Adapting Innovation Systems Indicators to assess Eco-Innovation

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Abstract

A large amount of work has analysed systems approaches to innovation and investigated associated methods of innovation measurement. However, relatively little of this literature has discussed the measurement of **eco-**innovation. Policies and measures to promote eco-innovation are hampered by a lack of relevant data and indicators. Hence, the research reported here aimed to assess whether innovation systems theory and indicators could be adapted to measuring eco-innovation.

The paper is organised in two stages: analysis of current innovation systems theory and indicators; and, synthesis of a set of eco-innovation indicators, adapted from the literature on innovation systems indicators.

In the first stage, four main strands of the wide range of innovation systems literature are analysed: Each of these strands of innovation systems literature proposes a conceptual model of innovation and a corresponding set of indicators or guidance for the measurement of innovative capacity. The models are examined and key elements which cut across these models are identified. These three elements are: **The Firm; The Conditions;** and **The Linkages.**

These key elements are then used as a generic framework through which the adaptation of innovation indicators could be guided. Two further considerations were then added to the key elements based on the desirability of their measurement: The **radical or incremental** nature of innovation; and the **overall innovative performance** of an innovation system.

In the second stage of the paper, indicators proposed in each of the four strands of innovation theory are examined, to identify those indicators suitably adaptable to the measurement of eco-innovation. Several such indicators are identified, covering each of the five key elements. In addition, several original indicators are created to complement those adapted from the four strands of the literature. These original indicators are proposed because of ongoing data collection activities which may facilitate their use. A final list of 24 indicators is presented.

The creation of defensible eco-innovation indicators is found to be a complicated task and there are issues regarding the validity of some of the proposed indicators. The list of indicators proposed here is therefore presented as a “straw-man” through which the development of a fuller understanding of eco-innovation measurement can be pursued.

Key Words: Innovation System; Eco-innovation; Indicators; Oslo Manual

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1. Introduction

The pursuit of good indicators of eco-innovative capacity is increasingly politically salient, for at least two reasons: the Lisbon Strategy's stated EU goal to become "…the most dynamic and competitive knowledge-based economy in the world, capable of sustainable economic growth with more and better jobs and greater social cohesion, and respect for the environment by 2010" (European Commission 2004); and the emphasis on low carbon innovation in the recent EU Energy and Climate Policy. Without a method of measuring the development of eco-innovation, the achievement of these goals may not be sufficiently guided or substantiated. Though there is much within the current innovation systems literature regarding the measurement of innovation, there is a distinct paucity of literature on the measurement of 'eco-innovation'. Consequently, this paper aims to assess the feasibility of adapting current innovation systems indicators to measure eco-innovation.

The work leading to this paper formed part of a EC 6th Framework funded scoping project examining different approaches to measuring eco-innovation (Kemp and Pearson, 2008). We follow the definition adopted in that project, which was based on the definition of innovation in the Oslo Manual (OECD, 2005) and was informed by stakeholder consultations:

Eco-innovation is the production, assimilation or exploitation of a product, production process, service or management or business method that is **novel to the organisation** (developing or adopting it) and which **results**, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) **compared to relevant alternatives**.

This definition includes not only innovation aimed at reducing environmental impacts, but also cases where innovation leads reduced impacts without this being an explicit aim.

During the 1990s, a paradigm shift took place within innovation theory (Arnold & Kuhlman 2001; Mytelka and Smith 2002). Before this, neo-classical economics considered innovating firms as autonomous entities, using the information available to drive forward successful innovation through the funding of R&D – known as the linear model of innovation (OECD 1997). This science driven concept of innovation gave rise to the view that government science policy alone was sufficient to foster and develop the innovative capacity of nations (OECD 1997). Through the concepts of evolutionary economics and research on the innovation process, the conventional linear model of innovation has been superseded by integrated, systems based, conceptual models of innovation (Edquist, 2005). This has in turn given rise to "innovation" policy in its own right (Arnold & Kuhlman 2001; Mytelka and Smith 2002).

Several distinct strands of innovation systems theory offer both models of innovation systems and a means of measuring the performance of those systems through indicators. Though these strands of literature each offer a distinct conceptual model of innovation and conclude with a set of specific indicators, the methodology by which the authors created indicators from the proposed conceptual model is often not transparent. This makes it hard to appraise such work critically or to emulate the process to create indicators for another purpose, such as creating a set of eco-innovation indicators based on a generic conceptual model of innovation systems. Also, it may be highly desirable to adapt current indicators for new purposes, to make use of currently collected data. The cost of collecting these kinds of data can make the development of original indicators prohibitively expensive. This paper presents work aimed at creating eco-innovation indicators adapted from the current innovation systems literature. It is hoped that the work presented here will provide a platform to facilitate the measurement of eco-innovation in the future.

2. Innovation Systems Models

This section briefly reviews the four conceptual models of innovation systems that will form the basis for the development of eco-innovation indicators in this paper:

The *Innovation Policy Terrain*, proposed in the Oslo Manual (OECD 1997);

The *Generic Model* proposed in OECD National Innovation Systems (Remøe *et al.* 2005);

The *Elements of NIC* model found in National Innovative Capacity (Porter *et al.* 2002); and

The *Functions of Innovation* model proposed in Technological Innovation Systems (Jacobsson & Bergek 2004; Hekkert *et al.* 2007).

