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Conceptualising the Assessment of Eco-Innovation Performance

A Theory Based Framework for Deriving Eco-Innovation Key Performance Indicators and Drivers (EI-KPIs)

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ABSTRACT

This paper aims at establishing a conceptual framework of eco-innovation in order to derive a set of key performance indicators and drivers eligible to assess the eco-innovation performance of firms, sectors and nation states from a business perspective. In order to establish such a set eco-innovation key performance indicators and drivers (EI-KPIs), first of all, rules of indicator development need to be taken into account. Following these rules, the first step before indicator development can take place, is to provide a conceptual framework of the latent variable to be measured. Thus, in chapter three of this paper the eco-innovation process is conceptualised by defining eco-innovation and putting the eco-innovation process into a systems perspective. Furthermore, with regard to eco-innovation performance, the most important actors and their roles within and outside the firm, also with regard to networking and cooperation activities, are identified. Finally the eco-innovation process is split into different phases that allow for more structured identification of eco-innovation key performance indicators and drivers. Chapter four provides an overview of the lag, lead and sector specific indicators allocated to the different phases of the eco-innovation process. Since eco-efficiency is identified as the main lag indicator of eco-innovation performance, some more information on instruments and tools driving the improvement of eco-efficiency performance is provided. Finally, an outlook is given on what are the next steps towards the development of a comprehensive and structured eco-innovation assessment tool.

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LIST OF ACRONYMS & ABBREVIATIONS

ACCA	Association of Chartered Certified Accountants
CEN	Comité Européen de Normalisation (European Committee for Standardization)
CIESIN	Center for International Earth Science Information Network
CIS	Community Innovation Survey
CM	Contribution Margin
CSI	Core Set of Indicators
ECI	Environmental Condition Indicators
EEA	European Environmental Agency
EEG	Erneuerbare-Energien Gesetz; Renewable Energy Law
EIA	Environmental Impact Added
EI-KPI	Eco-Innovation Key Performance Indicator
EIS	European Innovation Scoreboard
EMAS	Eco-Management and Audit Scheme
EMS	Environmental Management System
ESG	Environmental, Social and Corporate Governance issues
ETAP	Environmental Technologies Action Plan
EU	European Union
Eurosif	European Social Investment Forum
EVA	Environmental Value Added
GRI	Global Reporting Initiative
IHK	Industrie- und Handelskammer
IISD	International Institute for Sustainable Development
IPCC	Intergovernmental Panel on Climate Change
ISO	International Standards Organisation
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
MEMA	Monetary Environmental Accounting
MIPS	Material Intensity per Service Unit
NGO	Non-Governmental Organisation

NPEIA	Net Present Environmental Impact Added
NPV	Net Present Value
OECD	Organisation for Economic Co-operation and Development
PEMA	Physical Environmental Accounting
PRI	Principles of Responsible Investment
PSS	Product Service System
ROCE	Return on Capital Employed
R&D	Research & Development
SDI	Sustainable Development Indicators
SD-KPIs	Sustainable Development Key Performance Indicators
SEEA	System of Integrated Environmental and Economic Accounting
SETAC	Society of Environmental Toxicology and Chemistry
SHV	Shareholder Value
StMUGV	Bayerisches Staatsministerium für Umwelt, Gesundheit und Verbraucherschutz
UN	United Nations
UNCSD	United Nations Commission on Sustainable Development
UNCTAD	United Nations Conference on Trade and Development
UNEP	United Nations Environment Program
VA	Value Added
WBCSD	World Business Council for Sustainable Development

1 INTRODUCTION

Eco-innovation is a core issue for linking innovativeness, which from a business perspective always implies economic progress, with sustainable development. As companies have to be increasingly innovative to survive and excel in the highly competitive environment of the 21st century, they cannot neglect the business opportunities provided by eco-industries. Any sustainable development of an economy and society requires a sustainable development of its companies. Corporate sustainability, in turn, requires convincing breaks and changes in common production, organisation and management patterns, which can only be achieved through innovations that shape and develop mass markets in a sustainable manner.

Given the pressing global environmental and sustainability issues and the political goals in the EU it is not astonishing that increasing attention is paid to approaches requiring businesses not just to be innovative and competitive but also to behave environmentally and socially responsible. As one important aspect of sustainable development and as an important driver of market changes and competitiveness, eco-innovation plays a crucial role when it comes to decoupling economic performance and environmental degradation. As a difference to earlier views of eco-innovation, which try to integrate environmental issues into purely economically motivated innovations reducing environmental burdens, it is important to pay attention to the more ambitious goals of recent ecopreneurs and sustainable entrepreneurs. Their focus is on creating competitiveness *through* environmental or sustainable progress, thus enabling companies to act as driving forces of sustainable development. Sustainable entrepreneurs consider striving for sustainable development as a key source of innovation, which can shape both the future development of markets and the sustainable development of the economy and society at the same time.

A core question in this context is, how political measures can foster an eco-innovation driven increase of the competitiveness of the European economy and its companies. Supporting eco-innovation in an optimal manner requires a basic framework taking into consideration companies and entrepreneurs as key actors shaping eco-innovation. This framework should help to identify and measure progress, strengths and deficiencies in the eco-innovative process towards sustainable development. However, not only political actors are interested in the assessment of eco-innovation performance. Also from the business perspective eco-innovation needs to be regarded as one of the key success factors when it comes to sustainable business management and development.

Hence, this paper aims at developing a systems and process oriented typology of the eco-innovation concept, which again serves as foundation for an eco-innovation framework in which the appropriate indicators and drivers of eco-innovation performance can be identified. The following broader research question will be answered:

From a business perspective, what are the eco-innovation key performance indicators and drivers (EI-KPIs) that enable the assessment, benchmarking and improvement of strategic decision making and management processes towards improving eco-innovation performance and thus sustainable competitive advantage?

2 INDICATOR DEVELOPMENT

2.1 Usefulness of indicators

According to the OECD's (n.d.) sustainable development glossary an indicator in general terms can be defined as "[a] summary measure that provides information on the state, or change in, a system." Indicators can be utilised for performance and trend monitoring, evaluation and comparison purposes and therefore are usually structured and summarised by means of scales or indices. Such sets of indicators are considered useful if they show

> (...) the capacity to simplify, quantify, analyse and communicate otherwise complex and complicated information, and the ability to make particular aspects of a complex situation stand out and thus reduce the level of uncertainty in the formulation of strategies, decisions or actions (Warhurst 2002, 10).

The OECD (2003, 5) more specifically defines the term indicator as "a parameter, or a value derived from parameters, which points to, provides information about, describes the state of a phenomenon/environment/area, with a significance extending beyond that directly associated with a parameter value" and the term as "a set of aggregated or weighted parameters or indicators" where parameter is defined as "a property that is measured or observed".

2.2 The what, why and how of measurement

2.2.1 Reasons for indicator development

The aim of this paper is to identify a set of key-performance indicators and drivers for the assessment of eco-innovation performance from a business perspective. The purpose of identifying eco-innovation key-performance indicators (EI-KPIs) is to construct an eco-innovation assessment tool that can be used for benchmarking purposes among firms in the same sector or other industries, or other comparable organisational units engaging in similar eco-innovation activities. According to Balm (1996, 28) expanded benchmarking can be defined as

> the ongoing activity of comparing one's own process, practice, product, or service against the best known similar activity so that challenging but attainable goals can be set and a realistic course of action implemented to efficiently become and remain best of the best in a reasonable time.

Thus, identification of EI-KPIs will help companies to understand the strengths and weaknesses of their performance regarding the successful development and realisation of eco-innovations in order to be able to make the strategic decisions necessary to improve their performance and gain the rewards coming along with improved or even best-in-class performance. Thereby it is important to consider that the assessment of performance against benchmarks is not only used by internal organisational members, e.g. management, but also by external stakeholders such as financial investors or competitors as a basis for future action and for further continual improvement (Schaltegger & Burritt 2000).[1]

According to Lucertini et al. (1995, 61)

> benchmarking deals with w*hat* (identify analogous process parts, i.e. subchains), w*hy* (identify performance indicators) and *how* (identify the new organization: interconnections, structure or behaviour of the part to be improved), practices or leader companies having conquered leadership positions, can be transferred.

Beroggi et al. (2006) suggest a stepwise logic for indicator development. In their work on designing a model for innovation indicators from a systems perspective, they follow a five-step approach that looks as follows (Beroggi et al. (2006, 217):

1. selection of the innovation system
2. identification of existing indicators that can be used
3. definition of additional indicators to complete the model
4. quantification of all indicators
5. data analysis and decision-making.

Hence, in a first step it is necessary to identify "(...) a conceptual model of the transformation process, that can be used to transform performance evaluation into improvement decisions" (Lucertini et al. 62), which in our case is a conceptual model of the eco-innovation process. Only afterwards, indicator development or even approaches towards performance improvement should be delineated.

