Networks [98, 99]. For example, in 2009, the Chinese wind turbine manufacturer acquired the German company Vensys, which had served as its source for designs for many years before [99]. Similarly, Suzlon, the leading wind turbine manufacturer from India has been 'shopping' on the global knowledge market for partners for different turbine components [100]. Sufficient market share and capital build-up allows emerging economy firms to gain more control of global production networks. Even if firms from advanced economies continue to perform knowledge production in this GPN, they have taken on the role of suppliers. Government policy may influence the form and extent of cooperation sought after by foreign and domestic firms (see 3.3.2 'Influence on the direction of the search' and 3.3.4 'Market formation').

3.3.2. Influence on the direction of search

The influence on the direction of the search encompasses TIS actors' efforts to ensure certain qualities in the technological solutions sought after. This includes the basic rationale e.g. low carbon power generation, but may be more specific, i.e. how much lower carbon generation, using which natural resources, limited secondary environmental impact etc. This search is the main selection process of technologies [12, 24].

The transnational context of the direction of the search is linked with the manner in which technologies are exported. The specific technological solution, either a product or production process, is a reflection of specific desires, needs and capabilities within the originating TIS. These do not necessarily match the recipient TIS, and domestic actors have less influence over the direction of the search outside the domestic context [101, 102]. Publicly organized technology transfer efforts, to economies with weaker technological capacities especially, do not necessarily include the technologies most needed by the recipient country [77, 103].

Governments in emerging economies may direct the search towards either foreign or domestic clean-tech manufacture, with a potential trade-off in relation to the policy goals for clean-tech. The expectable long time scale of domestic TIS formation may make it more attractive to import more matured foreign clean-tech manufacture for the immediate fulfilment of environmental targets. Longer term policy goals of domestic TIS formation would require demand for domestic manufacture, which will need government stimulus (see also 3.3.4, 'Market formation').

3.3.3. Entrepreneurial experimentation and materialization

This function refers to the effort and diversity with which alternative solutions are sought after, in (market) experiments. This function is performed by entrepreneurs that seek to transform knowledge into applications, or marketable products [24, 85]. Experimentation is characterized by high risk, because of uncertainties in technological performance and market demand. Entrepreneurs can be motivated to take such risk by the expectations on the potential windfall from first-mover advantages in case of successful experiments and market take-off [104, 105]. Indicative of strong experimentation is a large number and diversity of experiments and demonstration projects, and many new entrants into the market (that seek to capitalize on future markets) [21]. Entrepreneurial materialization is the investment in artefacts such as equipment, manufacturing plants and infrastructure [106]. Increased innovative activity in emerging economies means the global TIS expands as well.

A first transnational linkage is on the level of technology in the required entrepreneurial experimentation. Connected with the mechanisms elaborated under 3.3.1 'knowledge development and diffusion', TIS actors in emerging economies may shortcut much of the experimentation required to arrive at mature technological solutions [60]. The possibility to shortcut on experimentation is likely dependent on the type of transfer mechanisms and technology involved. Transfers in the form of turn-key solutions will provide less insight into the "how" and "why" of the design and manufacture of a technological solution, when compared with what cooperation a joint venture will offer. The type of technology involved matters, because some technologies that have matured in one domestic context may more readily be utilized in other domestic contexts. Any technological solution will have to be integrated into the broader economic system, which may or may not vary considerably from locale to locale. For example, all renewable power technologies have some requirements on power grid infrastructure and management. The resources required for hydropower generation, i.e. a flowing river, may be more comparable across different economic systems than are the resources for bio-power generation, i.e. the quality and quantity of available biomass resources. A technology that does not readily fit the receiving broader economic system will require more experimentation in order to develop successful solutions.

A second transnational linkage in entrepreneurial materialization is the degree and mechanisms through which foreign firms set up production facilities in emerging economies, and vice versa, that of emerging economy firms in advanced economies.

3.3.4. Market formation

In early formative stages of a TIS market demand is weakly articulated. New alternative technological solutions often have difficulties competing on a cost-performance basis with the conventional technological solutions offered through the incumbent system [24, 34]. Market demand is crucial, because the expectation of future revenue is what drives continued investment in technological development. New technological alternatives often require protection from direct competition with the incumbent system, in what have been termed 'nursing markets' or 'niches' [78, 107]. Government can help create nursing markets through fiscal incentives for consumption of the alternative vs. traditional solutions, with consumption quota or by acting as a launching customer [108, 109].

The transnational linkage in market formation can be found in the competitive strength of foreign and domestic manufacturers and the regulation of cross border trade. In initial stages of domestic TIS formation in emerging economies, it is likely that mature foreign industries are able to offer superior technological alternatives and out-compete domestic newcomers. Niches may be formed to protect embryonic domestic industries from direct foreign competition using tariffs or subsidies, localization quota, or preferential treatment in government procurement and private firm contracting [59, 73]. There will be a trade-off in the amount of protectionism, however, as contact with technologically leading firms may speed up domestic technological capacity development and thus TIS formation (as has been elaborated under 3.3.1. 'knowledge development and diffusion'). Vice versa, the domestic industry is also dependent on demand and entry rules of foreign markets.

A second transnational link in market formation specific to clean-tech is emissions trading, with the only currently active international trading systems being that for greenhouse gasses. This system creates additional value for emission reduction projects in developing and emerging economies, spurring foreign investment [110]. This spurs market formation and thus formation of domestic TIS.

3.3.5. Resource mobilization

Performing RD&D activities requires financial as well as human resources (i.e. skills). In early phases of TIS formation specific human resources may not have been developed for a lack of necessity before formation of the TIS. Capital is difficult to acquire because of the high uncertainty on both the possible technological prospects as well as the eventual economic value of products/solutions the TIS is seeking to supply.