2.1. The Innovation Policy Terrain

The second edition of the OECD's Oslo Manual (OECD, 1997), of the Frascati Family of manuals, proposes a conceptual model of the innovation system (Figure 1). The scope of the manual is intended to cover technological product and process (TPP) innovation at the firm or enterprise level and these are well defined within the Manual. In the most recent, third edition (OECD 2005), 'The Oslo Manual' widens this scope to include marketing and organisational innovation. The analysis here will largely focus on the conceptual framework proposed in the second edition of the manual, referred to here as 'The Innovation Policy Frame'.

This model's design is based on work published by the Australian Department of Industry Science and Technology (Bryant 1996), and other work on innovation systems described in the sections below.

The model consists of four domains representing four core areas of influence on innovation systems. The model's nested structure conveys the concept of a hierarchy of interdependence within the system. The four domains are discussed below.

2.1.1. Framework Conditions

This domain represents the external area within which the potentially innovating firm is situated. The conditions within this area have largely been developed independently of any innovation policy but define the environment within which a firm may carry out its business. The manual expresses the following component elements as:

the basic educational system, this being responsible for the general level of education throughout the workforce;

the communication infrastructure: roads, audio and data communications;

financial institutions, determining the access to finances including venture capital;

legislative and macro-economic settings, including patent law, taxation corporate governance rules and trade policy;

market accessibility, including possibilities for the establishment of close relations with customers, market size and ease of access, and

industry structure and the competitive environment, including the existence of supplier firms in complementary industry sectors.

2.1.2. Science and Engineering Base

'The Oslo Manual' identifies this domain as a primary support for business innovation. Scientific knowledge and engineering skills reside and are further developed in public sector science and technology institutions and the worldwide output of these provides an essential understanding and theoretical base for business innovation.

The Manual also highlights the distinction between these institutions and the scientific element of an innovating firm. It is mentioned that there are significant motivational differences. It is also mentioned that, while the individual within the public sector institution has a stronger role than its employer, the firm is, in general, more important than the individual in the private sector. The commonality between private and public sectors with regard to the networking and knowledge transfer between individuals is also commented on.

The Manual itemises the component elements of the science and engineering base as:

the specialised **technical training** system;

the university system;

the **basic research** support system;

public good R&D activities, meaning funding and institutions generally directed towards health, the environment and defence;

strategic R&D activities, meaning funding and institutions directed towards 'pre-competitive R&D' and or generic technologies; and

non-appropriable innovation support, meaning funding and institutions directed towards research in areas where private firms would find difficulty gaining benefit from their own in-house research.

2.1.3. Transfer Factors

It has been expressed in innovation research that a proportion of scientific and technical knowledge is tacit or unwritten. The only effective method of transferring this knowledge is therefore between two individuals or by the physical transfer of individuals as carriers of knowledge. These transfer factors are therefore human, social and cultural factors relating to learning within the innovating firm.

These transfer factors can be broadly expressed as:

formal and informal **linkages between firms**; referring to networks of small firms; user-supplier relationships; relationships between firms, regulatory agencies and research institutions; and stimuli within 'clusters' of competitors;

the presence of **expert technological 'gatekeepers'** or receptors, meaning individuals who keep abreast of technological developments and maintain personal networks facilitating the flow of that knowledge;

international links, meaning networks of international experts or 'invisible colleges';

the degree of mobility of expert technologists or scientists;

the ease of industry **access to public R&D** capabilities;

spin-off company formation, involving the transfer of knowledge through movement of experts;

ethics, community value-systems, trust and openness which affect the ability of various communication channels to be effective; and

codified knowledge in patents, the specialised press and scientific journals.

2.1.4. Innovation Dynamo

This domain, as expressed in the Manual, represents the complex system of factors that shape the innovative capacity of a firm. The propensity of a firm to innovate is said to depend on the technological opportunities faced, the ability to identify these opportunities and its ability to strategically manage its inputs (such as R&D or capital expenditure) in order to take advantage of these opportunities by producing a real innovation. The Manual also identifies the firm's ability to create opportunities by identifying and satisfying latent market demand.

The Manual goes on to identify three areas that can be managed by the firm in order to maximise the potential of this 'innovation dynamo'. They are:

strategic, relating to a firm's decision as to which markets it will serve or seek to create innovation for;

R&D, including basic research, strategic research and product concept development (this topic is covered extensively in the Frascati Manual (OECD 2002)); and

non-R&D, including: opportunity identification; production facility development; capital investment including technical information, patent writes human skills and process equipment; and management systems reorganisation.

As noted, previous innovation models have portrayed the firm as an autonomous entity. The innovation policy terrain acknowledges the systems approach to innovation by placing the firm, represented by the "Innovation Dynamo", within the other domains. The "Transfer Factors" domain is an acknowledgement of the importance, not only of the domains individually, but also of the linkages between domains within the innovation system. These two domains both exist within the "Framework Conditions" and the "Science Base" domains, which represent the wider conditions within which an innovating firm operates. These conditions are determined by factors that include: the basic education system; financial institutions; and legislative and macroeconomic issues.