Besides the above mentioned benchmarking purpose, a performance indicator system can be utilised for varying other specific goals such as fault diagnosis, early warning, assessment of trends, indentifying options for improvement and assistance of stakeholders in understanding and reacting to performance trends (Warhurst 2002).

2.2.2 Indicator characteristics

According to Kaplan and Norton (1996) indicators used as generic measures for strategic performance should be regarded as measuring a set of cause-and-effect relationships that require generic outcome measures, i.e. *lag indicators*, as well as performance drivers, i.e. *lead indicators*. It should be noticed that making use of a set of eco-innovation indicators for benchmarking purposes can be regarded as driver of eco-innovation itself since "[m]easurement drives behaviour (... and) is crucial to the alignment of (...) behaviours and activities with the strategic purpose of the organisation" (Dransfield et al. 1999, 102). However, as Warhurst (2002, 15) points out, "it is important to recognises the gap between indicators and a coherent and effective management system." Walls et al. (2008, 23) characterise lead indicators as measurements that drive or feed into rather "(...) forward looking strategies companies pursue in order to gain competitive advantage (...)" whereas

[1] For further information on different types of benchmarking see Schaltegger & Burritt's (2000, 367f.) description of five different functional types of benchmarking: internal benchmarking, best-in-class benchmarking, competitive benchmarking, sector benchmarking, and eco-rating.

lag indicators are characterised as providing information about past firm behaviour. Bearing in mind the cause-and-effect relationship, the creation of an set of indicators intended to serve as benchmarking tool should include a good mix of lead and lag indicators, since, as Kaplan & Norton (1996, 31) mention: “Outcome measures without performance drivers do not communicate how the outcomes are to be achieved. They also do not provide an early indication about whether the strategy is being implemented successfully.” Thereby a multi-indicator approach should be taken. According to Haagedorn & Clodt (2001, 1366)

> [t]he advantage of such a multi-indicator approach is that, instead of assuming the ‘correctness’ of a single indicator, probably taken for reasons of convenience, an analysis of multiple indicators might allow us to measure innovative performance through a more complex, more informative, composite measure. In addition to this, a composite measure can be analysed in detail, in terms of the individual indicators and with reference to the contribution of each indicator to the latent variable (...).

Nevertheless, the set of indicators composed should *stay simple* and be reduced to a minimum number possible. The intention to develop a set of drivers and indicators of eco-innovation rests on the idea to break down the complex settings, structures and processes related to eco-innovation development and corresponding management activities into a comprehensive and manageable level that provides a base for benchmarking and continuous performance measurement.

Construction of an indicator set cannot be done offhand but means paying attention to a set of *methodological principles*. This is to avoid composite indicators being exposed to misinterpretation or manipulation. As Bossel (1999) states, ad hoc or trial-and-error selection of indicators is inadequate; a *framework* and a *process* within a *system concept* need to be defined in order to identify a suitable set of indicators. The conceptual framework provided in this paper characterises eco-innovation as a process leading to the adoption and diffusion of innovation that positively contributes to the environmental as well as economic status of its surrounding socio-technical system over time.

As Fukasaku (2005, 254) mentions, “[the] characteristics of environmental innovation make it difficult to gather needed indicators and data for effective policy making.” Thereby, the idea is not to create an entirely new set of indicators, however, sets of existing and already applied drivers and indicators relevant to eco-innovation will be taken into account. That is why the indicator framework presented in this paper intends to consider and incorporate those existing sets of indicators where appropriate. Existing indicator sets consulted and analysed towards their applicability will be, e.g., the European Innovation Scoreboard (EIS), indicators defined in the Global Reporting Initiative (GRI), the UN Indicators of Sustainable Development, the environmental indicators identified by the European Environment Agency (EEA), the system of integrated Environmental and Economic Accounting (SEEA) by the United Nations Statistics Division, indicators used within the Eco-Management and Audit Scheme (EMAS), and indicators provided by the Environmental Sustainability Index (ESI), which was created cooperatively by Yale University, the Center for International Earth Science Information Network (CIESIN) at Columbia University and the World Economic Forum in Davos.

After having consulted existing indicator sets for their use towards eco-innovation, additional indicators to complete the model will be identified. Thereby general methodological principles with regard to indicator construction should be followed. It needs to be ensured that the set of chosen EI-KPIs provides *timely*, *accurate* and *meaningful* information on the current situation of the concept under measurement. This is a first prerequisite to achieve improvement in the future (Warhurst 2002).

Since the development of eco-innovations is directed towards sustainable development, the Bellagio principles represent one set of overarching principles to be noticed in this context. The Bellagio principles (box 1) provide a guideline for the development of indicators related to sustainable development. Also the UNCSD (UN 2007, 29) suggests various principles for indicator selection related to sustainable development that are:

- primarily national in scope;
- relevant to assessing sustainable development progress;
- limited in number, but remaining open-ended and adaptable to future needs;
- broad in coverage of Agenda 21 and all aspects of sustainable development;
- understandable, clear and unambiguous;
- conceptually sound;
- representative of an international consensus to the extent possible;
- within the capabilities of national governments to develop; and
- dependent on cost effective data of known quality.

Within the UN guidelines, indicator development is mainly regarded as policy oriented and therefore the indicators' national scope is the prime principle. Whether this is the right aggregate level for eco-innovation indicators depends on the stakeholders' information need as will be explained later. General indicators show the overall performance at a higher aggregate level than specific indicators providing detailed process, product and site information about operations. Stakeholders interested in eco-innovation indicators require that those indicators address their area of interest resulting in different stakeholders being "(...) interested in different kinds of information as well as in different levels of detail" (Schaltegger & Burritt 2000, 363).

One of the main tasks of indicator development is that the set of indicators should be comprehensive and suited to capture the complexities of the selected system or framework, whereas at the same time it needs to remain simple and small enough to be easily and routinely monitored. Dale & Beyeler (2001, 6f.) define a set of criteria for environmental indicator selection that can be applied to general indicator selection as follows. According to them selected indicators should:

- be easily measured
- be sensitive to stresses on the system
- respond to stress in a predictable manner

- be anticipatory, i.e. signify an impending change in key characteristics of the system
- predict changes that can be averted by management actions
- be integrative, i.e. the full suite of indicators provides a measure of coverage of the key gradients across the system
- have a known response to disturbances, stresses and changes over time.

Resuming from the UN's Sustainable Development Indicators (SDIs) the indicators can have a role in several phases of the processes they are related to, i.e., "(...) the identification of strategic priorities, through the planning and implementation of specific policy interventions, monitoring progress and learning from successes and failures" leading to the conclusion that "indicator development and strategy development are sometimes coupled, though this connection is certainly one that should be strengthened" (Pintér et al. 2005, 9). A set of indicators on eco-innovation shall not just inform, it shall also provide the possibility to draw trends, to identify flaws and bottlenecks and to be able to infer from these and make the right strategic decisions.

1. GUIDING VISION AND GOALS
Assessment of progress toward sustainable development should:
• be guided by a clear vision of sustainable development and goals that define that vision

2. HOLISTIC PERSPECTIVE
Assessment of progress toward sustainable development should:
• include review of the whole system as well as its parts
• consider the well-being of social, ecological, and economic sub-systems, their state as well as the direction and rate of change of that state, of their component parts, and the interaction between parts
• consider both positive and negative consequences of human activity, in a way that reflects the costs and benefits for human and ecological systems, in monetary and non-monetary terms

3. ESSENTIAL ELEMENTS
Assessment of progress toward sustainable development should:
• consider equity and disparity within the current population and between present and future generations, dealing with such concerns as resource use, over-consumption and poverty, human rights, and access to services, as appropriate
• consider the ecological conditions on which life depends
• consider economic development and other, non-market activities that contribute to human/social well-being

4. ADEQUATE SCOPE
Assessment of progress toward sustainable development should:
• adopt a time horizon long enough to capture both human and ecosystem time scales thus responding to needs of future generations as well as those current to short term decision-making
• define the space of study large enough to include not only local but also long distance impacts on people and ecosystems
• build on historic and current conditions to anticipate future conditions - where we want to go, where we could go

5. PRACTICAL FOCUS
Assessment of progress toward sustainable development should be based on:
• an explicit set of categories or an organizing framework that links vision and goals to indicators and assessment criteria
• a limited number of key issues for analysis
• a limited number of indicators or indicator combinations to provide a clearer signal of progress
• standardizing measurement wherever possible to permit comparison
• comparing indicator values to targets, reference values, ranges, thresholds, or direction of trends, as appropriate

6. OPENNESS
Assessment of progress toward sustainable development should:
• make the methods and data that are used accessible to all
• make explicit all judgments, assumptions, and uncertainties in data and interpretations

7. EFFECTIVE COMMUNICATION
Assessment of progress toward sustainable development should:
• be designed to address the needs of the audience and set of users
• draw from indicators and other tools that are stimulating and serve to engage decision-makers
• aim, from the outset, for simplicity in structure and use of clear and plain language

8. BROAD PARTICIPATION
Assessment of progress toward sustainable development should:
• obtain broad representation of key grass-roots, professional, technical and social groups, including youth, women, and indigenous people - to ensure recognition of diverse and changing values
• ensure the participation of decision-makers to secure a firm link to adopted policies and resulting action

9. ONGOING ASSESSMENT
Assessment of progress toward sustainable development should:
• develop a capacity for repeated measurement to determine trends
• be iterative, adaptive, and responsive to change and uncertainty because systems are complex and change frequently
• adjust goals, frameworks, and indicators as new insights are gained
• promote development of collective learning and feedback to decision-making

10. INSTITUTIONAL CAPACITY
Continuity of assessing progress toward sustainable development should be assured by:
• clearly assigning responsibility and providing ongoing support in the decision-making process
• providing institutional capacity for data collection, maintenance, and documentation
• supporting development of local assessment capacity

Box 1: The Bellagio Principles of sustainable development indicators

Source: Hardi & Zdan (1997, 2ff.).