For capital, transnational linkages exist in foreign direct investment, venture capital, and through relocation decisions, and with progressive formation of domestic TIS in emerging economies, outgoing direct investment becomes relevant (see also 3.3.1 'knowledge development and diffusion'). For clean-tech projects, funds may also be made available from the Global Environmental Facility, World Bank and Regional Development Banks, or bilateral development/environmental programmes. For low carbon technology specifically, funds can be made available through the CDM mechanism. These funds are aimed mostly at expanding the utilization of existing technologies rather than the development of new technologies.

In terms of human resources, education, especially at the university level, as well as scientific cooperation is strongly internationalised, and helps disseminate knowledge and skills. International university exchange programmes can help improve education levels of individuals from emerging economies [111]. To spur domestic TIS formation with such exchanges, it is crucial that nationals return to their home countries. Problems arise when there is a net outbound migration of skilled nationals that seek employment in countries with higher salaries and better job or business opportunities. This so-called 'brain-drain' has long been recognised as an issue for developing and emerging countries [112, 113]. Talented individuals with strong leadership and management experiences in (foreign) firms and science organizations are of high value to international competitiveness of firms, and by extension, industries and national innovation systems [114, 115].

Experiences in the Asian Tiger economies have made clear that at some stages of economic development, living conditions, labour and business opportunities will have improved to a point that nationals residing abroad increasingly seek to return. The experience, education and connection with foreign knowledge clusters and business that these individuals have, may spur development of the domestic industry and science complex [116]. This so-called 'reversed brain drain' may be stimulated by the provision of benefit packages to returnees, in headhunting programmes organized by industry or government agencies. China has such headhunting programmes in place; the national government has lured both foreign and Chinese nationals to work in key positions in industry, government and science by providing smoother visa procedures for talented individuals and their families, attractive research funds and high financial compensation (the so-called 'one-thousand' and 'ten-thousand' programmes) [117]. Both the national and local governments offer improved business start-up opportunities in so-called 'Returning Students Venture Parks', specifically for returnees, which offer infrastructural and financial (mostly tax breaks) benefits and smoother procedures for residency [112].

3.3.6. Legitimation

Legitimation is the recognition and valuation of societal benefits of the sustainability transition the TIS is seeking to produce. In national TIS evaluations, this refers to stakeholders' attitudes, lobbying and interest groups and debate in parliament and the media [21, 24].

A first transnational link in the creation of legitimacy is international environmental regimes. Negotiations in such regimes help converge individual parties' expectations of other parties' contributions to achieving a collective goal [118]. They serve to create collective management of a transnational environmental issue, which is more efficient than individual action [119]. Regimes may be formalized in treaties, but these formal agreements are not necessarily the only source of mutual influence over parties' behaviour. In terms of effects, i.e. whether environmental regimes and international pressure do indeed compel nations to take on more stringent environmental policies is still a subject of debate [120].

A second transnational link stems from the 'Porter hypotheses', which state that environmental regulation leads to environmental innovation; and innovation leads to consecutive international leadership of domestic industries [121]. The Porter hypotheses refer mostly to higher factor productivity in production processes, i.e. environmentally friendly will be economically efficient production. Leadership in clean-tech industries as their development has similarly been connected with stringent environmental legislation in the home countries of the firms involved [122, 123]. This possibility of long-term 'first mover advantage' in clean-tech industries has been used by politicians to legitimate initial additional costs of environmental regulation for firms or government spending [92, 124]. In contrast with the Porter hypotheses, concern over the international competitiveness of domestic industries when faced with stringent environmental legislation has been used to avert or stall both domestic and international policy schemes.

3.3.7. Development of positive externalities

The development of positive externalities refers to positive feedback processes, when accumulated TIS formation leads it to develop or strengthen activities that further spur TIS formation and better enable it to compete with the incumbent technological system [106].

A first transnational dimension is the global division of labour. Sufficiently successful TIS formation may lead to a specialization of firms, improving competition and product quality and reducing production cost. On the global scale, such division of labour may come with the establishment of Global Production Networks in which firms from advanced and emerging economies utilize competitive advantages originating from the relative availability of different economic resources in their respective home nations (see also section 3.2.1). Increased competition and the division of labour lead to reduced production costs and therefore a higher level of competitiveness of the technological alternative.

A second international component is related to the porter hypothesis and first mover advantage mentioned in '3.3.6 Legitimation'. The belief in possible windfalls from the support of environmental innovation becomes stronger when more nations develop stimulus programmes. Increased global support will increase market demand and increase the possible windfalls associated with an active domestic industry.

Furthermore, the enactment of strong support abroad may induce a sense of urgency. In order to occupy a favourable position in emerging global industries, one cannot fall behind in the global technology race. This notion, when concerning clean-tech, is perhaps best captured by the US 2011 state of the Union. More support for renewable energy industries was urged as current global developments were considered a 'sputnik moment' for clean energy. This statement came shortly after the US Energy Secretary had already warned of the US falling behind in the technological race on China and other countries [125].