The Oslo Manual also acknowledges the importance of defining a model in order to formalise the approach to data collection. However, the Manual proposes no model as definitive and indeed acknowledges the criticisms of all available innovation systems models.

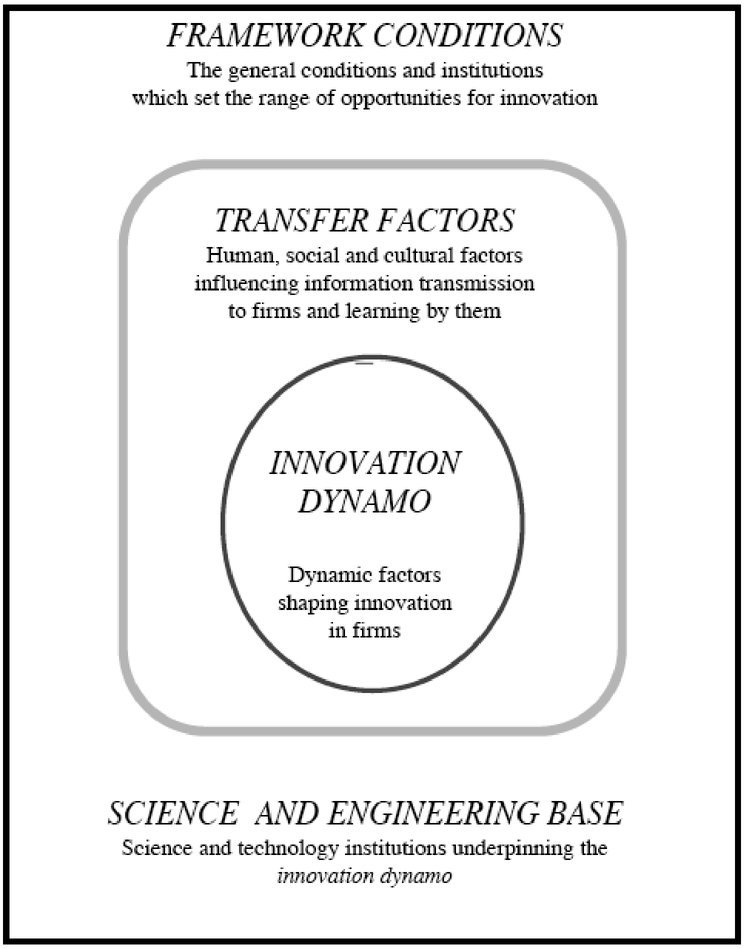

Figure 1:The Innovation System Frame as presented in the second edition of the Oslo Manual (OECD 1997)

2.2. A Generic National Innovation System

The OECD report "Governance of Innovation Systems" (Remøe *et al.* 2005) presents a conceptual model of innovation, taken from the report "A Singular Council: Evaluation of the Research Council of Norway" by Arnold and Kuhlman (2001). The approach used in this report, like the previous strand, focused on the firm or enterprise level and its interactions throughout the system. The approach is primarily directed towards technological innovation, which should be viewed as analogous to TPP innovation in the Oslo Manual. However, brief consideration is given to the increasing evidence of the importance of organisational and marketing (referred to as 'branding') innovations. The transformation of the telecommunications firm Nokia is cited as an example of organisational and branding innovation.

This model, presented in Figure 2, is based on a synthesis of ideas from innovation systems research, including those of Freeman (1987), Lundvall (1992) and Nelson (1993). The model is more complex than that seen in the innovation system frame, with more actors representing a greater level of demarcation.

The linkages between domains are represented by connecting arrows. The importance of these linkages for the innovation system emphasises that innovation is now seen more as a network or collective activity. In this approach, because firms and other economic actors have 'bounded rationality', learning and institutions are key to successful innovation and the resulting economic performance of national economies. Here, the "Company System" represents firms of innovators and can be seen as analogous to the "Innovation Dynamo" found in the "Innovation Policy Terrain" in Fig. 1 above. The remaining boxes represent the larger innovation environment and can be viewed as a demarcated analogue of the "Framework Conditions" and "Science Base" identified in the "Innovation Policy Terrain".

The concept of clusters of innovative entities inherent in the company system domain seen in Figure 1 involves an inherent dependence on interactions and these interactions are central to the goals of innovation systems literature (i.e. to generate a non-linear model of innovation). The interactions considered in the report "Governance of Innovation Systems" (Remøe *et al.* 2005) are summarised as including three basic ideas:

Competition, creating incentives for innovation through rivalry between innovating firms.

Transaction, representing traded knowledge between actors including tacit and technology embodied knowledge.

Networking, or knowledge transfer through collaboration, co-operation and long term networking arrangements.