2.3 Formative versus reflective indicator models

In order to avoid misspecification and biases when developing a set of indicators operationalising the complex construct of eco innovation performance, the relationship between the determined *lead* and *lag* indicators and the *latent* variable measured by the indicators, needs to be determined. This will be done by making use of theoretical decision making criteria on *reflective* (effect) indicator and *formative* (cause, causal) indicator constructs (Diamantopoulos & Winklhofer 2001; Diamantopoulos & Siguaw 2006; Eberl 2004). Reflective indicators are usually needed for conventional scale development procedures, whereas formative indicators are geared towards index construction. As displayed in box 2 in reflective indicator models indicators are regarded "(...) as functions of the latent variable, whereby changes in the latent variable are reflected (i.e. manifested) in changes in the observable indicators" whereas with formative indicator modelling "it is changes in the indicators that determine changes in the value of the latent variable rather than the other way round" (Diamantopoulos & Siguaw 2006, 263). Hence, the main differences between the reflective and the formative perspective lie in their direction of causality between latent variable and indicator and in the difference in interchangeability of indicators due to their differing degree of correlation.

Reflective specification model:

$x_i = \lambda_i \square + \xi_i$

where λ_i is the expected effect of the latent variable □ on a set of observable indicators x_n and ξ_i is the measurement error for the *i*th indicator (i = 1, 2, …. □). Here the correlation between all x_n is high.

Formative specification model:

$\square = y_1 x_1 + y_2 x_2 + \ldots + y_\square x_\square + \xi$

where y_i is the expected effect of x_i on the latent variable □ and ξ is a disturbance term. Here the correlation between all x_n can lie anywhere between the interval [-1;+1].

Box 2: Difference between reflective and formative specification models

Source: adapted from Diamantopoulos & Siguaw (2006, 263); Diamantopoulos & Winklhofer (2001, 270); Eberl (2004, 5; 8).

2.3.1 The reflective perspective

In the case of applying a reflective perspective, the latent variable is regarded as being the element that causes the change and the observable indicators are identified as the elements that show the effect of this change (effect indicators), i.e. they reflect and manifest changes in the latent variable. Thereby, the correlation between the effect indicators is supposed to be high, since a change of one indicator is regarded as not taking place in isolation from the other indicators. A sudden change in a particular direction of one such indicator caused by the latent variable is regarded as necessarily being accompanied by an effect on the other indicators as well, i.e. a change of the other indicators in a similar manner will take place due to the assumption that reflective indicators are highly correlated (Diamantopoulos & Winklhofer 2001; Eberl 2004). It is supposed that the defined indicator framework comprises all observable variables conceptually operationalising the not directly measurable construct or latent variable, which in our case is eco-innovation performance. The indicator framework therefore needs to be all-encompassing, which is barely realisable, since for any construct or latent variable an infinite pool of indicators is taken for granted. Nevertheless, since all the indicators embedded in one and the same conceptual framework are assumed to be rooted within the same concept or latent variable, all items are highly correlated, which leads to the assumption that they are of equal validity and thus, if they are equally reliable, too, essentially interchangeable. "[T]herefore the removal of an item does not change the essential nature of the underlying construct" (Diamantopoulos & Winklhofer 2001, 271). Hence, indicators not or barely correlating are regarded as not corresponding to the defined indicator framework and therefore as being without avail for operationalising the latent variable (Eberl 2004).

2.3.2 The formative perspective

A formative indicator framework, on the other hand, follows the perspective that the individual indicators are not necessarily correlated, however, are regarded as independent constituents of the latent variable, where in contrast to the reflective indicator model, the indicators are regarded as causing rather than being caused by the latent variable. Due to the possibility of low or no correlation between the indicators defining the construct, a change in the latent variable might be caused by one separate indicator without the necessity of related change in the other indicators. Moreover, the change in the latent variable might not even be caused by an indicator defined within the indicator framework at all, but by an indicator outside the framework. Consequently, an indicator change causes a change in the latent variable, however, a change in the latent variable does not necessarily imply a change in the indicator framework having been defined; moreover, the indicator causing the change might even lie outside the defined framework, which leads to the assumption that the defined formative indicator framework might not be all-encompassing and "(...) taken in isolation, the formative indicator measurement model (...) is statistically underidentified; the model can be estimated only if it is placed within a larger model that incorporates consequences (i.e. effects) of the latent variable in question" (Diamantopoulos & Winklhofer 2001, 271). Due to the fact that the indicators might be negatively related, every indicator can be allocated its own specific and independent influence on the latent variable, implying that the indicators are not interchangeable or dispensable but add up to a linear combination of indicators constituting the latent variable. Additionally, it needs to be mentioned that "(...) unlike their reflective counterparts, formative indicators do not have error terms; error variance is represented only in the disturbance term, ζ, which is uncorrelated with the xs (i.e. cov[x_i, ζ]=0)" (Diamantopoulos & Winklhofer 2001, 271) as shown in box 2.

2.3.3 Making a choice

Reflective and formative indicator models showing different characteristics (a more detailed list of all characteristic differences can be found in Diamantopoulos & Winklhofer 2001) call for different procedures when it comes to constructing valid and reliable indicator sets. According to Diamantopoulos & Siguaw (2006) the causal priority between the construct and its observable indicators that determines the choice between a reflective versus a formative approach also determines whether conventional scale development guidelines should be followed (reflective) or index construction strategies (formative) are applicable. In order to decide whether the set of indicators to be created is of reflective or formative nature, Jarvis et al. (2003, 203) formulated four sets of questions to be applied in combination for the determination of the appropriate measurement model (table 1).

Table 1: Decision rules for determining whether a construct is formative or reflective

Source: Jarvis et al. (2003, 203).

	Formative model	Reflective model
1. Direction of causality from construct to measure implied by the conceptual definition	Direction of causality is from items to construct	Direction of causality is from construct to items
Are the indicators (items) (*a*) defining characteristics or (*b*) manifestations of the construct?	Indicators are defining characteristics of the construct	Indicators are manifestations of the construct
Would changes in the indicators/items cause changes in the construct or not?	Changes in the indicators should cause changes in the construct	Changes in the indicator should not cause changes in the construct
Would changes in the construct cause changes in the indicators?	Changes in the construct do not cause changes in the indicators	Changes in the construct do cause changes in the indicators
2. Interchangeability of the indicators/items	Indicators need not be interchangeable	Indicators should be interchangeable
Should the indicators have the same or similar content? Do the indicators share a common theme?	Indicators need not have the same or similar content/indicators need not share a common theme	Indicators should have the same or similar content/indicators should share a common theme
Would dropping one of the indicators alter the conceptual domain of the construct?	Dropping an indicator may alter the conceptual domain of the construct	Dropping an indicator should not alter the conceptual domain of the construct
3. Covariation among the indicators	Not necessary for indicators to covary with each other	Indicators are expected to covary with each other
Should a change in one of the indicators be associated with changes in the other indicators?	Not necessarily	Yes
4. Nomological net of the construct indicators	Nomological net for the indicators may differ	Nomological net for the indicators should not differ
Are the indicators/items expected to have the same antecedents and consequences?	Indicators are not required to have the same antecedents and consequences	Indicators are required to have the same antecedents and consequences

The table highlights four main areas of interest when it comes to making a choice between a formative and a reflective indicator development approach, which are:

1. direction of causality from construct to measure implied by the conceptual definition;
2. interchangeability of the indicators/items;
3. covariation among the indicators;
4. nomological net of the construct indicators.

Having answered the relevant questions the appropriate indicator model should be set up. As mentioned before, the suitable choice of indicators is also determined by the interests of the stakeholders basing their strategic decisions on derived benchmarking results.