Table 1. TIS functions: domestic system activities and international linkages

System function	Domestic system activities	Transnational linkages
1 Knowledge development and diffusion	• Basic R&D phase funding and activities, patenting and demonstration • Knowledge exchange in networks (e.g. workshops and conferences)	• Scholarly: International workshops, research collaboration, international exchanges of students and research fellows • Firm strategy: foreign direct investment, joint ventures, relocation decisions, merger and acquisitions • Trade in equipment, licenses, patents, technical support services • IPR and Trade related aspects of intellectual property rights (TRIPS)
2 Influence on the direction of search	• Steering tech development, e.g. in the direction of low carbon technologies • Specifications in regulatory or fiscal instruments • Future outlook of alternative vs. traditional	• Match/mismatch of foreign technological solutions with domestic needs • Environmental and industrial policy goals and the preference for foreign or domestic manufacture
3 Entrepreneurial experimentation and materialization	• Demonstration plants/activities • Diversification of activities of incumbents • Variety in technological options considered • New entrants in market	• Possibilities to shortcut experimentation with matured foreign solutions • Transferability and adaptability of foreign solutions to broader economic systems • Degree and firm strategy of foreign firms in domestic industry
4 Market formation	• Value creation for the consumption of the tech; both through tech. improvements and pricing policies • Regulatory or fiscal instruments; feed-in tariffs, consumption quota, targets	• Domestic and foreign markets and competitive advantage of domestic and foreign firms therein • Regulation of cross border trade: localization quota, import taxes and export subsidies, non-tariff barriers • International cap-and-trade systems for carbon emissions
5 Resource mobilization	• Capital • Human resources • Complementary resources	• Foreign direct investment, venture capital, international banking sector • CDM projects and CER taxation • Funds from Global Environmental Facility, Developmental Banks • Brain Drain vs. Head hunting programmes
6 Legitimation	• Recognition of societal benefits of the tech • Stakeholders attitudes towards the tech • Rise of interest groups and lobbying activities • Political debate in parliament and media	• International regimes on border crossing environmental issues, such as the UNFCCC negotiation track; • 'Strong Porter hypothesis' vs. international competiveness concerns
7 Development of positive externalities	• Learning curves driving down prices • Strength of political power of TIS actors • Improved division of labour	• Global division of labour; • 'Sputnik moment' for clean energy; i.e. urgency to move forward for fear of losing out to other nations

Source: 'functions' and 'domestic system activities' [21, 23]; 'transnational linkages' see sections 3.3.1-3.3.7.

3.4. Step 4: Assessing TIS functionality vis-à-vis the global TIS

The fourth step of the TIS framework is 'Assessing functionality'. More befitting a multi-scalar framing of TIS, with national TIS as constituents of a global TIS, is 'Assessing TIS functionality vis-à-vis the global TIS'. The premise in TIS functions analyses is that weakly performed functions may indicate a barrier to system formation [23]. In nationally framed TIS analyses, this implies judging the level of fulfilment of these seven system functions within the domestic context. When framed as a constituent of the global TIS, the domestic system may be more specialized in its reliance on or contribution to the global TIS for the fulfilment of some of the system functions.

In terms of economic activities, this reliance on or contribution to global TIS can be broken down into 1) generation of new knowledge, 2) application of that knowledge in manufacturing, and 3) utilization of the manufactured solution; following closely on the usual break-up of innovation into 'generation, diffusion and utilization' of technology [12].

The relevance of this more global view on TIS functioning can be clarified with a few examples of highly specialized constituent TIS. The Austrian wind power TIS, for example, contributes in the generation of knowledge to the global TIS. Austria is home to Windtec, a company that designs wind turbines and provides training for the manufacture according to those designs. Windtec's designs have been licensed to firms in China, Germany, India, Japan, and Korea, etc. but Austria itself has no domestic manufacturer of turbines [126]. The Chinese solar PV TIS contributes to the global TIS mostly in manufacturing. Up until recently, Chinese PV panel firms acquired manufacturing technologies, or even entire production lines, from foreign developers, whilst manufacture was virtually entirely destined for foreign markets [75]. Lastly, it is entirely possible to realize environmental targets with imported products from foreign TIS. Many EU member nations with biofuel policies depend to a high extent on imports of biodiesel and bio-ethanol, mostly from Argentine, Brazil, and the US, or other EU member nations [127, 128]. Another example is the international trade in electrical power generated from renewable resources.

3.5. Step 5: Identifying inducement and blocking mechanisms

The analysis of TIS structure and functioning serves to identify the mechanisms that induce or block further formation. When framing a national TIS as a constituent of a global TIS, this question should include how the global TIS may contribute to or frustrate domestic TIS formation and vice-versa, and under what circumstances. These mechanics have been dealt with in the sections on structure and functioning (sections 3.2 and 3.3).

3.6. Step 6: Specifying key policy issues

When it is clear what mechanisms block or induce TIS formation, analysts may suggest policy measures to improve TIS functioning [23]. Analysts should appreciate how the latecomer nature of emerging economy TIS and transnational linkages with the more matured global TIS affect this question.

An important policy question is how the economic circumstances and technological capabilities in the emergent TIS make certain forms of contribution to or reliance on the global TIS more suited or realistic. A key issue is the measure of dependency on foreign knowledge, equipment, firm activity, resources etc. In initial formative stages of the domestic TIS, governments of emerging economies would be ill advised to seek to build an entirely nationally rooted innovation system, i.e. to rely entirely on domestic actors for the development and manufacture of technological solutions. The possibility to draw on the accumulated investment, knowledge and experience in the global TIS may prevent development costs and time that would be incurred when following an entirely nationally rooted TIS formation strategy [60]. Conversely, an overly high and continued dependency on foreign technology is likely to frustrate domestic TIS development.

As such, there is a trade-off between the quick fix offered by importing and utilizing foreign technology and the long-term development of the domestic science-industry complex for a specific technology. Furthermore, the benefits from policy strategies closer to either end of this trade-off will change with progressing domestic capacity [60, 67, 95]. Crucially, the term 'emerging' and the notion of technological 'catch-up' do not describe a static developmental status, but an evolution from lagging behind to closing in on the global technological forefront. Policy makers ought to consider the likeliness of certain functional patterns of the domestic TIS arising within the global TIS, as well as the changing nature of the relationship between the domestic and global TIS over time.

