Global Green Growth Institute

A Guide to Innovation System Analysis for Green Growth

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Abbreviations

BA – Business Angel

BERD – Business Enterprise Research and Development

BoP – Bottom of the Pyramid

FDI – Foreign Direct Investment

FTE – Full-Time Equivalent

HEI – Higher Education Institute

HERD – Higher Education Expenditures in Research and Development

ICT – Information and Communications Technology

IO – International Organization

IPR – Intellectual Property Rights

IS – Innovation System

NGO – Non-Governmental Organization

PEF – Private Equity Fund

PRO – Public Research Organization

RD&D – Research, Development & Demonstration

S&T – Science and Technology

SME – Small and Medium-Sized Enterprises

SNA – Social Network Analysis

VC – Venture Capital

Executive summary

Innovation is at the heart of sustained economic growth and prosperity for both advanced and developing countries. Broadly defined as the introduction of new technologies and practices into an economy, innovation leads to positive spill-over effects and can enable a transition to a knowledge-based economy. By analyzing how innovation occurs, policymakers can develop more effective strategies to enable and accelerate it.

Despite the importance of innovation, there are many misconceptions about it. A major one is the mistaken assumption that it must involve “high technology”, requiring advanced scientific and technological resources. Instead, the lessons of innovation are relevant at all technological levels, because the introduction of technologies and practices to an economy for the first time – even if they are not globally new – faces similar challenges and barriers. Particularly within the context of green growth, where key socio-economic challenges like rural electrification or improved sanitation have to be addressed while minimizing environmental impact, innovation plays a critical role.

In order to analyze innovation and develop useful policy insights, it is important to approach the issue from a systemic perspective. There are many actors involved in the innovation process, including researchers, financiers, manufacturers, government, and consumers. Collectively and through their interactions, they constitute an “innovation system”. At the highest level, this system must perform certain functions in order to support successful innovative activity. Therefore, the analysis should not merely focus on the single actors but also on their interactions and how these contribute to the functioning of the system as a whole.

For innovation related to green growth, the structure and functions of the innovation system are similar to those for general innovation. However, in addition to the issues typical of innovation generally (such as market failures related to limited appropriability of economic benefits of knowledge), green growth innovation is also hindered by market failures related to the environment (pollution externalities). It is possible (and not uncommon) for an innovation system to successfully support innovation in many technology areas, but not in ones related to green growth. For this reason, it is necessary to focus on addressing both kinds of failures in order to drive innovation towards a green growth trajectory.

This document provides an introduction to the analysis of innovation systems as they relate to green growth. The discussion begins by reviewing the basic elements of innovation systems theory, and then describes in detail a method of analysis that can be used by green growth practitioners to diagnose the functioning of an innovation system and develop policy recommendations to improve it. The first step is selecting the level of analysis (national, regional, sectoral or technological). The identification of the appropriate level for a practitioner interested in green growth is not straightforward and the first section provides a brief description of the benefits and drawbacks of each approach. Once the level of analysis is chosen, the next step is to understand the structure of the innovation system through a mapping of its key elements. The second section describes this mapping, including the main building blocks of an innovation system and information that can be gathered to analyze them. The final step is assessing the functioning of the innovation system and developing recommendations to improve it. The third section provides guidance on how to make this assessment along four fundamental dimensions, namely (a) generating and sharing new knowledge; (b) facilitating access to markets; (c) providing access to financing; and (d) nurturing skills for innovation.

A. Introduction

Innovation is the introduction of new technologies and practices to a given society/economy.

This definition is important to understand from the outset, since it highlights the fact that innovation need not involve technologies or practices that are universally new. Introducing technologies or practices into any economy for the first time involves similar challenges and dynamics, even in cases when their use is widespread elsewhere. An important related point is that new knowledge or technology that is discovered or developed but not introduced into use in the economy is not innovation, but instead merely research or knowledge generation (World Bank, 2010).

Innovation lies at the heart of green growth.

Innovation is the cornerstone of sustained economic growth and prosperity for both advanced and less advanced countries (OECD, 2010). A recent analysis confirmed that build-up of innovation capacity has played a central role in the growth of successful developing countries (OECD, 2012). For countries desiring a greener growth trajectory and a transformative break with unsustainable paths, as well as the ability to compete in new low-carbon global value chains, innovation is crucial (WRI, 2011). Green growth innovation will need to happen at an unprecedented pace, but if successful, it can unlock both sustained and sustainable growth (GGKP, 2013). Unfortunately, developing countries are largely unprepared to practice and benefit from green growth innovation. To do so will require better analysis and understanding of green growth innovation (Brookings, 2013).

To understand innovation, analysts must take a systems-level approach, given the iterative, multi-actor and non-linear process that shapes knowledge generation.

Innovation is the result of a complex set of relationships among firms, universities, government, financiers, research institutes and users/consumers. These do not take place in a vacuum but are shaped by laws, policies and social norms. In order to properly frame this diversity of elements, the concept of an "innovation system" (IS) – the ensemble of actors and conditions that enable the creation and flow of knowledge and technology into the economy – has been increasingly adopted by national and regional authorities/agencies as well as by international organizations that are interested in promoting innovation (UNIDO, 2006; OECD, 2012; EU, 2014).

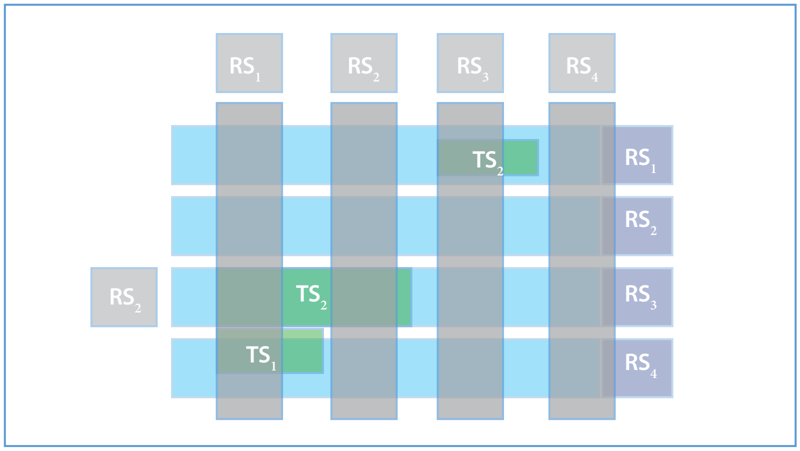
Innovation systems are usually analyzed at four different levels: national (NS), regional (RS), sectoral (SS) and technological (TS).

National- or regional-level studies identify the boundaries of an IS with geographical borders, like those of a country or a specific region (e.g. OECD Review of Norway, 2010; OECD Review of Mexican States, 2009). Sectoral-level studies focus on all the elements that interact "for the generation, adoption and use of (new and established technologies) and products that pertain to a specific sector" (Malerba, 2005). Finally, technological-level studies focus on a specific technology, which may be a sub-element of a sectoral system (when the technology is exclusive to a sector, such as electric vehicle engines) or may cut across several sectors (when the focus is a more "generic" knowledge field that is used in several sectors, such as ICT) (Bergek et al, 2008).

These different levels of analysis have several intersections.

For instance, a regional approach is likely to focus on policies, actors or organizations that play a role in multiple sectors, unless the whole geographic area of the study is specialized in one industry. A sectoral assessment might cover several regions if the sector's innovation activity is geographically dispersed. The level of assessment also determines what elements will be important in the analysis. For instance, a public procurement policy to buy only high-efficiency light bulbs might lead to a large impact on a particular industry or region – and thus be key to a sectoral or regional-level analysis – but it might be irrelevant from a national perspective and therefore excluded from the analysis (see Figure 1).