2.3.4 Applying modelling rules to the eco-innovation construct

Eco-innovation KPIs are thought of as being lead as well as lag indicators. Therefore, it seems probable that the indicator model will be made up of reflective as well as formative elements. Hence, it needs to be assumed that eco-innovation performance might be a "(...) multidimensional construct [that] might have one type of measurement model relating its measures to its first-order components and a different measurement model relating its components to the underlying second-order factor" (Jarvis et al. 2003, 204). Assuming that "*(a)* a first-order construct can have either formative or reflective indicators, and *(b)* those first-order constructs can, themselves, be either formative or reflective indicators of an underlying second order construct" (Jarvis et al. 2003, 204), the model for a set of eco-innovation performance indicators is assumed to look as follows:

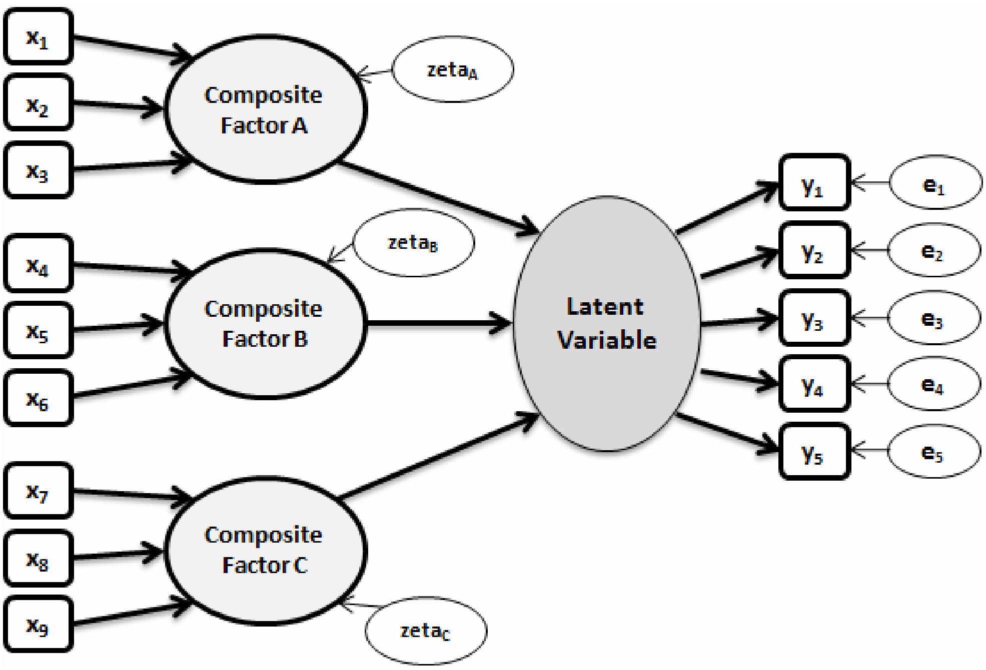

Figure 1: Multidimensional construct of eco-innovation performance

Source: based on Jarvis et al. (2003).

Here the latent variable "eco-innovation performance" can be regarded as principal factor causing the measures y_n, which are expected to be highly correlated lag indicators reflecting eco-innovation performance. A change in the latent variable will cause a change in all the measures y_n meaning that the measures should possess internal consistency and reliability. Moreover, dropping one measure y_n does not alter the meaning of the construct. Measurement errors are taken into account at the item level. The composite factors represent groups of measures x_n, where the causality is expected to be from measure to construct. There is no reason to expect the measures represented by lead indicators are correlated, thus internal consistency is not implied. Here every measure x is important to the formation of the construct. Hence, dropping one indicator from the measurement model may alter the meaning of the construct. Measurement error is taken into account at the construct level. The composite factors again serve as formative indicators for the latent variable “eco-innovation performance”. Identifying indicators as formative or reflective measurements of the indicator model is crucial to ensuring validity and thus avoiding any bias in the estimates, since “(...) any bias in the estimates produced by (...) misspecification could affect the conclusions about the theoretical relationships among the constructs that are drawn from the research” (Jarvis et al. 2003, 207).

2.4 The need for integrated indicator model construction

Various objectives including environmental performance, sustainable economic performance, innovativeness, long-term orientation and further sustainability management aspects need to be taken into account when composing an eco-innovation performance index that strives for systemic completeness. However, as Ronchi et al. (2002, 200) point out, “(...) systemic completeness aside, too large indicator sets may give rise to confusing messages to the public and to decision makers.” This is an important aspect that needs to be taken into account for indicator construction, however, it should not be forgotten that the idea behind improving eco-innovation performance is not to develop new end-of-pipe solutions. Improvement of eco-efficiency by incremental innovation or redesign of the existing should be widened into long-term upstream oriented function- or even system innovation (figure 2) taking into account rebound effects.

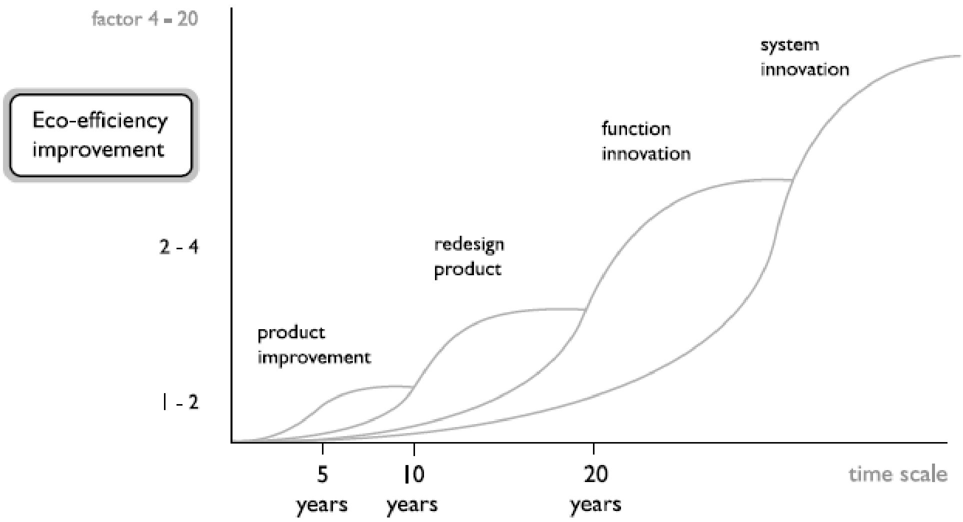

Figure 2: Eco-efficiency curves

Source: Brezet et al. (2000) in Nuji (2001, 50).

Expecting eco-innovation to bear the potential for system innovation claims for *a holistic systems thinking approach* that looks “(...) at the big picture while maintaining awareness of the interconnectedness of the components of the big picture” (Kelly 1998, 460). One of the main aspects to consider here is that an innovation process is not a closed but an open system interacting with its environment at micro-, meso- and macro level without which it could not come into existence. This open system surrounding the eco-innovation process is composed of processes shaped by people interacting with each other in various ways. Eco-innovation itself is one such process being embedded into an open system and being shaped by the actors interacting in the open system, i.e. internal and external processes appearing between all kinds of actors shape and are shaped by the eco-innovation process.

The mix of drivers and outcomes or lead and lag indicators chosen to represent the relevant cause-and-effect relationships of eco-innovation should account for the system's complexity represented by aspects characterising eco-innovation, such as a long-term time dimension, associated feedback processes and rebound effects, different levels of analysis (networks of actors within micro-meso- and macro environment), the interactions between involved actors, the mutual dependency as well as the tangible and intangible resources exchanged via those interactions, the external legal and legitimacy aspects influencing eco-innovation development, as well as the internal operational and management factors influencing eco-innovation progress. Due to the system's complexity, integration of all eco-innovation KPIs into an eco-innovation assessment tool might result into multidimensional formative and reflective indicator constructs that need to be defined carefully in order to ensure construct validity since "(...) measurement model misspecification severely biases structural parameter estimates and can lead to inappropriate conclusions about hypothesized relationships between constructs [...and] can lead to different conclusions about the empirical relationships between latent constructs" (Jarvis et al. 2003, 216).

2.5 Providing stakeholder specific information

The broader the level of activity at which eco-innovation is taking place, the more complex the management of these activities due to an increasing amount of actors involved, which in turn makes the analysis of the activities related to eco-innovations more complex (Schaltegger & Dyllick 2002). As outlined before, eco-innovation indicators can be regarded as condensed information for decision making (Olsthoorn et al. 2000). By simplifying a complex reality they help to communicate relevant aspects or even complex interrelations between different aspects of the organisational environment. Indicators supply information, they identify key factors or driving forces, they support monitoring the impact of certain activities or policy responses, they may be used as a powerful tool to raise public awareness and they help to identify trends and progress of activities over time (EEA 1999; EEA 2005). The purpose of eco-innovation indicators is to inform stakeholders for instance about environmental performance vis-à-vis economic performance of activities related to eco-innovations. Aiming at the derivation of appropriate eco-innovation indicators and drivers, the innovative product, product group or other functional units as well as the system boundaries and the time frame for measurement have to be defined. Moreover, one should bear in mind that indicators need to serve internal and external stakeholders' differing information needs with differing degrees of detail. In their book on issues, concepts and practice of environmental accounting Schaltegger & Burritt (2000) outline this circumstance for the definition of eco-efficiency indicators as follows:

> Of critical importance is that eco-efficiency indicators must be unambiguously defined in such a way that the economic and environmental dimensions measured reflect and are focused on the activities of concern to specific stakeholders (...). Divisional management may, for example, need to focus on the economic and environmental impacts of strategic business units or sites. Middle and lower levels of management focus on product groups, product units, sites and production steps. As indicators are used to guide management control and strategic planning activities, indicators must be defined with care and must take the specific circumstances of a company into account" (Schaltegger & Burritt, 2000, 363ff.).