Domestic TIS may develop different forms of specialization vis-à-vis the global TIS, and policy recommendations ought to suit the specialization selected in policy goals. National economic policy may pursue more knowledge intensive or more industrial economic activity. Policies for clean-tech development are furthermore driven by a dual track of industrial and environmental policies. National governments may pursue a domestic clean-tech industry for the fulfilment of domestic and/or foreign demand. Similarly, national governments may seek to fulfil environmental targets with domestically developed and/or manufactured technologies, but may also choose to rely on technology and/or equipment as offered by the global TIS.

4. Conclusion and discussion

The formation of TIS in emerging economies is subject to different mechanics than that in advanced economies. The latecomer nature of innovative activity in emerging economies implies that TIS at the global level will have matured, likely to the point where these have a transnational reach. For clean-tech especially, institutions exist that seek to spur global diffusion, making these transnational linkages more relevant for system formation in emerging economies.

The TIS literature, including much of the empirical testing of the list of system functions, has focused largely on the advanced economies and early phases of global TIS formation. The challenges and opportunities in the build-up of innovative activity in emerging economies are different, but these could however all be labelled using the seven system functions as identified by Bergek and colleagues [23]. We found no need to include more or different functions in order to appropriately grasp the issues that frustrate or spur clean-tech TIS formation in emerging economies.

This gives two inroads for future investigation. Firstly, the existing literature on innovation in emerging economies has used rather generic concepts such as 'improving absorptive capacity' and 'industrial upgrading' to describe the mechanics for improving innovation system functioning. The system functions of the TIS framework offer more analytical grasp. A current string of investigation is to determine what functions matter most in different phases of TIS maturation, in so-called 'motors of innovation' or 'virtuous circles of cumulative causation', including the blocking mechanisms and policy issues that are most pertinent in each phase [e.g. 36, 44, 129, 130]. Secondly, analysts have been in search of possible 'typical' system failures (for certain categories of technologies) [35]. Both of these lines of investigation would offer insights into commonalities in TIS mechanics across different TIS. Although we found the same set of functions may be used to analyse emerging economy TIS, we would require a fair number of empirical applications before we could comment on differences or commonalities in types of cumulative causation or system failures with those found in advanced economy case studies. The scarcity of empirical work on emerging economies clean-tech TIS in contrast with their fast increasing contribution to global environmental pressure and innovative activity justifies more such attention in any case.

We have focused on the role of transnational linkages in emerging economy TIS formation, but there is evidence of their relevance for advanced economy TIS, especially in more mature global TIS. The formation of TIS for both first and second generation biofuels for transport is subject to a well-developed global market for biofuels, with biofuel production concentrated in a small number of countries [131, 132]. The Dutch wind power TIS is often perceived as having failed to mature due to the lack of a domestic manufacturing industry [e.g. 133]. Nevertheless, 3.5 per cent of Dutch electricity consumption is wind power [134], and the Netherlands has a number of design houses, e.g. Darwind B.V., STX Windpower B.V. and EWT International, that supply to manufacturers . This would not have been possible without transnational linkages with a vibrant global TIS.

In conclusion, in our search for geographical dimensions in the TIS framework, we have zoomed in on the linkages between the national and the global. Other work on the geography of innovation has stressed the importance of regions or clusters, and how these may form the nodes for globally connected innovation systems [30, 95, 135]. The most proper geographic delineation of innovation systems will probably remain subject of discussion for some time, and is likely always dependent on the sort of analysis made. As for national borders, our framework concurs with the notion that these do not confine technology, but this should not be confused to imply that national borders are of no relevance in global TIS formation patterns.

Footnote

1) Throughout this paper we use a country grouping suggested by the World Bank [4], which groups countries into four groups, being 1) advanced economies, i.e. the industrialized nations, including Australia, Canada, the EU-15, Iceland, Japan, New Zealand, Norway, Switzerland, and the United States of America; 2) emerging economies, countries with a pace of economic growth higher than that of the advanced economies or developing countries, consisting of a total of 74 countries; 3) major emerging economies, a subset of six emerging economies - Brazil, China, India, Indonesia, the Republic of Korea, and the Russian Federation-, whose large economic size combined and especially high growth rates means that they will collectively account for more than half of all global growth by the year 2025; 4) developing economies, a group of 89 countries with a low level of economic development and low pace of economic growth.

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References

[1] P. Raskin, G. Gallopin, P. Gutman, A. Hammond, R. Swart, Bending the Curve: Toward Global Sustainability. A report of the Global Scenario Group, Stockholm Environment Institute, (1998).

[2] UNCED, Agenda 21: The United Nations program of action from Rio, (1992).

[3] L. Dendler, M. Sharmina, D. Calverley, M. Traut, Sustainable futures: Multi-disciplinary perspectives on multi-level transitions, Environ. Devel., 2 (2012) 2 5.

[4] World Bank, Global Development Horizons 2011 -- Multipolarity: The New Global Economy, (2011).

[5] European Commission, Emission Database for Global Atmospheric Research (EDGAR), release version 4.2. Available online via edgar.jrc.ec.europe.eu, last accesed Aug. 30th '12, (2012).

[6] IPCC, Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007, in: B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (Eds.), Cambridge university press, Cambridge, United Kingdom and New York, NY, 2007.

[7] OECD, Invention and transfer of environmental technologies, OECD studies on environmental innovation, (2011).

[8] T. Foxon, P. Pearson, Overcoming barriers to innovation and diffusion of cleaner technologies: some features of a sustainable innovation policy regime, J. Clean. Prod., 16 (2008) S148 S161.