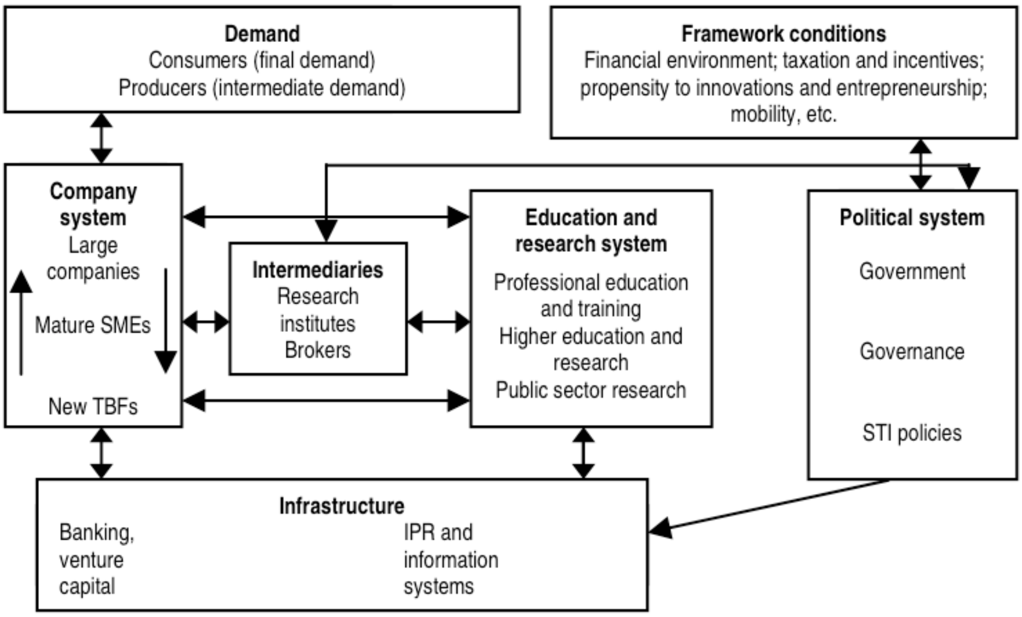

Figure 2: The generic model of national innovation systems as presented in OECD (2003)

2.3. Elements of National Innovative Capacity

Michael Porter and Scott Stern offered a conceptual model of the innovation process in the Global Competitiveness Report 2001-2002 (Porter and Stern, 2002), shown in Figure 3. Their innovation system conceptual model is presented as three elements which are discussed below.

2.3.1. The Common Innovation Infrastructure

This element is defined as the set of human and financial resources devoted to innovation, the public policies impacting on innovation, and the economy's level of technological sophistication. It is the environment within which all innovating enterprises must operate. In this way the 'common innovation infrastructure' can be seen as analogous to the 'framework conditions' referred to in the 'innovation policy terrain' of the 'Oslo Manual'.

The authors go on to comment on some of the fundamental components of a strong innovative infrastructure, including human capital, excellence in basic research and crosscutting policy areas such as protection of intellectual property and tax based innovation incentives.

2.3.2. Cluster-Specific Conditions

The concept of the innovating 'cluster' creates a slightly more inclusive approach to the characterisation of innovation at the enterprise level than other innovation conceptual frameworks considered. The idea of an innovating 'cluster' is defined as a:

"….geographic concentration of interconnected companies and institutions in a particular field."

This concept, therefore, expands slightly on the idea of the 'innovation dynamo' found in the innovation policy terrain to include the relationship between innovating enterprise on a localised level, an element confined to 'transfer factors' within previous conceptual frameworks. This concept also gives significant weight to the effects of localised rivalries to drive innovation, an idea not fully expressed in other conceptual frameworks of innovation.

The environment at this 'cluster' level is further viewed as four interrelating attributes, each contributing to the innovative capacity of the 'cluster'.

They are defined as:

the context for firm strategy and rivalry, representing the local encouragement of investment and rivalry between local enterprise;

factor or input conditions, including human capital, risk capital, research infrastructure and information infrastructure;

demand conditions, including insight gained from sophisticated local demand; and

related supporting industries, including local suppliers, related companies and the presence of these in localised industries or 'clusters'.

The benefits of cluster-specific interactions are referred to, developing the idea of heightened efficiency and competitiveness as a result of this environment. These benefits may include faster adaptation to changing demand or market forces and the competitive efficiency developed in peer-oriented environments. It could be argued that these elements may not be adequately accounted for in conceptual frameworks that do not address this 'cluster' environment.

2.3.3. Quality of Linkages

The quality of linkages is defined as the relationship between the common infrastructure and a nation's industrial clusters. The relationship is described as reciprocal as clusters are said to be able to feed and benefit the common infrastructure. Porter and Stern propose that this relationship is governed by formal or informal organisations that facilitate the links between the common innovation infrastructure and industrial clusters. One such organisation given in example is that of the national university system which provides a particularly strong bridge between technology and companies.

This model shares some common elements with the models mentioned earlier. Firstly the model's domains are called "determinants of national innovative capacity". The "Common Innovation Infrastructure" represents the concept of the innovation environment, analogous to the "Framework Conditions" discussed in previous models. The concept of linkages is also represented here within the "Quality of Linkages" determinant. The concept of the firm and its relationship to the innovation system is treated differently in this model. The "Clusters-Specific Conditions" determinant represents the interacting groups of firms, called "Clusters", which Porter & Stern (2002) define as "geographic concentrations of interconnected companies and institutions in a particular field". The "Cluster-Specific Conditions" involve the acts of individual innovative companies and the interactions of closely associated companies in the same field. These interactions would be considered as part of the wider linkages oriented domain in other models and this is a fundamental distinction between these models.