Depending on the stakeholders' main interest, the eco-innovation indicators need to be related to their level of concern. That is why the KPIs defined for eco-innovation analysis need to distinguish between different aggregation and activity levels (figure 3), i.e. the product dimension, process dimension, activity level and site or spatial orientation.

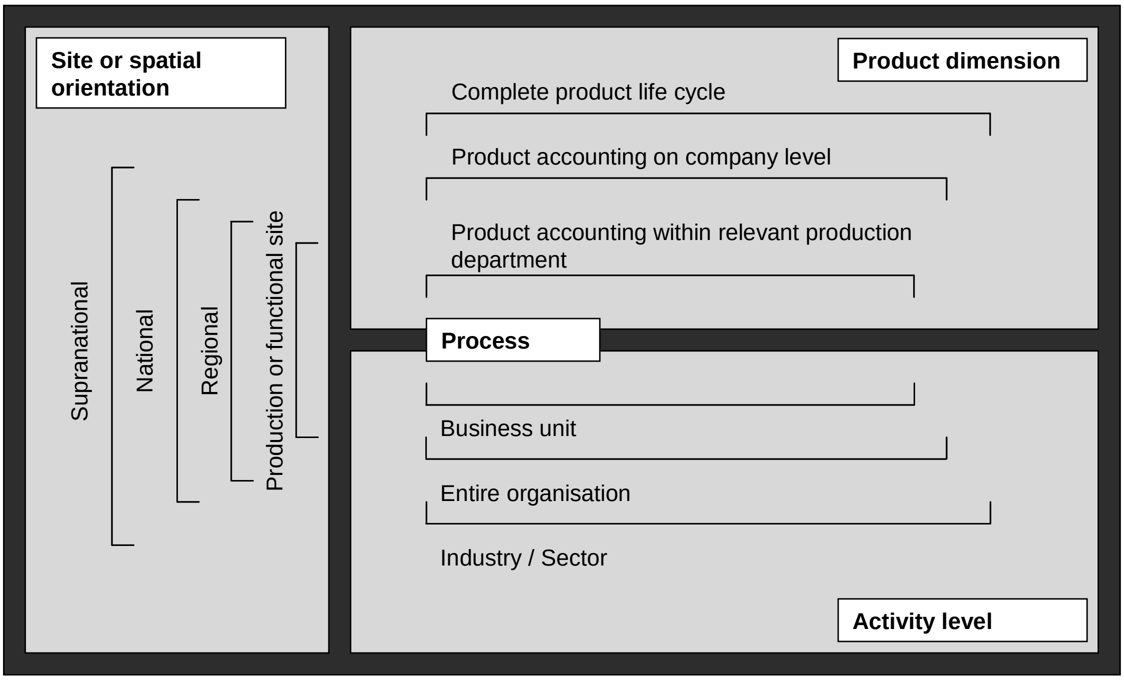

Figure 3: Aggregation levels for different innovative products, product groups or other functional units

Source: adapted from Schaltegger & Sturm (1992, 147).

Besides being stakeholder specific, indicators also need to meet the challenge that decision makers, especially those at policy level, claim for support in understanding the relationships between processes taking place on micro-, meso- and macro-level. Therefore, an all-inclusive holistic conceptual model or framework depicting all system and process related behaviour of eco-innovation is requested.

3 STEP ONE: DEFINING A CONCEPTUAL FRAMEWORK FOR THE ECO-INNOVATION PROCESS

In their decision on establishing a Competitiveness and Innovation Framework Programme (2007-2013) the European Parliament & European Council (2006, 11) define eco-innovation as "(…) any form of innovation aiming at significant and demonstrable progress towards the goal of sustainable development, through reducing impacts on the environment or achieving a more efficient and responsible use of natural resources, including energy."

The term eco-innovation has found its way into research literature only since a decade (e.g. Fussler & James 1996; James 1997; Nuji 2001; Klemmer er al. 1999; Schaltegger & Petersen 2001). Early definitions of eco-innovation read as follows:

> (…) new products and processes which provide customer and business value but significantly decrease environmental impacts (James 1997, 57).
>
> (…) measures of relevant actors (firms, politicians, unions, associations, churches, private households) which:
>
> - develop new ideas, behaviour, products and processes, apply or introduce them and
> - which contribute to a reduction of environmental burdens to ecologically specified sustainability targets (Klemmer et al. 1999).
>
> Eco-innovation aims to develop new products and services that are not based on redesign or incremental changes to existing products but rather on providing the consumer with the function they require (Nuji 2001, 49).

In order to delineate a conceptual framework supporting the assessment of drivers and indicators of eco-innovation, it is important to grasp a more detailed and deeper understanding of what eco-innovations are and how they are determined. Therefore, the concept will be approached from innovation research literature regarding innovation as driver of creative destruction of unsustainable structures.

3.1 Eco-innovation as interactive process within a socio-technical system of innovation

3.1.1 Innovation as a driver of creative destruction of unsustainable structures

The basic understanding and categorizations of innovation from Schumpeter (1976/79), Hauschildt (2004) and Sabisch et al. (1998) are useful starting points for the discussion of dimensions of eco-innovations. Schumpeter's innovation perspective and idea is a core concept for economic development. He saw innovation as a "perennial gale of creative destruction (…) that incessantly revolutionizes the economic structure *from within,* incessantly destroying the old one, incessantly creating a new one" (Schumpeter 1976/1979, 77f.).

> Those revolutions are not strictly incessant; they occur in discrete rushes which are separated from each other by spans of comparative quiet. The process as a whole works incessantly, however, in the sense that their analysis is either revolution or absorption of the results of revolution, both together forming what are known as business cycles (Schumpeter, 1976/1979, p.77).

Innovation is at the heart of economic change and therefore one of the main driving forces behind economic growth and development (Cameron 1996). A core characteristic of any innovation according to Schumpeter is that it is *market relevant,* i.e. it influences markets and market conditions on basis of market (or market-similar) processes and market success. Furthermore, Schumpeter emphasizes the *role of entrepreneurial actors* in creating and shaping innovation. This paper is based on the assumption that eco-innovation is substantially driven and shaped by entrepreneurial actors, i.e. by ecopreneurs (chapter 3.1.5.1).

Schumpeter´s approach has influenced the political agenda of economic renewal in Europe. In their decision of establishing a "Competitive and Innovation Framework Programme (2007-2013)" the European Parliament and the European Council (2006, 6) define innovation as

> comprising the renewal and enlargement of a range of products and services and their associated markets; the establishment of new methods of design, production, supply and distribution; the introduction of changes in management, work organisation, and working conditions and skills of the workforce; and covers technological, non-technological and organisational innovation.

Innovations support sustainable development, environmental and social progress and economic competitiveness if they make unsustainable current structures and systems redundant through the replacement by more sustainable solutions. Given the role of innovations for sustainable development and competitiveness, it is necessary to investigate the different types of innovation and their role for combining economic and environmental progress more in depth. According to Hauschildt (2004) innovations can take place in four areas:

- *technological* innovations, e.g., in products, processes and technological knowledge
- *organisational* innovations, e.g., in structures, institutions, cultures and systems
- *business-related* innovations, e.g., in industrial structures, market structures and boundaries, rules and other economic aspects
- *social* innovations: socio-technical systems, political innovations, lifestyles, etc.

Based on the general categorisation of innovations by Hauschildt (2004) the following four dimensions of eco-innovation can be distinguished:

- *technological eco-innovations* as for example solar energy or wind power systems;
- *organisational eco-innovations* leading, for instance, to new forms of organisational concepts like that of car sharing (www.carsharing.de);
- *business park related eco-innovations* as for example that of the loop closing eco-town Hyogo in Japan (www.hyogo-kobe.jp/english/area/project/echotown. html) realising a

zero-waste industry by utilising the by-products, waste, and recovered materials from different industrial sectors as inputs to production and

- *social eco-innovations*, e.g. with regard to more environmentally friendly lifestyle and consumption habits or the introduction of new regulations like the Renewable Energy Law (Erneuerbare-Energien-Gesetz, EEG) introduced by the German Bundestag in 2004.