[9] M. Abramovitz, Catching Up, Forging Ahead, and Falling Behind, J. Econ. Hist., 46 (1986) 385 486.

[10] E.B. Viotti, National Learning Systems: A new approach on technological change in late industrializing economies and evidences from the cases of Brazil and South Korea, Technol. Forecast. Soc. Change, 69 (2002) 653 680.

[11] B.-Å. Lundvall, B. Johnson, E.S. Andersen, B. Dalum, National systems of production, innovation and competence building, Res. Pol., 31 (2002) 213 231.

[12] B. Carlsson, R. Stankiewicz, On the nature, function and composition of technological systems, J. Evol. Econ., 1 (1991) 93 118.

[13] C. Freeman, Technology, policy, and economic performance: lessons from Japan, Pinter Publishers, London, 1987.

[14] C. Freeman, The ‘National System of Innovation’ in historical perspective, Cambridge J. Econ., 19 (1995) 5 24.

[15] B. Truffer, The need for a global perspective on sustainability transitions, Environ. Devel., 3 (2012) 182 183.

[16] M.A. Levi, E.C. Economy, S.K. O'Neil, A. Segal, Energy Innovation; Driving Technology Competition and Cooperation Among the U.S., China, India, and Brazil. Report of the Council on Foreign Relations, (2010).

[17] Pew Environment Group, Who's winning the clean energy race? Growth, Competition and Opportunity in the World's largest economies, (2012).

[18] BTM, International wind energy development - World market update. Several years used, (2011).

[19] REN21, Renewables 2012 Global status report, REN21 secretariat, Paris, 2012.

[20] CEPP, China Electric Power Yearbook, several years used, Beijing, 2012.

[21] A. Bergek, M. Hekkert, S. Jacobsson, Functions in innovation systems: a framework for analysing energy system dynamics and identifying goals for system-building activities by entrepeneurs and policymakers, in: T.J. Foxon, J. Köhler, C. Oughton (Eds.) Innovation for a low carbon economy - economical, institutional and management approaches, Edward Elgar, Cheltenham and Northampton, 2008.

[22] J. Markard, B. Truffer, Technological innovation systems and the multi-level perspective: Towards an integrated framework, Res. Pol., 37 (2008) 596 615.

[23] A. Bergek, S. Jacobsson, B. Carlsson, S. Lindmark, A. Rickne, Analyzing the functional dynamics of technological innovation systems: A scheme of analysis, Res. Pol., 37 (2008) 407 429.

[24] M.P. Hekkert, R.A.A. Suurs, S.O. Negro, S. Kuhlmann, R.E.H.M. Smits, Functions of innovation systems: A new approach for analysing technological change, Technol. Forecast. Soc. Change, 74 (2007) 413 432.
[25] D. Archibugi, C. Pietrobelli, The globalisation of technology and its implications for developing countries: Windows of opportunity or further burden?, Technol. Forecast. Soc. Change, 70 (2003) 861 883.
[26] B.-A. Lundvall, National systems of innovation: Towards a theory of innovation and interactive learning, Pinter Publishers, London, 1992.
[27] K. van Alphen, M.P. Hekkert, W.G.J.H.M. van Sark, Renewable energy technologies in the Maldives—Realizing the potential, Renew. Sustain. Energy Rev., 12 (2008) 162 180.
[28] P. Cooke, M. Gomez Uranga, G. Etxebarria, Regional innovation systems: Institutional and organisational dimensions, Res. Pol., 26 (1997) 475-491.
[29] B. Asheim, M. Gertler, The geography of innovation: regional innovation systems, in: J. Fagerberg, D. Mowery, R. Nelson (Eds.) The Oxford Handbook of Innovation, Oxford, 2005.
[30] C. Chaminade, J. Vang, Globalisation of knowledge production and regional innovation policy: Supporting specialized hubs in the Bangalore software industry, Res. Pol., 37 (2008) 1684 1696.
[31] F. Malerba, Sectoral systems of innovation and production, Res. Pol., 31 (2002) 247 264.
[32] R. Garud, P. Karnøe, Bricolage versus breakthrough: distributed and embedded agency in technology entrepreneurship, Res. Pol., 32 (2003) 277 300.
[33] J. Buen, Danish and Norwegian wind industry: The relationship between policy instruments, innovation and diffusion, Energy Policy, 34 (2006) 3887 3897.
[34] M.P. Hekkert, S.O. Negro, Functions of innovation systems as a framework to understand sustainable technological change: Empirical evidence for earlier claims, Technol. Forecast. Soc. Change, 76 (2009) 584 594.
[35] S.O. Negro, M. Hekkert, F. Alkemade, Seven typical system failures that hanper the diffusion of sustainable energy technologies. Paper presented at the Druid Summer Conference 2010, (2010).
[36] L. Coenen, R. Suurs, E. Van Sandick, Upscaling emerging niche technologies in sustainable energy: an international comparison of policy approaches. CIRCLE Lund Working Paper no. 2010/17, (2010).
[37] N. Løvdal, F. Neumann, Internationalization as a strategy to overcome industry barriers—An assessment of the marine energy industry, Energy Policy, 39 (2011) 1093 1100.
[38] B. Carlsson, Internationalization of innovation systems: A survey of the literature, Res. Pol., 35 (2006) 56 67.
[39] R.A.A. Suurs, M.P. Hekkert, Cumulative causation in the formation of a technological innovation system: The case of biofuels in the Netherlands, Technol. Forecast. Soc. Change, 76 (2009) 1003 1020.
[40] B.-A. Lundvall, Post script: innovation system research: where it came from and where it might go, in: B.-A. Lundvall (Ed.) National systems of innovation: toward a theory of innovation and interactive learning, Anthem Press, London and New York, 2010.
[41] G. Nemet, Demand-pull energy technology policies, diffusion and improvements in California wind power, in: T.J. Foxon, J. Köhler, C. Oughton (Eds.) Innovation for a low carbon economy - economical, institutional and management approaches, Edward Elgar, Cheltenham and Northampton, 2008.
[42] F. Alkemade, M.P. Hekkert, S.O. Negro, Transition policy and innovation policy: Friends or foes?, Environ. Innov. Soc. Transit., 1 (2011) 125 129.
[43] Z.F. Mohamad, The emergence of fuel cell technology and challenges for catching-up by latecomers: Insights from Malaysia and Singapore, Int. J. Technol. Glob., 5 (2011) 206 326.
[44] S.O. Negro, R.A.A. Suurs, M.P. Hekkert, The bumpy road of biomass gasification in the Netherlands: Explaining the rise and fall of an emerging innovation system, Technol. Forecast. Soc. Change, 75 (2008) 57 77.