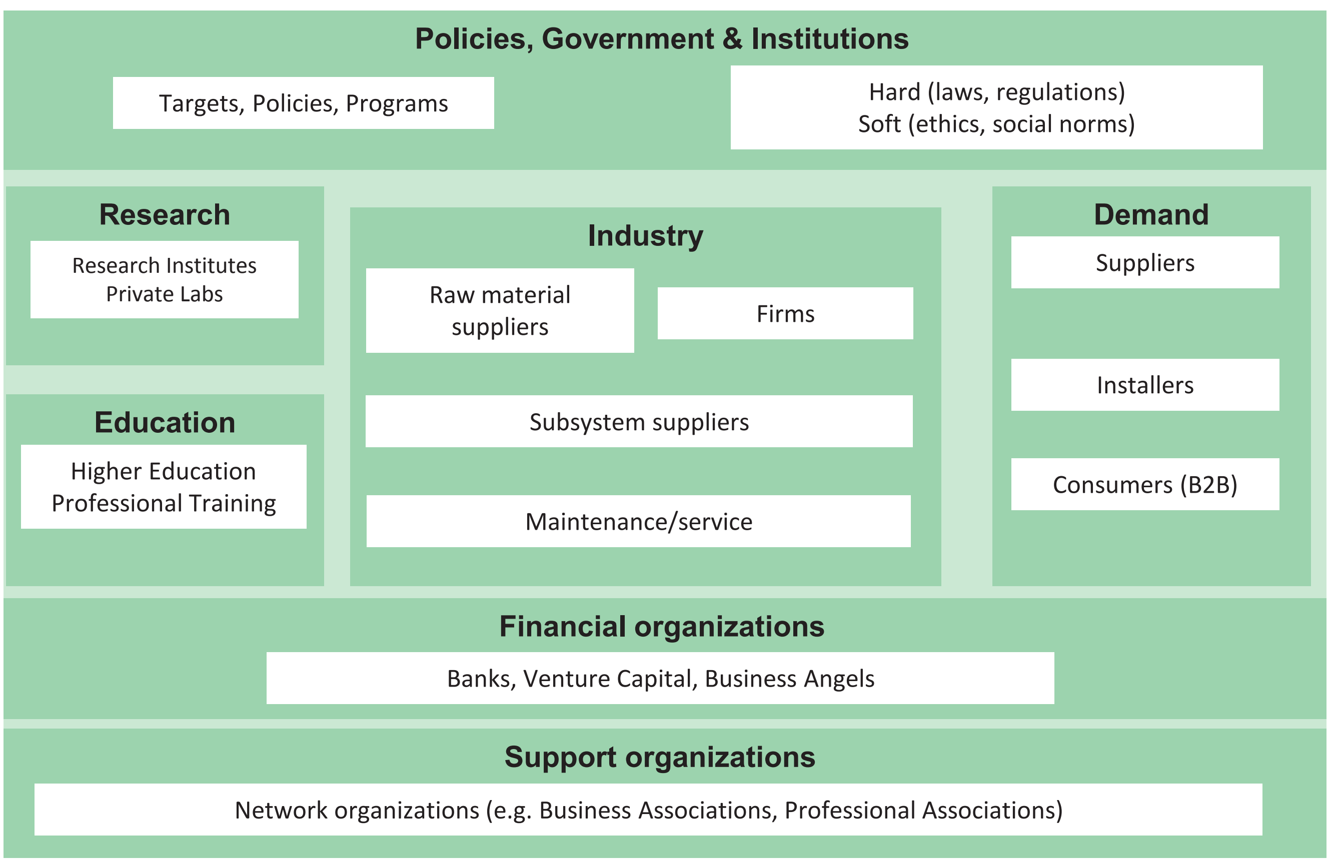
FIGURE 1. OVERLAP OF LEVELS OF ANALYSIS



In order to understand the functioning of an innovation system, it is necessary to understand its structure.

Regardless of the level of analysis chosen, innovation systems generally include the same basic elements: Higher Education Institutes (HEIs); Public Research Organizations (PROs); Government Agencies and Policies; Financial Organizations; Industry; Support Organizations (mainly network-enabling and political lobbying); and Institutions (see Figure 2). In addition to these elements, a sectoral or technological perspective also includes a more detailed analysis of users (Demand/Users), which can be an important source of innovation (Von Hippel, 2005), and builds on a sound understanding of the technology underlying the IS assessed. A key difference for green growth innovation system analysis is the need to also examine policies that serve to internalize environmental externalities, and therefore contribute to creating a market for green technologies.

FIGURE 2. STRUCTURE OF AN IS



Source: BASED ON HEKKERT ET AL, 2011

Once the structure of the IS is understood, the focus of analysis should move to the interactions among the different elements.

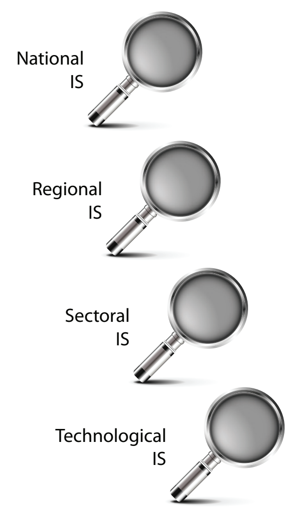
The goal of mapping the elements of an innovation system is not to list all the actors involved (which would be impossible) but instead to understand their roles, interactions, and possible barriers that might hinder the overall performance of the IS. The basic objective of mapping is to answer the question "what are the key elements of the IS under analysis?" while the study of their interactions answers questions such as: "how is knowledge shared among actors?", "what are the barriers to technology deployment?", etc. These questions highlight the "functions" of the IS, which include (a) generating and sharing new knowledge; (b) facilitating access to markets; (c) providing access to financing; and (d) nurturing skills for innovation (see below for further discussion of each function). Addressing these questions constitutes the object of analysis and ultimately the focus of policy advice. The final objective of the mapping exercise is to diagnose failures of these functions, in order to propose policies that could address them (e.g. "how can the knowledge exchange between actors be improved?", "how can the main financial barriers be eliminated?" etc.). Of course, the line between understanding the structure of an IS and the interaction among its key actors is subtle and these two steps are closely linked (Bergek et al, 2008).

Overall, innovation system analysis has three steps.

The first step is to define the relevant level of analysis (national, regional, sectoral or technological). The second step is to identify the structural components of the IS (actors, networks, institutions, etc.). Finally, the third step is to describe the activities and dynamics of the IS in terms of key functions, and develop recommendations for mechanisms to improve those functions. The key difference for green growth innovation, compared to traditional innovation system analysis, is the need to focus on both knowledge and environmental market failures, since these both constrain green innovation (see Figure 3).

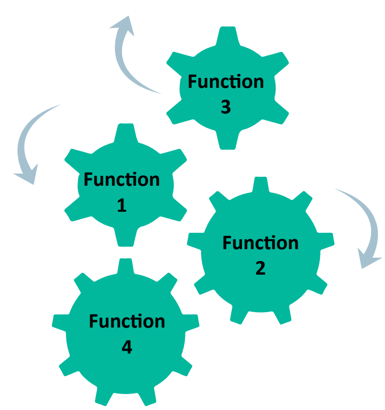
FIGURE 3. MACRO STEPS OF IS ANALYSIS

Step 1. Select "Tool" of Analysis



Step 2. Map Innovation System

Step 3. Assess functionality and recommend policies



B. Identifying and specifying the appropriate level/s of analysis

After having reviewed the literature to collect any previous relevant analysis, the first step is to decide whether to adopt a national, regional, sectoral or technological perspective.

If no assessment at the national level has been undertaken for the country under review, this is probably a good starting point since any lower level of analysis is likely to build on this, and it is likely to include information on framework conditions (see Box 1). In addition, achieving balanced and diversified growth in the long run requires sound "cross-cutting" innovation conditions, which are best analyzed using a national (or regional) IS approach. However, a focus on country-wide conditions necessarily leads to the adoption of a high-level perspective which is likely to fail to explain why some regions (or sectors) within a country are more (or less) innovative. For these reasons and given the success of specific regions (e.g. Silicon Valley) or the strategic importance of some sectors, subnational levels of analysis (regional, sectoral or technological) are often preferable.

A regional approach is of particular value when there is preliminary evidence of an emerging innovative cluster or special economic zones are enforced.

If a national economy is characterized by "islands of excellence" (regions with strong economic performance, often connected to Special Economic Zones in developing countries), these are good candidates for a Regional IS analysis. The key drawback of this approach is the possibility that relevant steps of a value chain could be missed in the analysis if they are based in different regions. In addition, the analyst should be aware that the success of a region might actually be the success of one or more sectors, which would suggest using a sectoral approach instead. This approach is usually applied to sub-national regions, in order to develop policies to improve that region's innovation performance or to draw lessons for other regions.

A sectoral or technological approach is advisable when specific segments of the innovation system are considered to have a higher potential or are of particular policy interest.

This is particularly true in the context of a wider policy objective, such as securing access to clean water or improving agricultural productivity. However, these approaches are complicated by the need to identify the appropriate level of disaggregation, since both products and technology components are actually composed of different subcomponents (e.g. should the study focus on solar panels or solar cells?). For a sectoral approach, this is generally based on the commercial value chain (e.g. wind blades, generators, towers and other components can be used as the basic units of analysis for the wind sector) and can sometimes use harmonized statistics on product classification, such as ISIC by the UN. The situation is more difficult for a technological approach, since the same technological subcomponent can be used in different configurations for various end-uses (e.g. activated carbon filters are used for water purification, air purification, and biogas treatment) so it is important to identify the range of end-uses to be included in the study (Coenen et al, 2009; Carlson B., 2003; Bergek et al, 2008).

Box 1. Framework conditions and green growth indicators

A country's overall innovation performance is influenced by several "framework conditions", which are often included in the analysis at a macro level (national or regional). These include macroeconomic stability, well-designed product and labour market regulations, low barriers to entrepreneurship, and openness to international trade and foreign direct investment (FDI). Competitive markets are central to innovation, although the circumstances under which competition has the best effect on innovation remains an open question (OECD, 2012). Robust law enforcement, which may be of particular concern in countries with a lower quality of public sector organizations or large unofficial economies, is particularly important for green technologies, because their adoption often relies on regulations to discourage polluting behavior (such as vehicle emissions standards) which are ineffective if enforcement is weak (Kojima et al, 2001). However, even the performance of OECD countries in these areas varies considerably, and therefore the lack of some of these conditions is not a show-stopper for innovation.

Several sources of information can be used to assess the framework conditions, including statistics from the World Bank, OECD and other organizations. From this standpoint, understanding the framework conditions for innovation should be complemented by understanding progress on the adoption of a green growth model. While no agreement exists yet, different organizations are working on the identification of a set of (possibly common) indicators for green growth (GGKP, 2013) which can be used to ground innovation analysis in a country's progress towards a sustainable development path. See Annex 1 for more discussion of green growth indicators.

A key difference between analyzing a sectoral or technological IS and a geographically identified IS lies in the different focus on users.

A geographically identified approach analyses countries across sectors/products and therefore often misses demand-side barriers, because many of these barriers are technology-specific (e.g. high switching costs or conflicting regulations). The only demand-related element often included in these analyses is a review of how public procurement policies are geared towards innovation. Alternatively, a technological/sectoral perspective can provide important insights about user demand, which is especially relevant for green innovation (because user demand for environmentally sustainable products and services is often a key factor) and inclusive innovation (because demand by "Bottom of the Pyramid" (BoP) populations is often hidden from the larger economy; USAID, 2014). In addition to this, technology users increasingly play a more active role of directly participating in the innovation process through crowd-sourced designs and funding, an element that could be missed in a geographically identified approach to the IS.

A common issue for both a technological and sectoral approach is the risk of losing sight of the multi-disciplinary nature of green innovation.