Most fundamentally, two kinds of innovation can be distinguished, product innovation and process innovation. *Product innovations* are the improvement (in the sense of incremental improvement) of goods and services or the creation of new goods and services whereas *process innovations* result in an improved input output relation of organisational or production processes (Rennings et al. 2005). With regard to environmental process innovations, two further categories can be identified, which are *innovations in end-of-pipe technologies* and *innovations in cleaner production technologies* (integrated technologies), which according to Kemp & Arundel (1998, 2) can be divided into six further sub-categories:

1) *Pollution control* technologies that prevent the direct release of environmentally hazardous emissions into the air, surface water or soil.
2) *Waste management*: handling, treatment, and disposal of waste; both on-site by the producer of the waste and off-site by waste management firms.
3) *Clean technology*: process-integrated changes in production technology that reduce the amount of pollutants and waste material that is generated during production.
4) *Recycling:* waste minimisation through the re-use of materials recovered from waste streams.
5) *Clean products*: products that give rise to low levels of environmental impact through the entire life cycle of design, production, use and disposal. Examples are low-solvent paints and bicycles.
6) *Clean-up technology*: remediation technologies such as air purifiers, land farming and bioremediation, which uses plant species to remove toxic materials from contaminated soil.

In the business context, an innovation can be regarded as being realised as soon as the new product is substantially diffused into the market or a novel process is adopted within an organisation. Furthermore, innovations can be categorised according to their diffusion rate as new to an organisation or the regional, national, or international level. Here, an organisational innovation can be seen as novel if a certain organisation adopts an innovative process or management structure for the first time, independent from other organisations already having implemented the same innovative process (Sabisch et al. 1998). Based on Schumpeter's ideas, innovations can thus be further categorized as (see also Sabisch et al. 1998):

- *Product innovations:* development, production and commercialisation of a new good
- *Production process innovations:* development, implementation and commercialisation of a new method of production (not necessarily scientifically new but also a new way of handling a commodity commercially)

- *Market innovations:* opening up of a new market (new to the organisation but not necessarily new to the world) and use of new marketing methods
- *Supply innovations:* opening up of a new source of supply (new to the organisation but not necessarily to the world)
- *Organisational innovations:* implementation of new organisational structures and methods
- *Management innovations:* implementation of new management methods
- *Social relationship innovations:* change of social relationships within organisations
- *Environmental procedure innovations:* improvement of environmental protection procedures within organisations.
- *Corporate strategy innovations:* substantially changed "corporate strategic orientation" can be defined as innovation (OECD & Eurostat 1997, 54).

When applying the above discussed fundamental aspects of innovation to sustainability, *sustainability oriented innovation* can be described as a market relevant creative destruction of unsustainable or less sustainable organisational structures, production processes, social relationships or goods resulting in the creation of a new, more sustainable solution or situation. Equivalently, an eco-innovation creates a market relevant destruction of environmentally harmful organisational structures, production processes, social relationships and goods that results in a more environmentally friendly outcome. From a business perspective, eco-innovations therefore must encompass and integrate economic success and environmental performance, improving in the output dimension eco-efficiency as the relation between economic and environmental performance (for a further discussion of eco-efficiency see chapter 4.1).

Sabisch et al. (1998) categorize technological innovations according to the degree of their newness into:

- *basic innovations* (with totally new designed product generations, products or processes; e.g. thin layer solar foils)
- *improvements* (where individual quality parameters are improved, e.g. a more efficient diesel car engine)
- *adaptations* (where already existent solutions are adapted to customer preferences, e.g. eco-textiles with modern style and fashionable colours)
- *imitations* (of innovations already existent in other firms; copies of hybrid car engines)
- *pseudo-innovations* (which are changes that do not bear any substantial improvement; e.g. new product names).

Furthermore, innovations can be distinguished into *incremental* innovations where the *means-end relation* is improved in already existent markets and *radical* innovations which provide novel means for novel ends with a very high degree of newness and comprehensive change of organisational processes. Moreover, Sabisch et al. (1998) distinguish between *revolutionary* innovations (basic and abrupt) and *evolutionary* innovations (continuous improvement of already existing solutions keeping their functional effect). Garud & Karnøe

(2003) even distinguish between *bricolage* versus *breakthrough* in terms of innovation emergence and its underlying processes.

Regarding eco-innovation as being embedded into a micro-meso-macro structure brings along the necessity to look at it from a systemic perspective where innovations are defined as a long term multi-level transformation process (Weber et al. 2006). As mentioned in chapter 2.6, innovation does not only involve a whole system of actors, relationships and networks, however, it can also lead to an entire system change (figure 2). *System innovations* are of socio-technical nature involving transformations in a whole cluster of elements leading towards the emergence of new functionalities. This cluster of elements is not limited to technological transformations but also includes social aspects such as new markets, user practices, regulations, infrastructures and cultural meanings, maintenance networks and supply networks (Geels 2004). Thus economic incentives such as “market pull” and “technology push” aspects, which have been regarded as the core innovation drivers for a long time, are now extended by the idea that a complex network of actors and institutions is indispensible for knowledge genesis and conversion into sustainable system innovations (Hafkesbrink 2007).

Having given an overview of different categorisations of innovation identified in the literature, the following matrix (figure 4) shows how innovation is understood throughout this paper. Here an innovation’s degree of novelty and impact is integrated with different categorisations of innovation.

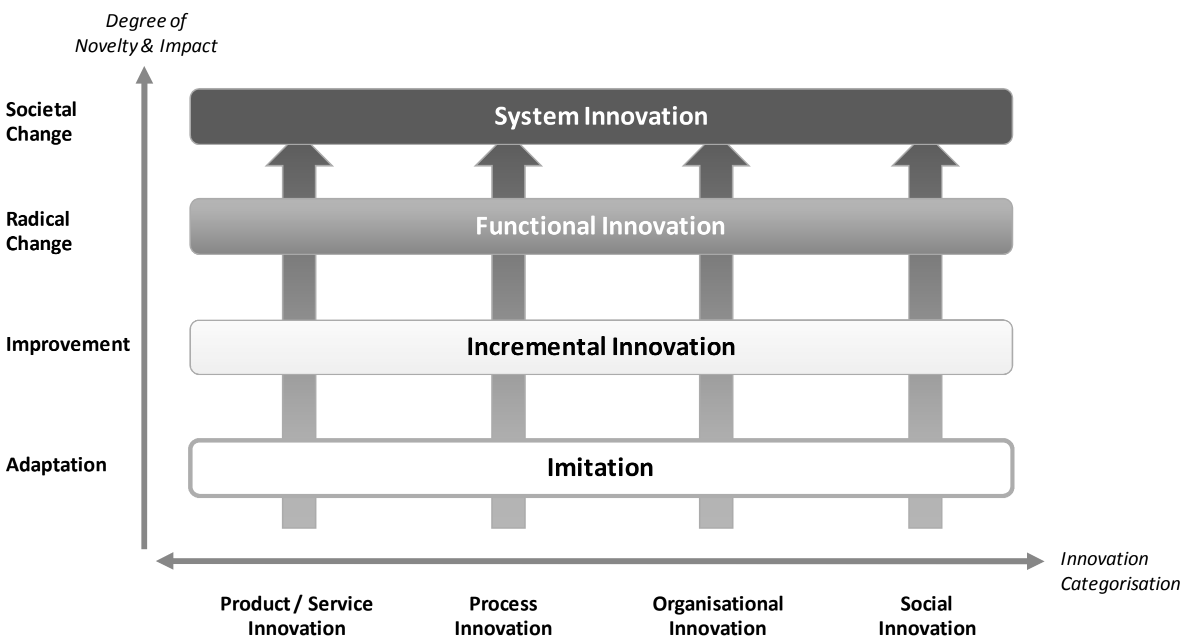

Figure 4: Innovation matrix

These categorisations show that the different kinds of innovation have a divergent influence on the scope of the destruction of the old and the construction of the new. Thus, depending on the state of development of and in an economy, society or company, the needed scope of innovation for environmental and sustainability progress will be accordingly different.

3.1.2 Eco-innovation in a broad and in a narrow sense

The discussion of different classification approaches to innovation has shown that eco-innovation can be defined in a *narrow* and in a *broad* sense. Based on the premise that eco-innovation increases eco-efficiency by definition, i.e. that it is efficient from an economic perspective as well as from an environmental perspective (see chapter 4.1), eco-innovation can be defined in a narrow sense only considering the *direct* environmental and economic effects, for instance of a technological innovation directly linked to improved environmental and economic performance. However, economically and environmentally efficient innovation related to organisational, business-related or social changes will in many cases, due to its systemic nature and the business' embeddedness into a greater spheres of influence, also have effects on broader systems. Thus, eco-innovation will often not only lead to environmental and economic improvement but also be a social, cultural, political, technological or other kind of organisational innovation. Moreover, eco-innovation may be interconnected with social aspects of sustainable development and therefore lead to improved social performance or improved overall sustainability performance. Many eco-innovations involve and require social processes and changes in order to become effective. They can be considered as eco-innovations in a broader sense. Such *broader* "social eco-innovations", as for instance an effective and efficient tax system on hydrocarbon fuels, may strive for changing social behaviour and interactions with the goal of increasing the eco-efficiency of energy consumption. However, depending on how such a taxing system is exactly defined and introduced, it may also primarily aim at creating other effects or benefits such as a broader financial base for social security financing. Nevertheless, also such a broader political innovation may indirectly trigger the invention of more eco-efficient technologies, e.g. alternative fuel technologies for cars.