[45] S.O. Negro, M.P. Hekkert, R.E. Smits, Explaining the failure of the Dutch innovation system for biomass digestion - A functional analysis, Energy Policy, 35 (2007) 925 938.
[46] R.A.A. Suurs, Motors of sustainable innovation - Towards a theory on the dynamics of technological innovation systems (PhD-thesis), Utrecht University, Utrecht, 2009.
[47] CACETC, China wind power - study report. As part of UNFCCC Technological needs assesment, (2000).
[48] A. Lema, K. Ruby, Between fragmented authoritarianism and policy coordination: Creating a Chinese market for wind energy, Energy Policy, 35 (2007) 3879 3890.
[49] P. Ru, Q. Zhi, F. Zhang, X. Zhong, J. Li, J. Su, Behind the development of technology: The transition of innovation modes in China's wind turbine manufacturing industry, Energy Policy, 43 (2012) 58 69.
[50] UNFCCC, CDM Registry. Available via cdm.unfccc.int/Registry/index.html, last accesed Aug. 30th '12, (2012).
[51] CRESP (China Renewable Energy Scale-up Program), National action plan for china's wind power industry development, (2005).
[52] State Council, State Council decisions on accelerating the creation and development of strategic emerging industries (In Chinese), (2010).
[53] MOF (Ministry of Finance), Management Regulations on Special Fund for the Industrialization of Wind Power Manufacturing Sector in China (MOF [2008] No. 476) (2008).
[54] NEA (National Energy Administration), Twelfth National Five-year Plan for Energy Technology, 2011-2015 (2011).
[55] R. Nelson, National innovation systems: a comparative analysis, Oxford University Press, New York and Oxford, 1993.
[56] W. Cohen, D. Levinthal, Absorptive Capacity: A New Perspective on Learning and Innovation, Adm. Sci. Q., 35 (1990) 128 152.
[57] R. Lema, A. Lema, Technology transfer? The rise of China and India in green technology sectors, Innov. Dev., 2 (2012) 23 44.
[58] D.G. Ockwell, J. Watson, G. MacKerron, P. Pal, F. Yamin, Key policy considerations for facilitating low carbon technology transfer to developing countries, Energy Policy, 36 (2008) 4104 4115.
[59] B.M. Hoekman, K.E. Maskus, K. Saggi, Transfer of technology to developing countries: Unilateral and multilateral policy options, World Devel., 33 (2005) 1587 1602.
[60] D. Ernst, Global production networks and the changing geography of innovation systems. Implications for developing countries, Econ. Innov. New Tech., 11 (2002) 497 523.
[61] J. Henderson, P. Dicken, M. Hess, N. Coe, H.W.-C. Yeung, Global production networks and the analysis of economic development, Rev. Int. Polit. Econ., 9 (2002) 436 464.
[62] C. Binz, B. Truffer, L. Li, Y. Shi, Y. Lu, Conceptualizing leapfrogging with spatially coupled innovation systems: The case of onsite wastewater treatment in China, Technol. Forecast. Soc. Change, 79 (2012) 155 171.
[63] C.-H. Miao, Y. Wei, H. Ma, Technological Learning and Innovation in China in the Context of Globalization, Eurasian Geogr. Econ., 48 (2007) 713 732.
[64] M. Fromhold-Eisebith, Effectively linking international, national, and regional innovation systems: insights from India and Indonesia, in: B. Lundvall, P. Intarakumnerd, J. Vang (Eds.) Asia's innovation systems in transition, Edward Elgar, Cheltenham and Northampton, 2006.
[65] G. Gereffi, J. Humphrey, T. Sturgeon, The governance of global value chains, Rev. Int. Polit. Econ., 12 (2005) 78 104.
[66] D. Ernst, L. Kim, Global production networks, knowledge diffusion, and local capability formation, Res. Pol., 31 (2002) 1417 1429.
[67] G. Gereffi, K. Fernandez-Stark, Global Value Chain Analysis: A primer. Center on Globalization, Governance & Competitiveness, (2011).