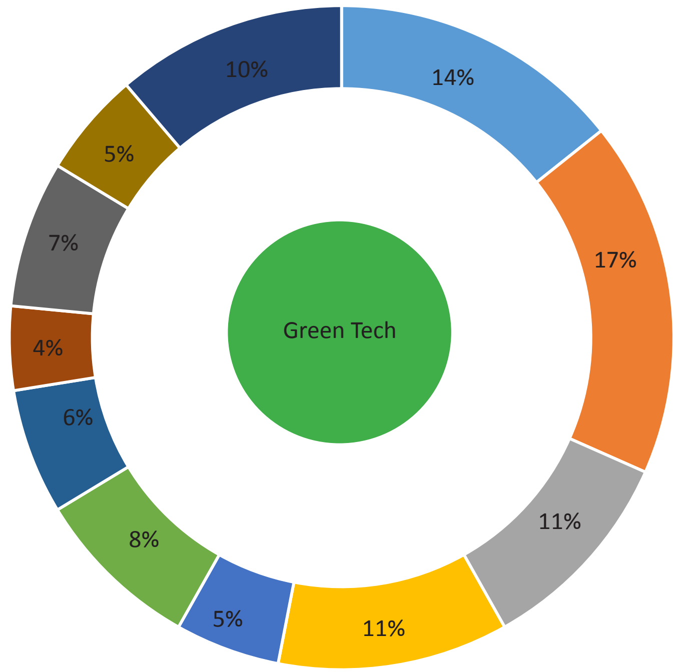
Green innovation is particularly cross-cutting (see Box 2), which introduces challenges in balancing breadth and depth of analysis. Therefore sectoral or technological-based analyses should still pay attention to the importance of cross-sectoral linkages.

Box 2. Green innovation is multi-disciplinary in nature

Increasingly, innovations are achieved through the convergence of different scientific fields and technologies. This interaction might also lead to the identification of whole new research areas. For example, “nanoscience” research has arisen from the interaction of physics and chemistry and is interdisciplinary in character.

This interdisciplinary nature is also evident for green technologies. A review of the literature cited in patents, a technique used to assess science and industry linkages, shows that green innovations frequently draw on material science, chemistry and engineering and therefore go beyond the narrow categories of environmental science (Igami, 2007; OECD, 201; Kozluk, 2012). This has important consequences in green innovation planning. For example, the development of smart grids, which has important implications for the energy sector, is likely to draw heavily on information and communications technologies (ICT), which would not be captured by a narrow focus on energy or environmental RD&D.

The innovation science link in green technologies



If the analysis chooses a sub national approach, the next step is to decide which regions (or sectors or technologies) to prioritize.

The criteria under which a specific sub national level is prioritized (a region, a sector or a technology) must be clearly defined in order to avoid overlooking important sources of growth. This decision might be grounded in the preliminary evidence built on a review of innovation performance, relevance within national economic activity (e.g. contribution to GDP, value added, export competitiveness, etc.) or specific national or regional plans. For instance, if a country has a national energy plan that is strongly focused on geothermal energy, then this would be a good choice for an analysis using a sectoral or technological approach. Another example could be the presence of a Special Economic Zone which might suggest the need to focus on specific regions. When choosing an area of focus, it is important to remember that innovation does not only take place in high-tech sectors; there can be important innovation in more traditional sectors such as leather or agriculture (see Box 3).

Box 3. How to choose a sector or technology of focus

Example 1: If a country already has established national plans or policies that include (or could include) industrial policies, this could be a starting point to identify sectors to prioritize in a green innovation system assessment. For instance, over the past decade Mexico has increased its commitment to address the challenges of climate change by setting ambitious emission reduction objectives, including greater use of renewables. The recent General Law on Climate Change set a target for the power sector to generate 35% of electricity by non-fossil-based sources by 2024, which represents a significant challenge. The potential contribution of the different renewable technologies could be used as preliminary criteria to identify sectors or technologies to analyze in more detail (SENER, 2013).

Example 2: If a country is facing challenges to its access to key export markets, this could also be a rationale for a focus area. For example, in order to comply with the EU import regulations that came into effect in 2005, the tomato industry in Morocco was required to decrease agrochemical contamination due to the use of pest control and of preserving agents during storage. Through investments in improved technology, the country met the food safety requirements but also reduced production and storage costs (UNIDO, 2011). This example also underlines that green innovation does not take place only in high-tech sectors and a full review of the economy should be conducted if a subnational approach is chosen.

Example 3: Several resource-rich countries have established goals of diversifying their economies, which could justify focusing on several different sectors or technologies. For example, in 2009 Kazakhstan launched a program to diversify its sources of foreign direct investment in order to reduce dependence on the oil & gas sector. In order to prioritize key sectors, an assessment of market attractiveness and country benefits was conducted. The assessment, based on variables like value added, trade balance, cost of labour and value-added share of the sector identified four key sectors to prioritize, including agri-business (OECD, 2010b).

The sectoral approach is often (but not always) the most useful for the purpose of green growth planning.

The identification of the appropriate level of analysis for a practitioner interested in green growth is not straightforward, and includes several considerations (see Table 1). First, as discussed, a national approach is often a necessary starting point (although often a national review has already been performed, so it may be redundant if the review is still current and if “green policies” have been included). In addition, achieving balanced and diversified growth in the long run requires good “cross-cutting” innovation conditions, which are best analyzed using a national (or regional) IS approach. However, in countries characterized by a small IS, it is more likely that innovation activities are concentrated in a few sectors or regions and therefore the trade-off (typical of innovation system analysis) between the assessment of overall performance and a more detailed understanding might favor a sectoral approach.

Sectoral/technological approaches are also better at identifying gaps in meeting the needs of BoP populations through innovation given the attention paid to demand/users (USAID, 2014). Finally, considering that a key priority of green growth planning is to identify the main sectors for a country's green growth, a sectoral approach could prove more useful and serve both as a diagnostic tool (to identify priority sectors) and as an operational tool (to understand how to improve those sectors' performance). Given these considerations, a sectoral approach is often the most useful within the context of green growth, although the appropriate level of analysis should always be chosen on case-by-case basis.

TABLE 1. LEVEL OF ANALYSIS OF INNOVATION SYSTEMS

Levels of Analysis	Main Benefits	Drawbacks
National	• Any lower level of analysis necessarily builds on an understanding of the overarching national elements • Long-run growth should be balanced and this requires good "cross-cutting" conditions for innovation, which are best analyzed nationally or regionally	• Within many countries, a few industries/regions are the main drivers of innovation • Lack of focus on market/demand
Regional	• Helps to explain why a specific geographic area is more successful in innovating than others within the same country (e.g. Silicon Valley) • Long-run growth should be balanced and this requires good "cross-cutting" conditions for innovation, which are best analyzed nationally or regionally	• The success of a region can actually be the success of a sector (geography might not be the relevant dimension of analysis) • Some relevant parts of a value chain will not be included in the analysis if they are localized in different regions • Lack of focus on market/demand
Sectoral	• Detailed understanding of sector-specific challenges/opportunities • Analysis matches sector economic data • Government planning and policies, and analyses by firms, tend to be sectoral or technology-specific, making policy recommendations more implementable • Demand-side analysis is usually included	• Need to repeat for all sectors of interest • Requires additional effort to capture phenomena of convergence across technologies/sectors
Technology	• Detailed understanding of technology-specific challenges/opportunities • Government planning and policies, and analyses by firms, tend to be sectoral or technology-specific, making policy recommendations more implementable • Demand-side analysis is usually included	• Need to repeat for all technologies of interest • Difficult to identify the appropriate level of technology dis-aggregation • Requires additional effort to capture phenomena of convergence across technologies/sectors

Box 4. An Example: Choosing the level of analysis.

As a first step, an analyst tasked with reviewing the Mexican Green Growth Innovation System gathers evidence of previous studies. He finds that analyses on Mexico's innovation system have been recently performed on the regional and national level by highly-reputed international organizations. These provide a comprehensive but generalized understanding of the country's innovation systems. More importantly, they highlight several barriers to innovation but do not focus on green growth.

The analyst also reviews National plans and he finds out that green growth is embedded in national policy at the highest level. The National Development Plan 2013-2018 includes as an objective promoting and guiding inclusive green growth that preserves natural capital, while generating wealth, competitiveness and employment. Ambitious greenhouse gas (GHG) emission reduction objectives have also been set by the General Law on Climate Change (enacted in October 2012) which establishes the interrelated targets of (a) cutting GHG emissions by 30% below BAU levels by 2020 and by 50% below 2000 levels by 2050; and (b) sourcing 35% of electricity generation from renewables by 2024.

The energy sector, among the highest contributors to GHG emissions, is receiving a large amount of political attention and recently underwent a process of privatization. Each year a national energy strategy document is produced and updated. The most recent Mexican National Energy Strategy (Estrategia Nacional de Energía, 2013-2027) sets ambitious deployment targets for several renewables and underlines the need for technical innovation in order to achieve these objectives.

A review of the national industrial base suggests that Mexico's current manufacturing base could be the foundation for the development of a national industry in several "green technologies". Its location next to the large US market coupled with its own large and growing internal market and its relatively low labour costs and manufacturing sophistication have already made Mexico an appealing manufacturing location for many firms in sophisticated industries such as automotive, auto parts, metalworking, electronics, and aerospace. In relation to renewable energy technology, the installed capacity of wind power grew quickly during recent years and the country has longstanding experience with geothermal power.

Given the elements gathered in this preliminary overview, including the potential impact on GHG emissions, existing policy priorities and the presence of a valuable industrial base, the analyst suggests performing a sectoral innovation system analysis, focusing on the energy sector.

C. Mapping the innovation system

Once the level of analysis is chosen, the next step is to understand the structure of the IS through a mapping of its key elements.