3.1.3 The scope of innovation: value chain and ecological leverage effect

Taking into account the indirect effects of eco-innovation in a broader sense, one should also address the ecological leverage effect of an innovation which addresses the consideration of the scope of effects and changes involved in an innovation. The ecological leverage effect shows whether it is worthwhile to invest in the environmental improvement of production devices and processes of a firm or in the improvement of products. The ecological leverage effect is defined by the following ratio (Schaltegger 1997, 2):

$$\text{Ecological leverage effect} = \frac{\text{Potential effect on the eco-efficiency of the customer}}{\text{Potential effect on the eco-efficiency of the own firm}}$$

reducing impacts in the consumption or utilisation phase with the customers. The numerator is caused by product, production or organisational innovations implemented into the market, i.e. at the customer, whereas the denominator stands for production device or process innovations implemented within the company itself. Both kinds of innovation are often related but may also be different options requiring a management choice. Hauschildt (2004) emphasizes that implementation problems of product innovations usually exceed those of process innovations. If the ecological leverage effect is high, one may prefer just improving the product, whereas a low ecological leverage effect recommends an investment in eco-innovations aiming at company-internal production devices and processes rather than mere product innovation. Furthermore, it should be considered that in manufacturing companies product innovations increasingly call for process innovations as well. That means when aiming at more eco-efficient innovations, not only should narrow technological improvements directly aiming at changing the product be considered, but also changes in technological as well as social processes. The resulting social and economic influences and effects may differ substantially depending on the phase of the innovation process.

3.1.4 Eco-innovation within a dynamic multi-level system of micro niches, meso regimes and macro landscapes

Besides eco-innovations bearing the potential to become system innovations, the eco-innovation process as such should be regarded as being *embedded* into a socio-technical system of processes. Change and transformation are taking place in terms of cause-and-effect activities (to be defined by the interrelationship between observable lead and lag indicators and the latent variable) within the eco-innovation process and between the eco-innovation process and the surrounding system processes. Hereby, it is important to realise the complexity of the relationships not represented by mere linear cause-and-effect relationships but rather by *non-linear* cause-and-effect relationships including positive and negative *feedback* as well as *causal loops*. Hence, eco-innovation is not an isolated and linear process but needs to be regarded as *complex* and *dynamic* process that is part of a larger institutional set-up within a *socio-technical system of innovation*.

Freeman and Louçã (2002, 5) suppose that the evolution of societies and economies through time shows “(...) recognisable patterns, depending on the relations between technological innovation, social structure, economic development, institutional framework, and cultural standards.” Geels (2004b, 898) supposes so called system builders to “(...) travel between domains such as economics, politics, technology, applied scientific research and aspects of social change, weaving a seamless web into a functioning whole.” According to Schaltegger et al. (2003) this general environment is being made up of the following five intertwined arenas influencing each other, the:

- *socio-cultural* arena with its customs, traditions, demographics, mobility patterns, life styles, religious practices, etc.;
- *economic* arena with its production and consumption processes, markets, trade systems, producing organisations, etc.;
- *scientific-technological* arena including scientific developments in universities, research, education, etc.;
- *legal* arena with its constitutions, laws, legal practices, police and enforcement structures, etc.;
- *political* arena with its distribution and concentration of power, negotiations, conflict and cooperation agreements, etc.

One example on how the different dimensions influence each other is that a change in the socio-cultural dimension - might it be a change in education that leads to a change in lifestyle (e.g. people start living a “green lifestyle”) due to a feeling of responsibility towards ecology and humanity created by new knowledge (e.g. the recent IPCC report, which proofs that only a change in lifestyle and consumption patterns can prevent a climate catastrophe) - results in changes in the economic dimension. These might be changed consumption processes (e.g. reduction of energy prodigality by switching to renewable energy sources) creating new market opportunities (e.g. for solar, wind, water and biomass technologies in a renewable energies market). This again might lead to changes in the legal dimension (e.g. new policies supporting the development of clean energy technologies), which again may lead to changes in the political dimension (e.g. the creation of new networks or NGOs whose actors aim at supporting sustainable development in industries) and so on. That means within these spheres of influence triggers and catalysers for all kinds of innovation can be identified.

The physical resources used for the creation of innovation are taken from our *natural environment* surrounding the societal environment. Resources generated within the socio-technical system, such as knowledge, technological-artefacts or “(...) technology involving infrastructures, e.g., electricity networks, railroad networks, telephone systems, videotext, internet” (Geels 2004b, 898) are all dependent on resources coming from the natural environment. That is why the socio-technical system in which innovations are evolving needs to be regarded as being embedded, influencing and being dependent on the natural environment. Natural resources are not infinite, thus, sustainability-oriented innovations meeting the requirements for sustainable economic development need to factor in the finiteness of natural resources. Sustainable and eco-efficient production systems are characterised by being *decoupled* from ecological degradation. This characteristic goes along with the European Union’s view of eco-innovation as progressive concept within the Environmental Technologies Action Plan (ETAP) that is “any form of innovation aiming at significant and demonstrable progress towards the goal of sustainable development, through reducing impacts on the environment or achieving a more efficient and responsible use of natural resources, including energy” (European Council & European Parliament 2006, 11). In order to determine the performance of this eco-innovation process by identifying and measuring the appropriate drivers and indicators, a closer look at what actually characterises this eco-innovation process itself is necessary, which will be provided in chapter 3.2.

As described before, eco-innovation is regarded to be complex and dynamic and therefore should not be regarded as “(...) the end-stage of a process driven mainly by scientific advances in basic research” (Andersen 2004, 11) but as an interactive and ongoing learning process emphasising the importance of knowledge sharing and networking within the holistic innovation system. Thus, it is important to understand where in the (national, sectoral, regional) innovation system’s arenas the knowledge and incentives driving eco-innovation can be realised. From a business perspective “[m]anagement balances the demands placed on business by all stakeholders and takes the particular goals of any stakeholder group into account when negotiating any matters of substance and when reporting on the success of business performance” (Schaltegger et al. 2003, 57). In return, stakeholders within each environmental arena give their consent or rejection, depending on how well management balances stakeholder claims. Schaltegger et al. (2003, 56) point out that “[b]alanced management is different from one-sided financial management”, which primarily aims at conventional economic rationality. Here, what is called *socio-economic rational management* is needed. Besides economic efficiency, socio-economic rational management defines further indicators as success criteria for balanced management that takes into account social and environmental aspects as well. For the scientific-technological arena the success criterion is effectiveness related to the successful introduction, development and use of technical processes, in the legal arena the success criterion is compliance and derived legality, for the socio-cultural arena it its legitimacy and for the political arena it is freedom of action. “Balanced business management has the role of making sure that an acceptable balance between all these goals and the means towards achieving these goals is maintained. Included in this balanced management is sound environmental management” (Schaltegger et al. 2003, 59).

A *micro-meso-macro perspective* on eco-innovation stresses the importance of institutional factors for understanding economic behaviour providing for a more holistic systems approach that bears the “(...) capacity to synthesise disparate parts of evolutionary economics into a unified framework” (Dopfer et al. 2004, 268) and therefore enables us to connect processes taking place at microeconomic level, such as firms’ eco-innovation activities, via institutional factors at meso-economic level to macro-economic phenomena, i.e. “(...) output flow or asset value aggregations that arise from the existence of interacting populations of meso rules” (Dopfer et al. 2004, 267). This approach acknowledges the assumption that “[t]he economic *macro*-structure is composed of *meso*-components that, in turn, are composed of *micro*-components” (Dopfer 2005, 50).

Micro is the level at which novelty actually originates and meso bears those populations of institutions that mainly influence the eco-innovation’s process from being an idea over being a niche-market concept towards possibly being diffused into the mass-market. Considering that innovation is an interactive and dynamic systemic concept, actors involved and their interactions, which defy traditionally identified rigid organisational and sector boundaries as well as boundaries between public and private involvement, need to be identified. Thereby, it is not always possible to make a clear distinction between categories, competencies and roles (Preissl & Solimene 2003). Different perspectives of innovation have evolved over time and focus on different aspects of innovation processes. May they be incremental or radical, evolutionary or revolutionary, enabling or disruptive (Preissl & Solimene 2003), they can be helpful to localise various agents and institutions within the overarching framework of an eco-innovation process. Taking into account the various dimensions of the societal context, innovation agents, components, structures and processes can be identified in the institutional and general environment with its socio-cultural, technological, political and economic spheres influencing and being influenced by the eco-innovation process (Schaltegger & Sturm 1992).