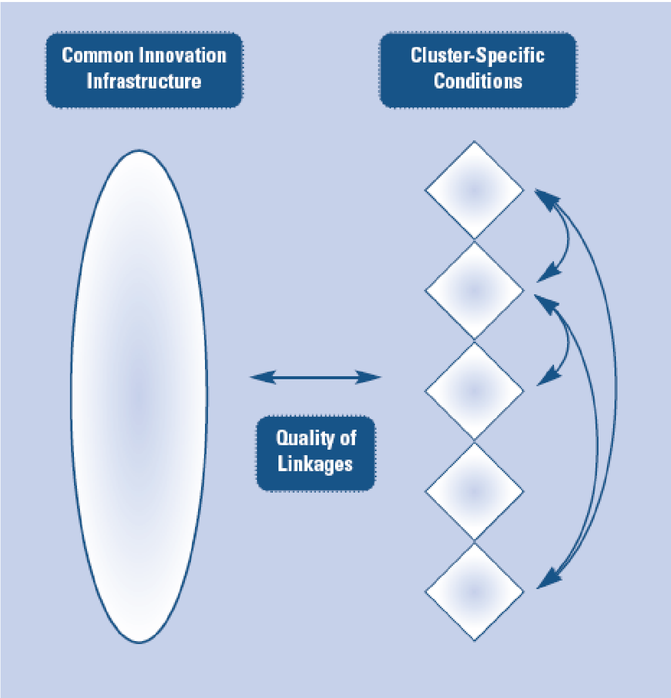

Figure 3: Elements of national innovative capacity as presented in Porter and Stern (2002).

2.4. Functions of Innovation Systems

The "Functions of Innovation Systems" approach aims to identify the key attributes or processes that have to be fulfilled within the innovation system for successful innovation to occur (Hekkert *et al.* 2007). Several authors have developed "Functions of Innovation Systems", as a conceptual framework for understanding innovation (Edquist & Johnson 1997; Rickne 2000; Johnson *et al.* 2001; Liu & White 2001) and, more recently, Jacobsson & Bergek (2004) and Hekkert *et al* (2007). The seven functions described by Hekkert *et al* are presented in Figure 4. The key concepts of other innovation systems models are represented. Jacobsson & Bergek (2004) highlight three key concepts of Technological Innovation Systems: actors (and their competencies); networks; and institutions. These are further discussed below.

Actors (and their competencies), including firms, users, suppliers, investors, and other organisations. Two highlighted actors are ‘prime movers’, defined as actors with a significant position within the technological innovation system, capable of influencing the development and diffusion of innovation, and non-commercial organisations, acting as proponents of specific technologies. This element can be seen as having some relation to the idea of clusters found in other chapters of this review.

Networks, defined as the channels for the transfer of tacit and explicit knowledge. These networks can include lines of information exchange on any level between any of the identified actors within a technological innovation system. The importance of this is seen as helping to increase the resource base of all actors within a network, and also to provide insight and guidance into what is desirable and possible, shaping the path of innovation. Again this element can be compared with other conceptualisations discussed in this review. In this case, networks can be compared to the idea of transfer factors or linkages.

Institutions, being the entities that govern and dictate the environment within which all actors operate. The methods of governance include the influence of market conditions and the influence of the connectivity of the system, resulting in the path and growth of innovation clusters. This may be comparable to framework conditions or common innovation infrastructure.

The functions highlighted by Hekkert *et al* (2007) reflect the commonality between “Functions of Innovation Systems” and the models discussed previously.“Entrepreneurial Activities” can be seen to represent firm oriented actions, while “Knowledge Diffusion Through Networks” is clearly related to the concept of linkages. “Market Formation” and “Creation of Legitimacy” are functions driven by institutions, and can be seen as conditions of the innovation system.

Figure 4: Functions of Innovation Systems, as presented by Hekkert et al. (2007).

3. The Generic Framework

Though these four models are distinct, all refer to certain key elements of the innovation system. Firstly, the conventional concept of innovation, that of the **firm** and its activities, is represented in all the considered models. This is seen as the "Innovation Dynamo" in "Innovation Policy Terrain", and the "Company System" in the "Generic National Innovation System Model". Firm activities are incorporated in the "Cluster-Specific Conditions" of "Elements of National Innovative Capacity", though this element also includes issues considered as network or linkage issues in other models. The idea of firm activities is covered to an extent by two functions in "Functions of Innovation Systems", namely "Entrepreneurial Activities" and "Knowledge Development".

The concept of the innovation **conditions**, within which innovative companies must operate, is another common concept between the considered models. This represents the first significant divergence from the traditional concept of innovation as a linear process. "Framework Conditions" in the "Innovation Policy Frame", and "Common Innovation Infrastructure" in the "Elements of National Innovative Capacity" represent the conditions concept. Several domains within the "Generic National Innovation System", represent the concept, namely "Framework Conditions", "Political System", "Demand", "Intermediaries", "Education and Research System", and "Infrastructure". The "Functions of Innovation Systems" approach represents only certain areas of this concept with the following functions: "Guidance of the Search"; "Market Formation"; "Resources mobilisation"; and "Creation of Legitimacy/ Counteract Resistance to Change".