As noted before, the key elements of an IS are: Higher Education Institutes (HEIs); Public Research Organizations (PROs); Government Agencies and Policies; Financial Organizations; Industry; Support Organizations (mainly network-enabling and political lobbying); Demand/Users; and Institutions. While the study of HEIs, PROs and policies is relatively similar across the different levels of analysis, national or regional approaches take a more "macro" view and tend to exclude the demand side, while technological and sectoral approaches take a more "micro" view and include the technology underlying the sector as a key element of analysis. The following paragraphs outline the types of information that can be used to frame these elements. This list is not exhaustive, and the collected information should always be tailored to the level of analysis chosen (e.g. national Higher Education Expenditures in Research and Development (HERD) vs. HERD at the regional level, leading national HEIs vs. HEIs with expertise in specific sectors, etc.).

Higher Education Institutes (HEIs).

In emerging and developing countries, the potential contribution of PROs and HEIs is particularly relevant since the business sector is often weak, so research capacities are concentrated in universities and PROs (OECD, 2014). While policy attention is often concentrated on the link between HEI research and "third mission" activities (patenting, spin-offs, etc.), it is important to remember that the most significant contribution of HEIs to innovation often lies in the creation of capabilities through teaching and research-training activities (OECD, 2011b). The following list provides examples of information usually gathered when analyzing HEIs.

- The process to set the research agenda (across HEIs)
- RD&D expenditures (as a percentage of total public and national amounts); also known as HERD
- HEI researchers (FTEs)
- Source of financing (federal subsidies, state subsidies, student tuition fees, private sector funding, NGO/IO funding, and other external sources of income)
- Number of publications and citations per HEI (in order to identify the most relevant HEIs and their field(s) of specialization)
- Number of patent applications and of granted patents (number and field in order to understand areas of specialization)
- Commercialization of findings (e.g. Is there a law that allows and/or incentivizes commercialization of research findings? How do the main HEIs support commercialization of research findings?)
- Mechanisms for cooperative research with PROs and industry (e.g. What legal instruments -- research contracts, cooperative agreements, etc. -- do HEIs have available to enable work with other organizations, and how often are they used?)
- Tertiary-educated share of the population
- Education of the working-age population, graduates in science-related fields, PISA tests data, brain drain-gain data, etc

Public Research Organizations (PROs).

The term "public research organization" is used to refer to a heterogeneous group of organizations performing research as their main activity (as opposed to HEIs, where education is equally relevant) with varying degrees of government influence on their activities and funding (see Table 2). PROs play a key role in bridging the divide between academia and industry and often account for a large share of direct government RD&D expenditures. The diverse institutional arrangements of PROs also influence their roles within the innovation system; some PROs have very specific and stable missions while others perform basic and applied research in many fields (OECD, 2001). In the context of PROs, it is important to note the role of Centers of Excellence, which are designed to encourage outstanding research by providing particularly large-scale, long-term funding to research units. These have become popular in OECD countries (with over two-thirds of countries operating them), and there is growing interest in them from developing countries (OECD, A). The following list provides examples of information usually gathered when analyzing PROs.

- The process to set the research agenda (across PROs)
- RD&D expenditures (as a percentage of total public and national amounts)
- PRO researchers (FTEs)
- Source of financing (federal subsidies, state subsidies and external sources of income)
- Number of publications and citations per PRO (in order to identify the most relevant PROs and their field(s) of specialization)
- Number of patent applications and of granted patents (number and field in order to understand areas of specialization)
- Commercialization of findings (e.g. Is there a law that allows and/or incentivizes commercialization of research findings? How do the main PROs support commercialization of research findings?)
- Mechanisms for cooperative research with HEIs and industry (e.g. What legal instruments -- research contracts, cooperative agreements, etc. -- do PROs have available to enable work with other organizations, and how often are they used?)
- Teaching and training programs offered
- Presence of initiatives to establish Centre(s) of Excellence

TABLE 2. EXAMPLES OF PUBLIC RESEARCH ORGANIZATIONS

Type of PROs	Status	Main focus	Examples
Mission oriented centers	Often run by government departments or ministries at the national or sub-national level.	Perform research in specific topics or sectors; support to policy making.	CSIRO – Australia; NASA – US; NREL – US; CERI – Canada; INSERM –France; KACARE – Saudi Arabia; IPT – Brazil; IIE - Mexico
Public research centers and councils	Overarching institutions of considerable size.	Perform basic and applied research in several fields.	CNRS-France; CNR-Italy; CSIC-Spain, Max Planck Society-Germany; NRC- Canada; CONACYT-Mexico; Polish Academy of Sciences; Russian Academy of Sciences; Chinese Academy of Sciences; NISLT - Nigeria
Public research centers and councils	Overarching institutions of considerable size.	Perform basic and applied research in several fields.	CNRS-France; CNR-Italy; CSIC-Spain, Max Planck Society-Germany; NRC- Canada; CONACYT-Mexico; Polish Academy of Sciences; Russian Academy of Sciences; Chinese Academy of Sciences; NISLT - Nigeria
Research technology organisations	Often in the semi-public sphere (although some are government-owned); private not-for-profit. Also known as industrial research institutes.	Link research and private-sector innovation; development and transfer of S&T to the private sector and society.	Fraunhofer Society – Germany; TNO – Netherlands; VTT Finland; Tecnalia – Spain; SINTEF – Norway

Source: OECD 2001

Government Agencies and Policies.

Policies that are relevant to green growth innovation include those focused on science & technology (S&T), intellectual property rights (IPR), industrial regulations, tax incentives, and other areas. While these are established by different agencies/ministries, they all form part of the innovation system. The type of policies included in the analysis is likely to vary according to the level of analysis. In particular, a study on a sectoral or technological level should take advantage of the narrower focus to include a high level of detail of the design features of sectoral policies (e.g. are technology-specific targets set in renewable portfolio obligations? Are feed-in tariffs established as fixed or premium?). Box 6 describes a common set of criteria to evaluate environmental policies aimed at improving innovation performance. In addition to mapping these policies (see Table 3), it is important to review their (recent) changes over time, because (1) there might be some lag between policies and their effects, and (2) innovation policies have to be stable over time in order to deliver results. A preliminary list of elements to include is:

- Evolution of S&T policies
- The main government actors (Ministries, Agencies, etc.)
- Governance (e.g. Who is in charge of ensuring inter-ministerial co-ordination and of setting the research agenda?)
- Structure of interaction with the private sector (e.g. Do ministries convene the leadership of key firms to discuss technology needs and set research agendas?)
- Public financing of S&T and innovation policy (e.g. Government expenditures vs. foregone tax income because of tax credits or other policy instruments)
- Funding per technology area
- Policy targets and objectives inherent to S&T (e.g. spending a certain percentage of GDP on RD&D) and to green growth sectors (e.g. providing a certain share of electricity from renewables by a fixed date)
- Portfolio of instruments and programs (e.g. direct support, tax credits, sectoral funds, mixed funds, etc.)
- allocation by stage of technology development (e.g. more emphasis on early-stage, basic research vs. applied research on commercially relevant technology)

Compared to "traditional" innovation system analysis, the review of policies to support green innovation has to include measures to address both knowledge and environmental market failures.

Green innovation differs from other innovation in that it suffers both "standard" knowledge-related market failures and failures related to environmental externalities, which occur because the cost of pollution produced by firms or individuals is shared by the community and thus individuals have little incentive to buy cleaner products and firms to invest in research. Ultimately, this means that policies to support demand creation are more important for green innovation, and innovation system analysis must take this into account (Brookings, 2013). Green innovation analysis should also focus on "market barriers", which are issues or forces distinct from market failures that slow the diffusion and adoption of green technology that would otherwise be market-viable on a purely cost basis. For example, a weak grid or a slow and unclear procedure for connection to the grid are market barriers to the adoption of renewable energy, and may apply in cases when renewable energy is otherwise cost-competitive with conventional energy. Market barriers are often more recognizable at a sectoral or technological level, because they are usually technology-specific. Ultimately, this means that innovation system analysis for green growth must take into account a larger set of policies (see Table 3). Note that the analysis of technology costs, and RD&D efforts to reduce costs, generally falls under the analysis of RD&D spending and prioritization.

Financial Organizations.

This group of actors is composed of a spectrum of private financial entities, some with a higher appetite for risk and a desire for higher returns, and others with less risk tolerance but lower required returns. Traditional banks usually take low risk in financing firms by providing credit, while private equity like Business Angels (BAs), Venture Capital (VCs) and Private Equity Funds (PEFs) take a higher risk by buying equity in private companies not listed on the stock exchange. One of the main differences among the types of private equity is the increasing amount of capital invested and decreasing technology risk accepted. Business Angels are private persons (often successful entrepreneurs) who invest in unlisted companies and provide a key bridge between seed and venture capital for growth companies. Venture Capital funds are companies (rather than individuals) specialized in investing in young, high-potential firms after the seed stage. Private Equity Funds invest in existing firms (well beyond the early stage) with clear products and existing cash flows. There are also examples of hybrid public-private financing organizations (see Box 5). The usual metrics to assess the performance of these actors are:

- Success in obtaining bank loans among SMEs
- Venture Capital investment as % of GDP
- Private Equity investment (excluding VCs and BAs investment) as % of GDP
- Number of business angel networks/groups

Industry (national and regional perspective).

The assessment of industry is likely to vary the most according to the level of analysis chosen. At the national and regional level, the analysis consists of reviewing summary statistics, including:

- Business RD&D intensity (BERD), if possible broken-down by sector and size of firms, in order to identify the research priorities and contributions of private firms
- Data on innovation co-operation arrangements (e.g. among firms, those that also include the public sector, etc.), if possible broken-down by focus area and size of firms
- Flows of financing from firms to external actors (Public Organisations, Private Organisations, Foreign investment) in order to track foreign knowledge flows into the economy
- RD&D expenditures by foreign firms in the domestic market
- Patenting activity, if possible broken-down by focus areas, size of firms and domestic vs. multinational firms

Industry (sectoral or technological perspective).