[68] D.L. Levy, Political Contestation in Global Production Networks Acad. Manag. Rev., 33 (2008) 943 963.
[69] S. Lall, Learning from the Asian Tigers: Studies in Technology and Industrial Policy, Palgrave Macmillan, London, 1996.
[70] L. Kim, Imitation to innovation: the dynamics of Korea's technological learning, Harvard Business School Press, 1997.
[71] C. Freeman, L. Soete, The economics of industrial innovation, 3 ed., Pinter, London, 1997.
[72] D.J. Lew, Alternatives to coal and candles: wind power in China, Energy Policy, 28 (2000) 271 286.
[73] J.I. Lewis, R.H. Wiser, Fostering a renewable energy technology industry: An international comparison of wind industry policy support mechanisms, Energy Policy, 35 (2007) 1844 1857.
[74] J. Han, A.P.J. Mol, Y. Lu, L. Zhang, Onshore wind power development in China: Challenges behind a successful story, Energy Policy, 37 (2009) 2941 2951.
[75] RED (Sino-Danish Renewable Energy Development Programme), The Renewable Energy Industrial Development Report 2010. Industry report, (2011).
[76] GWEC (Global Wind Energy Council), Global Wind report 2007; update of May 2008, (2008).
[77] S. Radosevic, International technology transfer policy: from “contract bargaining” to “sourcing”, Technovation, 19 (1999) 433 444.
[78] G.F. Nemet, Demand-pull, technology-push, and government-led incentives for non-incremental technical change, Res. Pol., 38 (2009) 700 709.
[79] GATT, Agreement on Subsidies and Countervailing Measures, (1994).
[80] T. Rumbaugh, N. Blancher, China: International trade and WTO accession. IMF working paper WP/04/36, (2004).
[81] K. Anderson, W. Martin, D. van der Mensbrugghe, Doha Merchandise Trade Reform: What Is at Stake for Developing Countries?, World Bank Econ. Rev., 20 (2006) 169 195.
[82] GATT, Agreement on Trade-Related Aspects of Intellectual Property Rights, Including Trade in Counterfeit Goods, (1994).
[83] UNFCCC, United Nations Framework Convention on Climate Change, (1992).
[84] UNFCCC, Kyoto Protocol to the United Nations Framework Convention on Climate Change, (1997).
[85] A. Bergek, S. Jacobsson, B. Carlsson, S. Lindmark, A. Rickne, Analyzing the dynamics and functionality of sectoral innovation systems - a manual. Paper presented at the DRUID Tenth Anniversary Summer Conference, Copenhagen, Denmark, June 27-29, (2005).
[86] B. Carlsson, S. Jacobsson, M. Holmén, A. Rickne, Innovation systems: analytical and methodological issues, Res. Pol., 31 (2002) 233 245.
[87] B. Smarzynska Javorcik, The composition of foreign direct investment and protection of intellectual property rights: Evidence from transition economies, Europ. Econ. Rev., 48 (2004) 39 62.
[88] N. Rosenberg, C. Frischtak, International technology transfer - concepts, measures and comparisons, Praeger, New York, 1985.
[89] D.J. Teece, Technology transfer by multinational firms: the resource costs of transferring technical know-how, Econ. J., 87 (1977).
[90] D.J. Teece, Firm capabilities and economic development: implications for the newly industrializing economies, in: L. Kim, R.R. Nelson (Eds.) Technology, learning and innovation: experiences of newly industrializing economies, Cambridge university press, Cambridge, 2001.
[91] J. Cantwell, The theory of technological competence and its application to international production, in: D. McFetridge (Ed.) Foreign investment, technology and economic growth, University of Calgary Press, Calgary, 1991.
[92] U.S. Brandt, G.T. Svendsen, Climate change negotiations and first-mover advantages: the case of the wind turbine industry, Energy Policy, 34 (2006) 1175 1184.

[93] P. Patel, K. Pavitt, National systems of innovation under strain: the internationalisation of corporate R&D, in: R. Barrell, G. Mason, M. O'Mahony (Eds.) Productivity, innovation, and economic performance, Cambridge Universtity Press, Cambridge, 2000.
[94] A. Amin, Spatialities of globalisation, Environ. Planning A, 34 (2002) 385 399.
[95] N.M. Coe, M. Hess, H.W.-c. Yeung, P. Dicken, J. Henderson, 'Globalizing' regional development: a global production networks perspective, Trans. Inst. Br. Geogr., 29 (2004) 468 484.
[96] A.M. Mattoo, K. Olareagga, M. Saggi, Mode of foreign entry, technology transfer, and FDI policy, J. Devel. Econ., 75 (2004) 95 111.
[97] OECD, Achieving the successful transfer of environmentally sound technologies: trade related aspects. OECD trade and environment working paper No. 2005-02, OECD, Paris, 2005.
[98] N.M. Coe, P. Dicken, M. Hess, Global production networks: realizing the potential, J. Econ. Geogr., 8 (2008) 271 295.
[99] J.I. Lewis, Building a national wind turbine industry: experiences from China, India and South Korea, Int. J. Technol. Glob., 5 (2011) 281 305.
[100] J.I. Lewis, Technology acquisition and innovation in the developing world: Wind turbine development in China and India, Stud. Comp. Int. Dev., 42 (2007) 208 232.
[101] E. Martinot, A. Chaurey, D. Lew, J.R. Moreira, N. Wamukonya, Renewable energy markets in developing countries, Ann. Rev. Energy Env., 27 (2002) 309 348.
[102] IEA, Technology without borders, case studies of successful technology transfer, OECD/IEA, Paris, 2001.
[103] S. Peterson, Greenhouse gas mitigation in developing countries through technology transfer?: a survey of empirical evidence, Mitig. Adapt. Strateg. Glob. Chang., 13 (2008) 283 305.
[104] I.S.M. Meijer, M.P. Hekkert, J.F.M. Koppenjan, The influence of perceived uncertainty on entrepreneurial action in emerging renewable energy technology; biomass gasification projects in the Netherlands, Energy Policy, 35 (2007) 5836 5854.
[105] F.W. Geels, From sectoral systems of innovation to socio-technical systems - Insights about dynamics and change from sociology and institutional theory, Res. Pol., 33 (2004) 897 920.
[106] A. Bergek, S. Jacobsson, B.A. Sandén, 'Legitimation' and 'development of positive externalities': two key processes in the formation phase of technological innovation systems, Tech. Anal. Strateg. Manag., 20 (2008) 575 592.
[107] F.W. Geels, Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study, Res. Pol., 31 (2002) 1257 1274.
[108] R. Kemp, J. Schot, R. Hoogma, Regime shifts to sustainability through processes of niche formation: The approach of strategic niche management, Tech. Anal. Strateg. Manag., 10 (1998) 175 195.
[109] R. Hoogma, R. Kemp, J. Schot, B. Truffer, Experimenting for sustainable transport futures. The approach of strategic niche management, Routledge, London, 2002.
[110] N.E. Hultman, S. Pulver, L. Guimarães, R. Deshmukh, J. Kane, Carbon market risks and rewards: Firm perceptions of CDM investment decisions in Brazil and India, Energy Policy, In Press, Corrected Proof (2010).
[111] J.A. Hansen, M. Lehmann, Agents of change: universities as development hubs, J. Clean. Prod., 14 (2006) 820 829.
[112] A. Saxenian, From Brain Drain to Brain Circulation: Transnational Communities and Regional Upgrading in India and China, Stud. Comp. Int. Dev., 40 (2005) 35 61.
[113] C.B. Keely, Return of Talent Programs: Rationale and Evaluation Criteria for Programs to Ameliorate a 'Brain Drain', Int. Migr., 24 (1986) 179 189.
[114] R. Taylor, China's Human Resource Management Strategies: The Role of Enterprise and Government, Asian Bus. Manag., 4 (2005) 5 21.
[115] J.V. Beaverstock, S.J.E. Hall, J.R. Faulconbridge, The internationalization of Europe's contemporary transnational executive search industry, in: J.W. Harrington, W. Daniels (Eds.)