The final key concept common to all models is that of **linkages** between actors within the system. This concept is fundamental to the modern, systems approach to conceptual models of innovation. It is represented by "Transfer Factors" in the "Innovation Policy Terrain", the connecting arrows in "A Generic National Innovation System", "Quality of Linkages" in "Elements of National Innovative Capacity", and by "Knowledge Diffusion Through Networks" in "Functions of Innovation Systems".

Having established the importance of a conceptual framework, within which the creation of indicators can be structured, we now define the conceptual framework to be used here. There are several differences in the models discussed above. Relatively complex models, such as "A Generic National Innovation System", have the benefit of precision. This aids the creation of indicators, giving clear guidance on issues such as indicator focus and coverage. However, there may be problems associated with the ability to collect data on all the indicator areas suggested by the model. In contrast, simplified models, such as "Elements of National Innovative Capacity" lack this specific guidance. It may be the case, however, that this level of detail in a conceptual framework is sufficient, given the practical and financial constraints on data collection that may be encountered.

For the purposes of indicator creation in this paper, we have adopted a generic framework. This level of detail will be practical, given the purpose of adapting current indicators while drawing on the key elements of the models described above. The framework thus has 3 concepts:

- The Firm
- The Conditions

- The Linkages

The generic framework is presented in Figure 5.

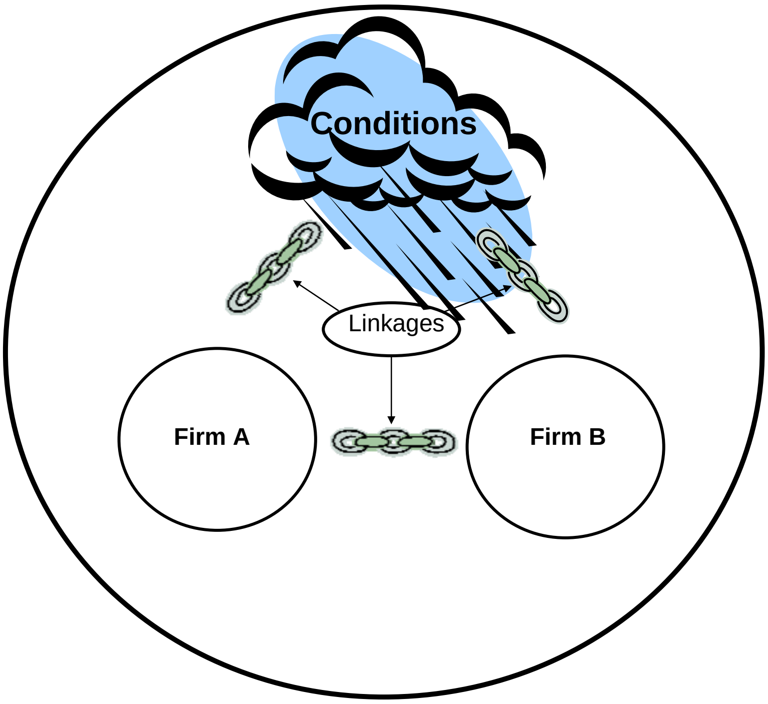

Figure 5: A Generic Framework of innovation systems

In addition to these guiding elements, the need for indicators on a further two classifications was identified. The **radical or incremental** nature of innovation is a potentially measurable dimension, which may indicate a level of associated desirability. Furthermore, indicators measuring the **overall innovative performance** of an innovation system are also of interest for comparing the relevant contributions of specific elements to overall innovative capacity. We used these two further classifications in addition to the generic framework, in order to classify the adapted indicators in section 4 and ensure indicators covering areas of interest were included.

4. Adapting Indicators for Eco-Innovation

Within each of the strands of innovation literature discussed above, large numbers of indicators have been proposed. We examined these indicators to assess whether they could be adapted to measure eco-innovation whilst relying on currently collected data. In addition, indicators of specific interest were created based on known ongoing data sources. This process could be valuable because it could provide an eco-innovation indicator set without new data collection activities, which have proved difficult to fund. In certain cases, we have proposed original indicators which are specific to eco-innovation. These arose out of the discussions within the 'Measuring eco-innovation' project. The indicators were then classified in relation to the generic framework, in order to assess the extent to which they could measure the whole eco-innovation system. The resulting indicators are presented below.

Table 1: List of proposed indicators of eco-innovation, adapted from the four examined strands of innovation theory

	Indicator	Actual/ Potential Data Source	Derivation
	The Firm		
1	R&D expenditures for environmental protection in industry.	STATCAN currently collects this information	Adapted from Remøe *et al*. (2005) "Innovation in the company system"
2	% of firms with EMAS or ISO14001	Numbers collected by German Federal Environmental Agency	Original
3	% of firms with environmental mission statements and/or officers	Would need to survey for this.	Original
4	Managers opinion of eco-innovation	Possibly for inclusion in Community Innovation Survey	Original
	The Conditions		
5	'Green Tax' as a percentage of government budget	OECD data	Adapted Porter & Stern (2002) "The innovation policy subindex"
6	Government expenditures on environmental R&D as: % of total R&D expenditure % of GDP	GBAORD data	Adapted from Remøe *et al*. (2005) "knowledge generation through education and research"
7	Uptake of environmental subsidies for eco-innovative activity	Government data	Original
8	Financial support for eco-innovation from public programmes	OECD data	Adapted from Remøe *et al*. (2005) "Innovation in the company system"
9	Demand for eco-innovative products.	Measure demand using survey techniques	Original
10	Environmental expenditure in college/university research	National Science Foundation collect this for US. EU source unknown	Original
11	Number of environmental graduates, MScs or PhDs	EIS & IRCE report	Adapted from Remøe *et al*. (2005) "knowledge generation through education and research"