The assessment under a sectoral or technological perspective is conducted at a more micro level and it entails the identification of key actors within the industry. While this process shares many features with industry value chain analysis (UNIDO, 2010), a complete value chain assessment includes many elements that are not usually included in an IS study (e.g. storage, logistics, etc.). As such, the analysis should aim to single out the main segments of the value chain and focus on identifying the domestic actors that perform (or might perform) some of the production steps. The analysis should pay attention to collecting information about innovation activities undertaken by firms and, if interviews are conducted, these could be used to gather insights on the extent of collaboration with HEIs/PROs and the process of technology scouting.

The steps of industry analysis from a sectoral or technological perspective should include:

- Identification of the main segments of the value chain and relative value added (ISIC sector classification or industry publications could provide guidance on this)
- Identification of the main international and domestic actors in the value chain. Potential tools that can be used to identify key national actors are:

  - Industry associations, via a list of exhibitions or conference attendees
  - A patent analysis may reveal the volume and direction of technological activity and may help identify firms, research organizations or individuals with a specific technological profile
  - Interviews and discussions with technology or industry experts, venture capitalists, researchers, etc. could further identify key actors

Demand/Users

The users of a technology are a key part of a sectoral or technological analysis. A robust knowledge exchange between users and producers of technologies is likely to increase innovation through two main mechanisms. First, users generate knowledge by giving feedback on a product's performance and failures which, together with a sound understanding of users' needs, are necessary for directing RD&D efforts towards the development of products as demanded by the market. Second, users sometimes directly innovate themselves, particularly "lead users" who face problems ahead of the majority of consumers and thus develop their own modifications to existing products, or entirely new products. User-led innovation is most common in the software industry, but it is also found in the manufacturing sectors, e.g. GE's collaboration with prominent MRI research users to improve machine design; LEGO's collaboration with adult users to improve the Mindstorms system; and Zeroprestige.com's crowd-sourced design innovations for the kite-surfing industry (Von Hippel, 2005).

Thus a complete assessment of the demand side should include:

- Identification of the category of users: private individuals, companies, etc.
- Identification of key product features evaluated by users at purchasing (price, product features, level of environmental friendliness, etc.)
- Assessment of level of engagement in innovation activities.

TABLE 3. POLICY INSTRUMENTS FOR GREEN INNOVATION

Policy instrument	..generally used to address market failures related to.. Knowledge	Environment	..the approach to technology development is.. Push	Pull	Barrier Removal
Fiscal incentives: (e.g. R&D Tax Credits; Purchase tax credits)	✓		✓	✓	
Financial support: (e.g. research grants; Pay-for-Performance Rewards; Demonstration projects; concessionary loans)	✓		✓	✓	
Mixed approaches: (Examples 1: "Sticky" City Policies; Compulsory License Agreements // Examples 2: Advanced Market Commitments /Public Procurement, Open Trade Policies)	✓ (examples 1)		✓ (examples 1)	✓ (examples 2)	✓ (e.g. infrastructure development)
Market based instruments: (e.g. Trading schemes; Taxes on emissions; Differential tax rates; Feed-in tariffs)	✓	✓		✓	
Command and control instruments: (e.g. Regulation; Standards; Mandatory eco-labeling schemes)	✓	✓		✓	✓
Soft instruments: (e.g. Voluntary certification; information campaigns)	✓	✓		✓	

Networks and support organizations

The number of possible support organization is very large and the analyst should focus mainly on those that connect actors with similar interests. These organizations serve multiple purposes (knowledge sharing, lobbying, etc.). Networks, both informal and formal, enable knowledge sharing and generation, and are therefore a key structural component of innovation systems. Formal networks, such as industry associations or consortia, should be included in the analysis as a first step as they are often easily recognized. The identification of informal networks -- which can include key supply-chain actors, technical experts, or individuals with common educational or professional backgrounds -- is more complex, and may require discussion with industry experts, or analysis of co-patenting, co-publishing or collaboration (e.g. joint ventures, supplier groups having a common customer, joint university-industry projects). Analyzing networks has two objectives: (1) understanding the density and type of national linkages in the innovation system (e.g. centralized, decentralized dense or decentralized sparse); and (2) understanding the extent of connections to global networks through international collaboration, labour mobility, Official Development Aid, etc. An advanced study of networks can be performed using Social Network Analysis techniques, although this involves significant analytical effort and it is not part of a common innovation system analysis (see Box 4) (Breschi and Lissoni, 2001; Whitford J, 2009).

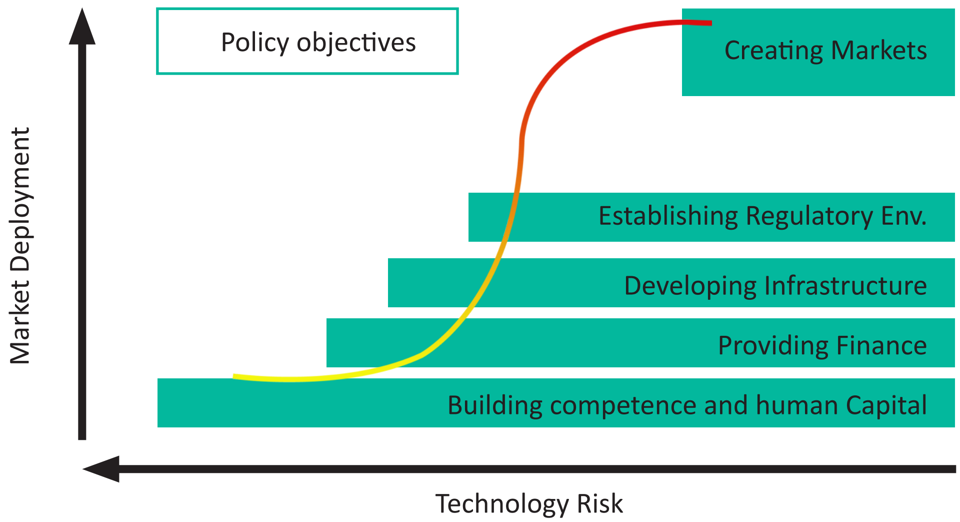
A vital but sometimes overlooked element of innovation systems is the set of social norms that shape the behavior of actors, usually defined as "institutions".

Institutions include social norms of behavior, habits, routines, values, and aspirations, all of which are rooted in a given society's history and culture and can directly affect the performance of an IS. Common examples are the attitude towards failure (e.g. does bankruptcy lead to a social stigma?) and the perception of the appropriate level of engagement of universities with the private sector. This is particularly true when the potential users of the outcome of the innovation process are poor or marginalized: these Institutions determine the extent to which the poor can participate in the innovation process and share the potential benefits. For instance, social norms may limit women's access to higher education, or prevent innovators from realizing that there may be business opportunities provided by poor or marginalized populations (World Bank, 2010; Berdegué 2005; Gupta 2007). While a detailed analysis of these factors is more appropriately conducted by sociologists than innovation analysts, a complete analysis of the innovation system will include some attention to these issues, probably by drawing on previous sociological studies.

Finally, a sectoral or technological approach builds on a sound understanding of the underlying technology.

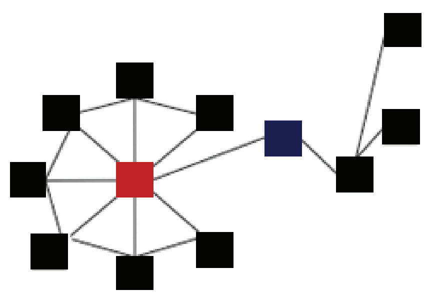
This includes two components. First, the policies and types of actors that support a specific technology evolve according to the stage of maturity of the technology (IRENA, 2013; IEA, 2011). As the technology matures and enters the market, the focus of policies should shift from largely basic research and development towards more demand-enabling policies, such as the removal of regulatory barriers or pricing emissions (see Figure 4). For example, in the case of renewable energy, the adoption of a demand-side policy like feed-in tariffs is unlikely to be effective (and may even be counter-productive) if the targeted technology is not yet close to market competitiveness. From this standpoint, sectoral or technological approaches have the key advantage of providing policy advice tailored to the technology under analysis. In order to properly frame the stage of technological maturity, the analysis might build on work by other organizations specialized in determining the maturity level of different technologies. The second component of this issue is the fact that an analyst must understand the basic elements of the value chain for the technology under consideration. For example, the value chain for wind power includes a set of hardware components (blades, towers, turbines, etc.) that are distinct for the purposes of RD&D and manufacturing. Without a clear understanding of this value chain structure, the analyst cannot correctly frame the analysis.

FIGURE 4. POLICY OBJECTIVES AND TECHNOLOGY MATURITY



Box 5. Social network analysis and network mapping

Non-linear innovation models have driven a growing interest in the study of social interactions. To this end, social network analysis (SNA) is often utilized to determine the connections ("ties") among the different 'actors' of a system (e.g. people, departments, firms). The resulting maps can be useful to understand the structure of the networks, key positions and structural weaknesses. However, SNA is not part of a common innovation system analysis approach, and can be time consuming.



The activity for a specific actor (or node) is measured by using the concept of degrees -- the number of direct connections a node has – and its position in the network. In the example map above, the red dot has the most direct connections in the network, making it the most active node (a so-called "hub"). The actor in this position is likely to have access to fined-grained information and knowledge exchange is likely to be smoother because of the large number of common ties, which suggests the presence of a group of actors with shared interests, beliefs, and norms.