Knowledge-based services, internationalization and regional development, Ashgate Publishing, Hampshire/Burlington, 2006.
[116] A. Saxenian, Transnational Communities and the Evolution of Global Production Networks: The Cases of Taiwan, China and India, Ind. Innov., 9 (2002) 183 202.
[117] C. Cao, China's brain drain at the high end, Asian Popul. Stud., 4 (2008) 331 345.
[118] S.D. Krasner, Structural causes and regime consequences: regimes as intervening variables, in: S.D. Krasner (Ed.) International regimes, Cornell University Press, Ithaca and London, 1983.
[119] M. List, V. Rittberger, Regime theory and international environmental management, in: A. Hurrell, B. Kingsbury (Eds.) The international politics of the environment, Clarendon Press, Oxford, 1992.
[120] K. Holzinger, C. Knill, T. Sommerer, Environmental Policy Convergence: The Impact of International Harmonization, Transnational Communication, and Regulatory Competition, Int. Organ., 62 (2008) 553 587.
[121] M.E. Porter, C. Van der Linde, Toward a New Conception of the Environment-Competitiveness Relationship, J. Econ. Perspect., 9 (1995) 97 118.
[122] M. Beise, K. Rennings, Lead markets and regulation: a framework for analyzing the international diffusion of environmental innovations, Ecolog. Econ., 52 (2005) 5 17.
[123] M. Jänicke, Trend-setters in environmental policy: the character and role of pioneer countries, Europ. Env., 15 (2005) 129 142.
[124] M. Beise, K. Rennings, Lead Markets of Environmental Innovations: A Framework for Innovation and Environmental Economics. ZEW Discussion Paper No. 03-01, (2003).
[125] White House Office of the Press Secretary, Remarks by the President in State of Union Address (online transcript), (2011).
[126] EWEA, Registry of the European Wind Energy Association. Accesible via ewea.org/index.php?id=467, last accesed Aug. 30th '12, (2012).
[127] M.B. Fonseca, A. Burrell, H. Gay, M. Henseler, A. Kavallari, R. M'Barek, I.P. Domínguez, A. Tonini, Impacts of the EU biofuel target on agricultural markets and land use: a comparative modelling assessment. EC-JRC report nr. EUR 24449 EN - 2010, in: A. Burrell (Ed.), 2010.
[128] B. Flach, S. Lieberz, K. Bendz, B. Dahlbacka, EU-27 Annual Biofuels Report. USDA-FAS-GAIN report nr. NL1013, (2011).
[129] K.M. Hillman, R.A.A. Suurs, M.P. Hekkert, B.A. Sanden, Cumulative causation in biofuels development: a critical comparison of the Netherlands and Sweden, Tech. Anal. Strateg. Manag., 20 (2008) 593 612.
[130] R.A.A. Suurs, M.P. Hekkert, Competition between first and second generation technologies: Lessons from the formation of a biofuels innovation system in the Netherlands, Energy, 34 (2009) 669 679.
[131] T. Wiesenthal, G. Leduc, P. Christidis, B. Schade, L. Pelkmans, L. Govaerts, P. Georgopoulos, Biofuel support policies in Europe: Lessons learnt for the long way ahead, Renew. Sustain. Energy Rev., 13 (2009) 789 800.
[132] P. Lamers, C. Hamelinck, M. Junginger, A. Faaij, International bioenergy trade—A review of past developments in the liquid biofuel market, Renew. Sustain. Energy Rev., 15 (2011) 2655 2676.
[133] L.M. Kamp, R.E.H.M. Smits, C.D. Andriesse, Notions on learning applied to wind turbine development in the Netherlands and Denmark, Energy Policy, 32 (2004) 1625 1637.
[134] CBS Statline, Dutch online statitics database, accesible via statline.cbs.nl/StatWeb/?LA=en, last accesed Aug. 30th '12, (2012).
[135] C. Chaminade, Exploring the role of regional innovation systems and institutions in global innovation networks. CIRCLE Working Paper 2011/15, (2011).

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