12	Waste management costs (landfill tariff etc)	Government data	Original
13	Executive opinion on environmental regulation (Stringency and transparency).	For possible inclusion in Community Innovation Survey	Adapted from the GCR Executive Opinion Survey
14	Attitudes towards eco-innovation	Eurobarometer data	Adapted from "Cultural Capital" of "Socio-Cultural Determinants of Eco-Innovation"
	The Linkages		
15	Frequency of eco-innovation workshops/conferences and number of people attending.	Web based searches	Adapted from. Hekkert *et al* (2007) Function 3
16	Value of "green funds" made available by financial institutions for innovating companies.	SRI fund service data	Original
17	Managers perception of overall quality of environmental research in scientific institutions.	For possible inclusion in the CIS	Adapted from Porter & Stern (2002) "The linkages subindex"
	Radical/incremental innovation indicators		
18	Ratio of eco-start-ups to incumbents in the market	Companies house data or European business register.	Original
19	Frequency of new entrants to the market.	Companies house data or European business register	Adapted from Hekkert *et al* (2007) Function 1
20	Diversification activities of incumbents, investment in smaller operations outside core business.	EUROSTAT entry and exit data	Adapted from Hekkert *et al* (2007) Function 1
21	Seed and start-up venture capital for eco-innovative firms (investment per 1000 GDP)	IRCE report or interpretation of EVCA data.	Adapted from Remøe *et al*. (2005) "Absorption Capacity"
	Overall performance indicators		
22	Eco-patents in triadic	US EU and Japan Patent	Adapted from Remøe *et*

	patent families per million population	offices	*al*. (2005) "Innovation in the company system"
23	Material productivity of eco innovative firms (TMR per capita or GDP)	IRCE report	Adapted from Remøe *et al*. (2005) "Overall performance"
24	Share of eco-innovative firms as a percentage of all firms (may need to divide into manufacturing and services)	CIS. May need to be reanalysed.	Adapted from Remøe *et al*. (2005) "Overall performance"

Notes on sources:

CIS: Community Innovation Statistics. Collected by EUROSTAT and available from: **http://epp.eurostat.ec.europa.eu/portal/page?_pageid=1090,30070682,1090_33076576&_dad=portal&_schema=PORTAL**

EIS: European Innovation Scoreboard. Collected by the European Commission and available from: **http://trendchart.cordis.lu/**

Eurobarometer. Available from: http://www.gesis.org/en/data_service/eurobarometer/

EUROSTAT: EUROpean STATistics. Available from: **http://epp.eurostat.ec.europa.eu/portal/page?_pageid=1090,30070682,1090_33076576&_dad=portal&_schema=PORTAL**

EVCA: European Venture Capital Association. Available from: http://www.evca.com/html/home.asp

GBAORD: Government Budget Appropriations of Outlays for R&D. Collected by EUROSTAT and available from: **http://epp.eurostat.ec.europa.eu/portal/page?_pageid=1073,46587259&_dad=portal&_schema=PORTAL&p_product_code=KS-NS-06-017**

IRCE: Impact of RTD on Competitiveness and Employment. Available from: **http://cordis.europa.eu/era/benchmarking.ht**

SRI: Socially Responsible Investment. Available from: **http://www.eurosif.org/sri**

STATCAN: STATistics CANada. Available from: **http://www.statcan.ca/**

4.1. The Firm

The first group of indicators, presented in section 4.1, represents indicators of conditions relevant specifically to the **firm**. Indicator 1 has been adapted from an indicator presented in the OECD report "Governance of Innovation Systems" (Remøe *et al.* 2005). The remaining three indicators of this group are original proposals: all refer to aspects of firm conditions that are relevant to eco-innovation and are also reasonably practical to collect.

4.2. The Conditions

The indicators presented in the second group are metrics that attempt to measure the **conditions** of the general eco-innovation environment. Indicator 5 is adapted from an indicator presented in the chapter National Innovative Capacity of the Global Competitiveness Report (GCR) (Porter *et al.* 2002). Indicators 6, 8 and 11 are adapted from indicators found in the OECD report "Governance of Innovation Systems" (Remøe *et al.* 2005). Indicators 7, 9, 10 and 12 are all original metrics. Indicator 13 is an adapted version of an indicator found in the executive opinion survey of the GCR. Finally, indicator 14 is an adaptation of indicators found in the document "Socio-cultural Determinants of Eco-innovation" (Bruno *et al.* 2008).

4.3. The Linkages

The third group of indicators is classified as indicators of the state of **linkages** between entities involved in the eco-innovative environment. Indicator 15 is an adaptation of an indicator presented in Hekkert *et al* (2007), found in the chapter "Function 3: Knowledge diffusion through networks". Indicator 16 here is an original proposal. Metric 17 of this group is adapted from a metric presented in "The linkages subindex" of Porter and Stern (2002).