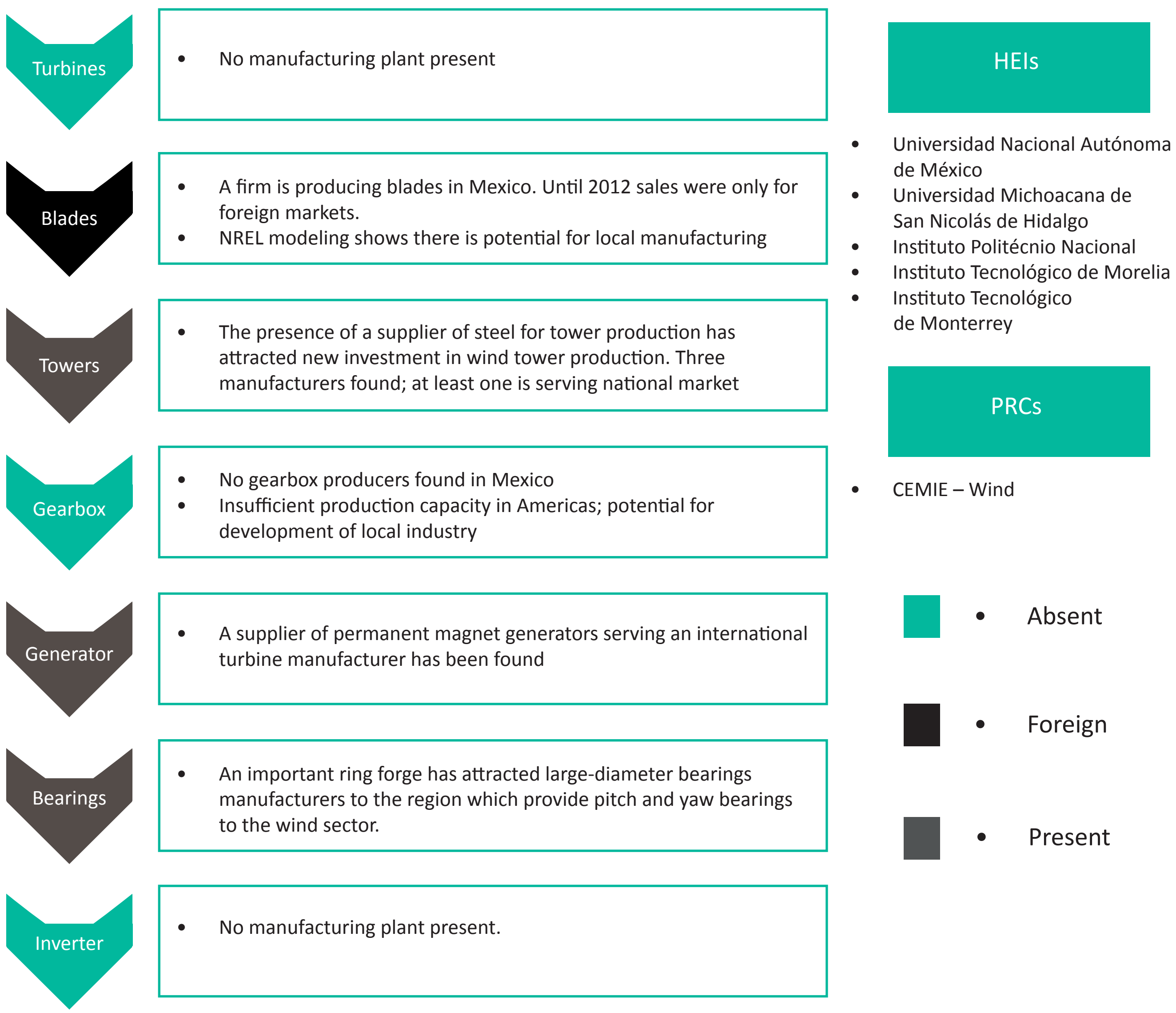
However, the red dot is not the only strategic node. The light blue dot, while it has few direct connections (fewer than the average in the network), occupies a structural position since it links actors who are not otherwise connected (it can be defined as a "knowledge broker"). For this reason, it is able to access new knowledge that other actors cannot and also control knowledge flows (Australian Business Foundation, 2008).

Box 6. An Example: Mapping the innovation system

The analyst starts reviewing policies that affect wind energy generation. He identifies the policy instruments that are in place. These include a methodology to establish service charges for transmission of renewable electricity (wheeling fees) and a 100% depreciation of capital investment for RE investment in the first year. More recently, a virtual energy bank has been created, which allows wind energy producers to generate the maximum possible amount of electricity when wind is available, and virtually "store" that electricity for up to 12 months if it is not consumed immediately by the off-taker.

Through bibliographic research, the analyst is also able to identify several universities that perform research in this field. Using web-based research, interviews with stakeholders and industry associations, the analyst begins to outline a map of the industry value chain present in Mexico (Figure below). As the analysis progresses, the analyst gathers information on the configuration of the innovation system for wind technology in Mexico, including key institutions, PROs and users of wind energy generation technologies.

Illustrative map of wind value chain in Mexico



D. Assessing the functionality of the innovation system

Once the structure of the innovation system is understood, the objective of the analysis shifts to understanding how the system supports (or inhibits) innovation by looking at how various functions are performed.

The underlying concept of this approach is that an IS should perform a basic set of common functions to create an environment that enables new technologies and practices to be developed, introduced into the economy, and widely scaled (see Table 4). Each function directly supports a certain part of the innovation process (e.g. providing access to financing for entrepreneurs) and also interacts with the other functions to strengthen their impact (e.g. nurturing the skills for innovation provides better researchers for creating new knowledge; see Table 5). While the specifics of which actors are relevant and which functions they perform will vary from economy to economy, the functions necessary for a robust and healthy innovation system are consistent across many levels of development. By focusing on these functions, and the degree to which they are successfully performed by system actors, the analyst can arrive at important insights and make useful recommendations for policy actions.

The key functions fall into four categories.

A convenient way to group the functions of the IS (but not the only possible approach) is as follows (see Table 4):

1) To create and share 'new' (to that economy) knowledge.

The purpose of this function ("knowledge generation") is to bring new scientific and technical knowledge into the economy, whether it is new to the world or simply new to that economy.

- Generally, this involves the process of basic research and technology development, like the improvement of scientific understanding of wind turbine aerodynamic behavior or the development of new drought-tolerant crop varieties. It also involves the process of adapting existing technologies from other countries for use in local conditions, which may require significant changes.
- This function also includes searching ("scouting") for relevant knowledge and technologies that are available in other countries, and performing benchmarking of the level of domestic knowledge/technology against best-in-the-world knowledge and capabilities. This requires mechanisms to facilitate knowledge inflow to the economy, and access to/monitoring of foreign knowledge.
- This function also includes sharing knowledge, which can occur formally (through scientific publications, patents, workshop presentations, trade journals, etc.) or informally (through meetings, discussions, research personnel exchanges, etc.).
- Several actors contribute to this function (firms, academia, users, research centers, etc.). In developed countries, the activities of scouting and benchmarking are generally performed by private firms; while in developing countries, private firms are more resource-constrained and cannot perform global scouting, so governments play a larger role. Cross-border collaboration in RD&D is often supported by public RD&D of multiple governments.
- The role of users is particularly relevant in order to generate new technology that meets market needs, so this function interacts with the market formation function by building on key insights about the purchasing motivations of users, including price, technology performance, potential as a status-symbol, regulations, robustness, maintenance costs, etc.

- Illustrative questions to ask are: "Which actors are producing knowledge? How is this knowledge shared? Who is determining where RD&D funds and innovation efforts are focused? What policies and planning processes are in place or could be implemented to enhance RD&D funds allocation? Are networks effective in supporting knowledge sharing and access to foreign knowledge? Are feedback channels between users and producers of technologies healthy and effective?"

2) To facilitate the formation of markets (a key element for green technologies).

The purpose of this function ("market formation") is to stimulate and/or understand demand for green-growth technologies and products, and smooth their path to adoption in the market.

- Generally, this involves identifying the mechanisms that create obstacles to the deployment of a technology. The presence of environmental market failures (e.g. pricing of pollution, enforced standards) and technological barriers (e.g. incompatibility with infrastructure, strong network effect of an incumbent technology, lack of an installed base) calls for specific attention to policies to cope with both of them. To this end, the analyst should assess possible conflicting policies (e.g. inconsistent tax benefits, confused or non-existent regulations, etc.). A key aspect is the process of international technical standards setting, since these standards can significantly affect access to foreign markets.

- The function of market formation is closely entwined with the function of creating and sharing new knowledge. For this reason, market-formation activities must evolve to match the stage of maturity of relevant technologies. At the earliest stage, activities to understand and uncover demand for innovation should take place. As the technology matures, demonstration projects become necessary both to provide producers with necessary learning-by-use experience and to increase the confidence of buyers in the technology. Once the deployment phase is reached, the focus should be mostly on addressing barriers to adoption.

- Several actors contribute to this function, including government ministries, private firms, and NGOs/users' organizations. In developing countries the government or NGOs may play a larger role in understanding and uncovering demand for innovation in order to steer innovation towards a more inclusive and pro-poor direction (e.g. identifying unmet demand for improved irrigation, better lighting or transportation) since the capacity of private firms to assess new markets might be constrained.

- Illustrative questions to ask are: "Do policies create the market for green products through incentives or obligations? Do other bottlenecks prevent deployment (e.g. weak grids limiting renewables)? Are some technologies affected by a "NIMBY syndrome"? Are policies stable and credible enough to provide industry with the required certainty to invest in RD&D? Are users willing to pay a premium price for environmental benefits? Are government procurement policies geared towards innovative and environmentally friendly products?"

3) To facilitate access to financing.

The purpose of this function ("access to financing") is to provide financial services to support innovation from its early stages to deployment.

- Generally, this entails the presence of a spectrum of financial organizations, some with a higher appetite for risk and a desire for higher returns (e.g. VCs or business angels) and others with less risk tolerance but lower required returns (e.g. private equity firms, traditional banks), in order to provide adequate financial services to all system actors.

- This function includes two types of "clients" for the financial services. On one hand, the financing system should be able to support RD&D activities in both private and public organizations and to nurture the growth of firms throughout their life cycle (from the highly uncertain start-up phase to the more predictable expansion of a mature company). On the other hand, adequate financing should be available for users to buy capital-intensive products, such as those involved in energy efficiency.

- Several actors contribute to this function. While the private sector fills much of the financing spectrum (e.g. venture capital and private equity), government funding also plays a role, generally for earlier-stage, higher-risk research efforts. Some degree of self-financing is also possible, generally for larger private firms (who have significant internal resources) or because of direct funds transfer from users to private firms (e.g. surcharges on electricity bills to finance RD&D). Finally, crowd-funding is emerging as an important tool to finance both firms and private demand in developing countries (e.g. solar panel acquisition).

- The function of financing closely interacts with nurturing skills for innovation since the financial support provided by venture capital and business angels is often accompanied by training in business skills (marketing, commercialization strategies, etc.). In addition, the allocation of financial support (by both private and public funders), especially when markets for a technology are not fully established, shapes the direction of research.

- Particularly for green-growth technologies – which are newer and have shorter performance histories – actors that provide financial services must have the necessary skills to evaluate new technologies and new business models. For example, an important barrier to the deployment of energy efficiency technologies is the lack of capital by potential buyers and the lack of expertise of traditional banks in evaluating energy efficiency home improvements. These elements combine to slow the deployment of innovative technologies, and are the symptoms of a weak financing function on the demand side.

- Illustrative questions to ask are: "Can innovators access finance throughout the innovation process? Is there a range of financiers differentiated by their appetite for risk? Is the lack of funding related to the risk of the investments, poor understanding of technologies or some other factor? Can potential users access capital to finance the purchase of green technologies (particularly in the case of efficiency)? Can financiers facilitate user engagement and market formation?"

TABLE 4. FUNCTIONS OF AN INNOVATION SYSTEM

Functionality	Key activities	Typical actors	Indicators/questions
Knowledge generation and sharing. Purpose: To bring new scientific and technical knowledge into the economy ("new" to that economy).	• Scientific research • Technology development, demonstration • Technology scouting, importing, and adaptation • Technology benchmarking • Knowledge sharing	• Universities, public research organizations, private firms • Advanced users • Government ministries (scouting) • S&T societies, Industry organizations, etc.	• Who is producing knowledge, and how is it shared? • Who is searching for existing technology solutions in other countries? • Who is determining research priorities and goals?
Market formation. Purpose: To stimulate and/or understand demand for green growth technologies and products and smooth their path to market by removing barriers.	• Identifying market failures and removing them • Identifying barriers to adoption and implementing solutions to remove them • Identifying and addressing conflicting policies and regulations • Identifying and assessing market demand for innovation • Objective testing of technology performance • Diffusion of information on technology advantages	• Private firms • Government ministries • NGOs/ Users' organizations	• Are policies in place to cope with environmental externalities? • Who is studying the barriers to technology adoption (other than cost) and implementing solutions to remove them? • Who is analyzing demand for green growth technologies, and who is working to stimulate it? • Who is providing education to the public on technology performance and value?
Access to financing. Purpose: To provide financial support for innovation, from early stages to full deployment.	• Providing funding for scientific research and technology development and demonstration; may be (cost-shared) grants, or other arrangements • Providing financing to support the growth of innovative firms or adoption of innovative technologies into existing firms; may be debt or equity financing or other arrangements • Identifying and supporting high-potential innovators	• Government ministries • Banks • Venture capital, Business angels, Private equity funds	• Who is funding scientific research and technology development and demonstration, and how do they decide the allocation of funding? • Do innovators have sufficient access to finance throughout the innovation process? Is there a range of financiers differentiated by appetite for risk? • Do financiers have sufficient technical knowledge to evaluate emerging technologies? • Can potential users of green technologies access financing for capital-intensive purchases?
Nurturing skills for innovation. Purpose: To create the human capital necessary to enable innovation, whether it be home-grown talent or the attraction of highly qualified people from other countries.	• Educating workforce with relevant skills (scientific, technical and business-related) • Attracting and/or retaining highly qualified people internationally	• HEIs (education) • Private firms • Investors	• Do students' skills match what is needed by potential employers in innovation-related sectors? • Are programs to attract and retain talent successful?

4) To nurture skills for innovation.

The purpose of this function ("nurturing skills") is to create the human capital necessary to enable innovation, whether it be home-grown talent or the attraction of highly qualified people from other countries.

- Generally, this involves education and training in technical and business skills. It may also include targeted programs to re-train workers in technical fields, or programs to attract foreign talent to relocate to the country. In relation to HEIs, it should be noted that the experience of most successful universities in promoting innovation includes efforts to instill an entrepreneurial culture within staff and students (such as providing business training to technical researchers).

- Several actors contribute to this function. HEIs train a wide variety of skill levels, from production workers to technical researchers. Private firms conduct "on the job" training, work with HEIs to design curricula focused on needed skills, and search for foreign talent. Venture Capital and Business Angels perform a specific role in selecting and transferring skills to specific firms.

- In the generation of home-grown talent, there should be acknowledgement that the benefits of HEIs lie predominantly in the advanced skills they generate through research and education, provided that there is substantial inter-sectoral mobility and that the generated skill sets are well attuned to the demands of the labour market.

- A specific role of government lies in supporting the efforts of domestic actors to attract and retain top international talent. For instance, Sweden has introduced tax benefits for foreign experts, executives, scientists and researchers (OECD, 2012b) while Chile has launched a program to attract international start-ups by offering free seed capital and a 1-year visa to young firms willing to relocate to the country (Carmel, 2013). In addition, policies to enable the international mobility of domestic researchers for short periods, such as personnel research exchanges with foreign countries, can be powerful tools to improve the inflow of foreign knowledge.

- Illustrative questions to ask are: "Are universities graduating the right number of technically trained students? Do the skills acquired by graduates match the skills that are demanded by potential employers in innovation-related sectors? Are employers at innovative firms able to find the talent they need to grow their business? Are programs designed to attract students into particular high-priority fields successful? Do government policies support firms' skills development or retraining activities?"

Box 7. The Israeli experience in promoting venture capital

In the early 1990s, Israel had developed a strong human capital base due to early training in sophisticated technologies provided by the compulsory military service and the influx of about 82,000 Russian-trained engineers. To leverage this, the government's Office of the Chief Scientist (OCS) promoted private RD&D through grants to firms that covered between 66 and 90% of RD&D costs. However, this support did not translate into commercial success, because of a lack of risk-tolerant capital to help small innovative technology firms scale up (Senor, 2009; OECD, 2003).

Responding to this, in 1993 OCS launched the Yozma program, with three goals: to create a solid base for a competitive VC industry with a critical mass of capital and activity; to learn from foreign limited partners; and to acquire an international network. One of the most interesting features of the Yozma design was the ability not only to provide a supply of capital and risk sharing but also to create strong upside incentives. Investors had a call option on government-owned shares of participating funds, at initial cost (plus interest) for a period of five years. Therefore, in the case of successful ventures, the profits for investors would be substantial since they could buy valuable shares at low prices.

Yozma is often credited as one of the most innovative and successful programs to support innovation and it is deemed to have made an important contribution to the growth of the Israeli economy. Implemented together with other policies, it contributed to the global leadership of sectors like pharmaceuticals, computer hardware and software, while RD&D spending, calculated as a percentage of GDP, increased from 2.7% to 4.4% between the mid-1990s and early 2000 (World Bank data, indicator n. GB.XPD.RSDV.GD.ZSI).

An effective green growth innovation system is characterized by strong and cohesive interaction among the key functions.

Strong, mutually reinforcing interaction among the main functions of the IS lead to many benefits (see Table 5). For example, the function of nurturing skills through education provides the human capital for knowledge generation, while new knowledge that is generated must feed back to the educational curriculum in order to ensure the appropriate skills are taught. Also, access to financing supports the creation of skills through funding or direct training by venture capital firms and business angels, while the advanced skills produced by the nurturing skills function might contribute to the growth of a domestic finance ecosystem thanks to the creation of opportunities of financing potentially highly rewarding university spin-offs. These interactions are strongest when different system actors share a common set of expectations about the future, including what policies are likely to be in place and what market conditions are likely to exist. To this end, there is a crucial role for government to establish clear long-term goals and implement stable policies, which will allow actors in the innovation system to harmonize their expectations about the future and improve the value of their interactions.

Box 8: An Example – Assessing the knowledge generation function

The analysis of RD&D expenditures and patenting rates for clean energy technologies, as well as in-person interviews reveal a poor performance of the function of knowledge generation. This is happening despite the fact that market opportunities should be large enough to generate incentives for firms to invest in the sector. In fact, the proximity with the US market and the presence of domestic demand that is taking off even without subsidies (mainly generated by self-supply uses) suggests that the issue lies within the knowledge generation function and not in the market creation function.

Further analysis reveals that there is very weak cooperation between academia and industry. This seems to be due to traditional Institutions (in the sense of cultural values) that consider academia's primary role as performing research in full autonomy from industry, but another factor is the structure of some funding programs meant to support innovation. For instance, a Sectoral Fund focused on energy has been established but its funds can support only projects led and presented exclusively by higher education institutions and research organizations in the country, listed in the National Register of Scientific and Technological Institutions (RENIECYT). This limits the incentives of private firms or foreign organizations to participate in research projects with academia. The analyst suggests a review of the funding procedure and of the reward scheme/career progression mechanisms in universities in order to favor collaboration between industry and academia. Also, given that several multi-lateral financing organizations operate in the region (e.g. the IDB and the IMF), their funding could be linked to joint research activities between academia and industry.

Box 9. How to design green innovation policies

A common set of criteria to measure environmental policies aimed at improving innovation performance includes:

- Dynamic efficiency – Does the policy create incentives for searching continuously for cheaper abatement options?
- Predictability – What effect does the policy have on investor uncertainty?
- Flexibility – Are potential innovators free to identify the best way to meet the objective? (e.g. Performance standards are usually considered more effective tools compared to technology-specific standards.)
- Incidence – Does the policy target the environmental objective as closely as possible? (e.g. If the objective is to promote a higher share of renewables in the generation mix, then incentives should reward effective electricity production and not mere installations of nameplate capacity.)