4.4. Radical/Incremental Indicators

This group represents the first of two groups added to the generic framework. A radical innovation may be of more interest in the context of transitions to a low carbon economy, making it particularly worth identifying. Indicator 18 is original and is intended to identify the structure of the market, indicating the likelihood of either incremental or radical innovation. Indicators 19 and 20 are adapted from suggestions in Function 1 of Hekkert *et al* (2007). Indicator 19 attempts to measure the accessibility to the market for small companies, thought to be more likely to innovate radically. Indicator 20 aims to assess an incumbent business's desire to innovate radically. Indicator 21 is adapted from Remøe *et al*. (2005) and attempts to assess a level of financial support available to small (and potentially radically innovative) enterprise.

4.5. Overall Performance

This final group aims to provide a yard stick of performance against which relative contributions of innovative activity could be measured. The concept of overall performance measurement is covered in the Oslo Manual (OECD 1997). All three indicators in this group are adapted from Remøe *et al*. (2005). Indicator 22 attempts to use patents as a measure of innovative output. Indicator 23 is somewhat similar, though it attempts to use a measure of productivity (Total Material Requirement per capita or GDP). Finally, indicator 24 attempts to measure the proportion of eco-innovative firms within a market. Changes in this share would indicate an aspect of the success of eco-innovation oriented policy.

5. Discussion

The indicators presented in Table 1 represent an attempt to adapt innovation indicators for the purpose of measuring *eco-innovation*. From the literature strands examined, many indicators have been identified as measuring relevant factors within an eco-innovative environment. Our attempt to adapt these indicators has highlighted the value and also the challenges associated with adapting indicators successfully for other than their original purposes. These challenges are not insignificant and should be acknowledged.

For the **Firm** oriented indicators there could be concerns over whether or not EMAS or ISO 14001 (indicator 2) are accurate proxies for eco-innovative tendencies, as the evidence for the relation between environmental management systems and eco-innovative activity is mixed. Similarly, there could be concerns over indicators 3 and 4, where the link between eco-innovative activity and the presence of an "environmental officer" or "managers' opinions" of eco-innovation could be questioned. At best, these measures are likely to be indicative of incremental eco-innovation within the firm, rather than radical eco-innovation.

Similarly, there could be concerns over the value of the **Conditions** metrics as eco-innovation indicators. In particular, indicator 10 relies on a link between the expenditure on environmental research in tertiary education and the science base contribution to eco-innovation, which is proposed but not well established. Further research is needed to develop or critique the evidence base for these indicators.

Within the **Linkages** indicators, the validity of an "executive opinion" in indicator 17, while of interest to the topic, might have limited empirical relationship to the question of linkages between the science base and the firm.

Indicators of the **radical or incremental** nature of innovation might be thought to rely too heavily on the premise that small firms tend to innovate more radically than large firms, though this has been a recognised assumption within innovation theory for some time (Foster 1986). Furthermore, while indicator 20 assumes that diversification activities by incumbent firms will have a positive effect on radical innovation, this is relationship might not be supported by empirical evidence.

In addition, the use of many of these indicators relies in some part on the ability to distinguish between innovation and eco-innovation. For example, indicator 8 relies on the ability to distinguish between financial support directed at innovation and that dedicated to eco-innovation. This information may not be freely available. This also depends greatly on how eco-innovation is defined and the subtleties of this definition may directly affect the ease with which these two activities can be distinguished. Other documents discussing eco-innovation have spent some time defining eco-innovation in order to bring some clarity to this issue (Kemp & Foxon 2007).

A further issue is the complementary nature of eco-innovation indicators. We suggest that this work be viewed as additional to the ongoing pursuit of accurate and incisive innovation indicators. As such, the indicators here do not stand alone but are intended to augment current thinking about the way in which innovation is measured.

Finally, though many issues clearly remain about the adaptation of indicators for other purposes, the process followed here is a first attempt to develop a new perspective within innovation theory and measurement. The indicators proposed here provide a basis from which the development of new eco-innovation indicators could move forward and is a step towards the goal of measuring eco-innovation appropriately and accurately.

6. Conclusions

In the pursuit of a system of metrics designed to measure eco-innovation, it has been possible to create an indicator set derived from current innovation literature. This process has highlighted several issues which may prove valuable to the ongoing process of evaluating the innovation and eco-innovation environments. We suggest that in establishing an eco-innovation indicator system, it matters to find an indicator set that is both comprehensive with regard to the system analysis of innovation and generic and simple enough to be applied across jurisdictions and for comparison between jurisdictions. The process followed here is intended to achieve this balance. It is recognised, however, that there is a considerable challenge in adapting indicators for purposes other than those for which they were created.

Furthermore, the creation of defensible eco-innovation indicators is clearly a complex task, in which issues about the validity of some of the proposed indicators have arisen. Thus, for example, direct links between some of the indicators and the elements they are intended to measure were not always found to be clearly defined.

Given these issues, we propose the indicator set in this study as a “straw-man” through which the development of a fuller understanding of eco-innovation measurement could be pursued. And we recognise that the development of accurate indicators of eco-innovation should be considered as complementary to the measurement of innovation more widely (Kemp & Foxon 2007; Kemp and Pearson, 2008).

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