In general, market-based instruments are usually considered to score relative high on these four criteria. However, the best choice of instrument (or mix of instruments) is likely to vary according to the nature and size of the predominant market failures, differences in institutional capacities of respective countries as well as the cost/opportunity of monitoring pollution at the level of the production process (e.g. a tax on SOx emission or on sulfur content of fuel) (Johnstone, 2010; de Serres, 2010).

Once the green growth innovation system has been understood and diagnosed, the analyst should develop policy proposals to address the identified problems.

This step involves identifying specific shortcomings of the innovation system and outlining policy changes that would directly address those problems. In some cases, the analyst can look to examples of policies implemented in other countries in order to address similar problems, but this requires additional analysis to ensure that the same conditions are relevant in the country being analyzed. Some examples of possible diagnoses and policy recommendations are the following:

- If the IS analysis reveals that high-quality research on green technology is being conducted in HEIs but it is not being translated into commercial applications, the policy recommendation might be to create a program of support for commercialization activities between universities and private firms. For example: Brazil's 2004 Innovation Law (Sennes, 2009).

- If the IS analysis reveals that green technologies are available on the market but consumers are not aware of them or their benefits, the policy recommendation might be to launch an information campaign to improve consumer awareness, and to create a program of eco-labels. For example: Korea's Eco-labeling program (OECD, 2008).

- If the IS analysis reveals that there are many new green technology companies being started but most are unable to grow because of a lack of access to risk financing, the policy recommendation might be to create a program to encourage risk-tolerant investment by the private sector through government co-investment, or to create an innovation center which supports start-ups through advisory services, grants and matchmaking with potential financiers. For example: Israel's Yozma program (Avnimelech, 2009) and Kenya's Climate Innovation Centre (World Bank, 2014).

- If the IS analysis reveals that firms have little or no incentive to invest in green technologies because of a limited market, the policy recommendation might be to internalize environmental externalities through emissions taxes in order to increase incentives for innovation. For example: Norway's CO_2 tax (Sumner, 2009).

- If the IS analysis reveals that regulatory requirements are very cumbersome and expensive, the policy recommendation might be to review these regulations and eliminate or reduce the most burdensome ones. For example: Mexico's Rapid Business Opening System (Bruhn, 2008).

- If the IS analysis reveals that there are too few entrepreneurs with an interest in creating companies related to green technologies, the policy recommendation might be to create a program to attract entrepreneurs from other countries to launch new green technology businesses domestically. For example: Chile's Startup Chile program (Carmel, 2013).

TABLE 5. INTERACTIONS AMONG FUNCTIONS

supports → / supported by ↓	Knowledge generation and sharing	Market formation	Access to financing	Nurturing skills for innovation
Knowledge generation and sharing	X	New technology possibilities from research and adapting foreign technology create market demand (e.g. mobile phones)	Technological discoveries create opportunities for investing	New knowledge should feed into education and lifelong/continuing learning
Market formation	Demand signals from the market provide direction for areas of new research or technology scouting	X	Demand signals from the market convince capital to invest in knowledge generation and technology development	Demand signals from the market provide information on what technical areas should be learned by students and workers
Access to financing	Financing provides funding support for research	Innovative financing models can unlock demand (key for the BoP); Capital investors can conduct demand surveys to understand market opportunities	X	Funding support for degree studies or provision of business skills by venture capital and business angels
Nurturing skills for innovation	Skilled workers speed research and scanning for technologies emerging elsewhere	Higher education levels and income often leads to demand for more sophisticated technology products	Employees with technical knowledge enable financing organizations to identify promising technologies or innovative financing models	X

How to read this table: The table can be read both vertically and horizontally. For instance, the first row shows how "Knowledge Generation" supports the activities of the other functions, while the first column shows the inverse relation, that is, how other functions contribute to knowledge generation.

E. Conclusion

This paper has described an approach to innovation system analysis which, through careful choice of analysis level, use of systematic mapping, and a function-based framework, can lead to clear implications for policy recommendations.

The innovation system analysis framework is a useful tool for understanding how the process of innovation is working (or not working) in a country, and distilling recommendations for how to improve its performance. While the specifics of which actors are relevant and which functions they perform will vary from economy to economy, the functions necessary for a robust and healthy innovation system are consistent across many levels of development. By focusing on these functions, and the degree to which they are successfully performed by system actors, the analyst can arrive at important insights and make useful recommendations for policy actions.

While the global community has pursued economic development and innovation policy for a long time, the current situation poses new and unique challenges.

Emerging economies are increasingly positioned to play an important role on the frontier of new technologies. At the same time, as the window of opportunity to meet the environmental challenges of our time is closing fast, the need to quickly scale and develop new technologies is increasingly more evident. In this context, the focus of green growth on breaking with unsustainable growth paths and creating and disseminating new, more environmentally sustainable technologies plays a pivotal role.

Annex. Measuring the functioning of a green growth innovation system

Generally speaking, an indicator is a quantitative or a qualitative measure that can help to determine the relative positions of countries (or other actors) along several dimensions. Each indicator can be a single variable or the aggregation of several variables. Indicators can be helpful in determining the direction of change and benchmarking country performance. In addition, a small set of indicators are often easier to communicate and to interpret for the general public than long complex reports.

However, indicators can send misleading policy messages if they are poorly selected or misinterpreted. One risk of using indicators is that users (especially policy-makers) might draw simplistic analytical or policy conclusions and forget the number of conditions that contribute to determining a specific outcome. For instance, having a high level of enrollment in tertiary education will not lead to higher growth if quality of schooling is not high as well (but this is much more difficult to measure). Furthermore, tough environmental regulation of CO2 emissions could lead to innovation, but at the same time those regulations can stifle the industrial base if they became too stringent. A second risk is that improving the results of selected indicators can become the objective of policy making, without focusing on the actual improvement of the conditions the indicator is intended to summarize (OECD, 2008b). For instance, if the indicators include the stringency of emissions limits for NOx, this might drive policy attention to this pollutant while other pollutants might be more relevant in specific national contexts. Furthermore, if the indicators include standards or taxes, policy-makers might be led to focus on these types of instruments when other instruments might actually be better suited for a specific national context.

The multidimensionality of innovation systems and the paucity of data for developing countries further complicate the identification of appropriate indicators for green growth innovation systems. A well-functioning innovation system is characterized by several functions performed by multiple actors and the interactions among them. For this reason it is highly multidimensional, and therefore it is challenging to identify a small number of variables that can meaningfully frame the performance of an IS. Not by coincidence, the OECD innovation score board contains more than 260 indicators for Science, Technology and Industry (STI) in order to provide analysts with information to determine the performance of countries. Notwithstanding these limitations, a preliminary list of possible useful indicators and relative sources of information is provided below. These are organized in order to reflect the configuration of system functions discussed previously.

	Possible indicators	Meaning	Possible Sources
Knowledge generation and sharing	Input • RD&D expenditure (green technologies and others) by business and government Output • Number of patents, possibly weighted by citations (green/ non-green technologies) • Number of publications, possibly weighted by citations (green/ non-green technologies)	• Common metrics to determine the level of input/output within an IS. Citations are used to determine the relevance of the research.	• R&D data: World Bank database; IEA Database on Renewable Energy R&D; (Kempener, 2012), "Energy R&D Investment in Major Emerging Economies and USA". • Patent data: OECD/WIPO databases • Paper citations: Web of Science, Scopus and Google Scholar databases
Market formation	Market failures: • Presence of instruments for pricing CO2 emissions and relative price • Emission limit values (ELV) for specific pollutants (e.g. NOx from combustion plants) Market Barriers • Grid reliability • Time/difficulty for renewable generation to connect to the grid Steering towards Green Growth • Survey of users willingness to pay for more environmentally friendly goods	• Tax rates or enforced ELVs can be used to determine the extent to which the environmental market failures are being tackled. However, more stringent standards are not necessarily better. • Some market barriers are technology-specific while others are general. Selected specific barriers could be considered as indicative of the overall situation. • A survey can be used to determine user/consumer preference towards environmentally friendly goods.	• Environmental policy instruments: OECD/ EEA database; IEA Clean Coal Database on ELV; icapcarbonaction data; • Regulatory market barriers: World Bank Enterprise Survey: days to obtain an operating license; days to obtain a construction permit • Technical market barriers: World Bank enterprise survey: grid stability; • Willingness to pay: ad-hoc surveys
Access to financing	• Ease of access to loans • Venture Capital Investment as % of GDP • Investment in clean energy	• Access to loans, level of VC investment, and investment in green energy could be used to determine the success of the financing function.	• Access to loans: WEF Survey of Executives • Investment in clean energy: BNEF datasets • Venture capital: OECD, survey of regional venture capital associations
Nurturing skills for innovation	• Enrolment in secondary/ tertiary education, possibly by field (Engineering, Business, etc.) • Number of Universities/ Research organizations engaged in developing co-operative training and education programs with industry • Members of professional associations (e.g. engineering societies, standards development organizations/SDOs)	• Enrolment data provide insights on the training of workforce in technical fields. • Co-operation activities can provide insights on mechanisms to link education to the hiring needs of firms. • Participation in engineering societies or SDOs indicates number practicing technical workers.	• Education data: World Bank statistics • Co-operation activities: Ad-hoc surveys • Professional associations: Association websites

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About GGGI

Based in Seoul, GGGI is an intergovernmental organization founded to support and promote a new model of economic growth known as "green growth." The organization partners with countries to help them build economies that grow strongly and are more efficient and sustainable in the use of natural resources, less carbon intensive, and more resilient to climate change. GGGI's experts are already working with governments around the world, building their capacity and working collaboratively on green growth policies that can impact the lives of millions. To learn more, see http://www.gggi.org and visit us on Facebook and Twitter.