The eco-innovation process could be understood as meso trajectory (Dopfer et al. 2004) interacting with agents, structures, components, and processes at micro- and macro- levels of society. It should be looked at what drives and what indicates eco-innovations throughout the interacting processes between the various phases of the eco-innovation process and the associated processes taking place at micro and macro level. Since the development of eco-innovations is highly dependent on the *actors* involved, a special focus must lie on those agents as drivers in the micro, meso and macro environment. This includes micro-level agents such as entrepreneurs and interpreneurs but also macro-level agents such as governments and NGOs among others. Especially the relations and interactions between those agents within and between the different contextual dimensions of our society should be investigated in order to find out what influence they have on the development of eco-innovations and how they are reciprocally influencing each other and are influenced by proceeding eco-innovation development.

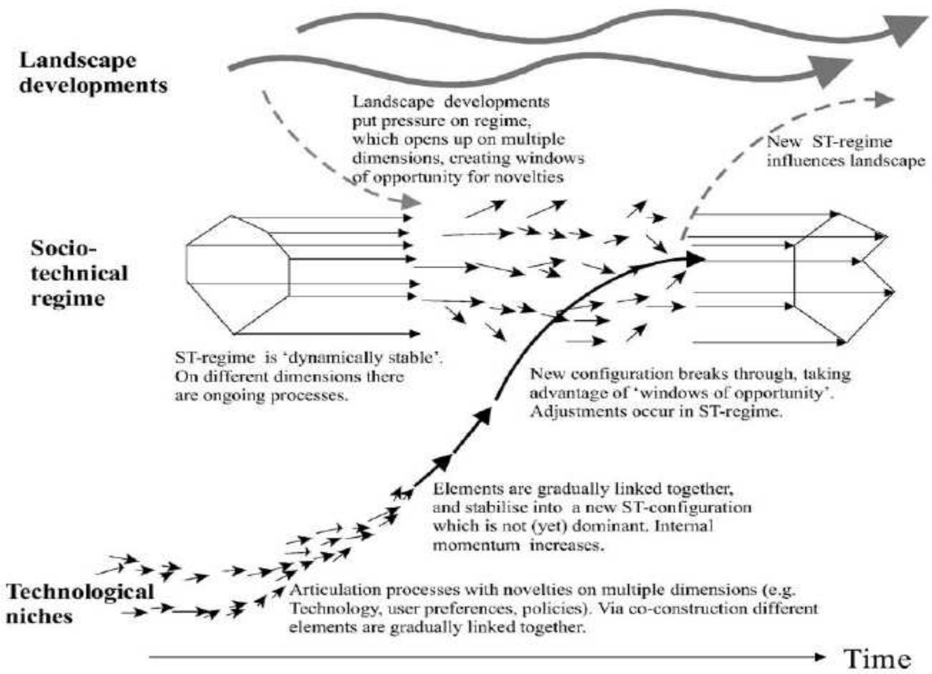

Figure 5: A dynamic multi-level perspective on system innovations

Source: Geels (2004b, 915).

Also Geels (2004a; 2004b) stresses the usefulness of a adopting a micro-meso-macro perspective towards innovation. Eco-innovation does not only come into existence due to some brilliant engineers, however, actors and other processes in the societal and technical arenas surrounding eco-innovation play an important role. Geels (2004a) denotes the term socio-technical landscape to this surrounding quite stable system at the macro level. "The socio-technical landscape contains a set of heterogeneous, slow-changing factors such as cultural and normative values, broad political coalitions, long-term economic developments, accumulating environmental problems growth, emigration. But it also contains shocks and surprises, such as wars, rapidly rising oil prices" (Geels 2004a, 34). Within the infrastructure of the socio-technical *landscape*, so called socio-technical *regimes* can be detected providing orientation and coordination to the activities of relevant actor groups. These regimes provide the rule set necessary, e.g. to generate incremental innovation and occupies an intermediate meso-level position between the macro-level socio-technical landscape and the micro-level niches. Within those *niches* that are protected from normal market selection and therefore act as incubation rooms, radical innovation is thought of as being generated. These niches are regarded as relevant “(...) because they provide locations for learning processes, such as learning by doing, learning by using and learning by interacting” (Geels 2004a, 35). Nevertheless, they are not to be regarded as functioning completely isolated from the surrounding socio-technical system, however, “[n]iches also provide the space to build social networks which support innovations, like supply chains and user-producer relationships” (Geels 2004a, 35), which is referred to as strategic niche management. For a visual depiction of Geels’ dynamic multi-level perspective on system innovation see Figure 5.

This dynamic and multi-level understanding of eco-innovation within a socio-technical system of innovation, points out the importance of actors on multiple levels, who are indispensable to develop, commercialise and use innovations. As will be explained in chapter 3.2.2, innovation includes the invention and development but also the adoption of a novelty. Geels (2004b) points out that as development and use of innovations have increasingly diverged into separate entities over time, the importance of interconnected social group networks has become increasingly apparent. They interconnect the processes behind the creation of knowledge and R&D on the one hand and needs and claims of users on the other hand via “(...) a process of mutual adaptations and feedbacks between technology and user environment” (Geels 2004b, 902). From an innovation system approach the market is recognised as not simply being coordinated “(...) by the anonymous arm length prize coordination, rather they are organized in stable learning relations based on shared understandings and trust that facilitate knowledge sharing and coordinated innovation between innovating companies” (Andersen 2004, 15). However, not only inter-company relations are emphasised but also use-producer relationships as significant feature of innovation processes (Andersen 2004). This *co-evolution of society and technology via dynamic networks of social groups*, whose precise configuration is presumed to differ between sectors and whose boundaries and relationships shift over time, is one major aspect to be considered when defining the drivers and indicators of eco-innovation. In this context Malerba (2006) mentions four challenges for research on the analysis of innovation and related industrial evolution: *demand, knowledge, networks and coevolution*.

Networks of social groups are significantly shaped by the actors interacting with each other: “Actors interact (struggle from alliances, exercise power, negotiate, and cooperate) within the constraints and opportunities of existing structures, at the same time they act upon and restructure these systems” (Geels 2004b, 907). Actors’ moves have effects not only within the social group they belong to (e.g. a specific industry) but also on other social groups, which again leads to changes in the socio-technical system. Geels (2004b, 909) describes this interplay between actors of different “social groups” and actors and the system as follows: “[Actors m]oves may lead to improvements of existing technologies or introduction of new technologies. In reaction to new technologies, policy makers may develop new rules to regulate it, and users may develop new behaviour. The consequence of these multiple games is that elements of [socio-technical] systems co-evolve.”

Nevertheless, due to existing cognitive, normative, regulative and formal rules, existing structures are stabilised and radical change will not happen easily. Webs of interdependent relationships within established networks lead to mutual dependencies and commitments, which, on the other hand, stabilise the existing structures. Moreover, artefacts and material networks within socio-technical systems lead to stable interdependencies reluctant to change, leading to *path dependent lock-ins* resulting rather in improvement via incremental innovation than via radical innovation (Berkhout 2002, Geels 2004b). Teece (1996, 195) describes this phenomenon by stating that "(...) within a paradigm[2], research efforts become channelled along certain trajectories. Relatedly, new product and process developments for a particular organisation are likely to lie in the technological neighborhood of previous successes." Within his model of endogenous innovation and growth, Redding (2002, 1244) points out the dilemma that

> (...) if secondary development[3] proceeds sufficiently far, the economy may become locked into an existing fundamental technology [...where] secondary development has improved the productivity of the existing fundamental technology to such an extent that it is no longer profitable to search for more advanced fundamental technologies, despite the fact that these would be more productive if they had benefited from the same level of secondary development.

Also Berkhout (2002, 2) emphasises that

> [i]n many technological systems incremental change is extremely significant, especially since capital turn-over rates are slow. (...) Numerous small adjustments and adaptations are made to industrial processes that over the time have a significant influence on the environmental performance of production plants and whole industries.

Nevertheless, Berkhout also mentions the existence of micro-meso-macro levels or niches, regimes and socio-technical systems where "(...) clear socio-technical goals are defined through a process of deliberation leading to a broad process systems innovation generated by integrating adjustments and changes across multiple levels" (Berkhout 2002, 2). According to Berkhout (2002, 3) "(...) [t]ruly revolutionary innovations are likely to start small, and they will come to define through co-evolutionary processes a new regime *for themselves*", which however may lead to new lock-in and the formation of new regimes that may be suboptimal again or even too fragile to develop. In order to reduce fragility revolutionary innovations require niches where they can be protectively developed and supported before they may actuate regime transformation. After these niche developments have come into existence within their niches, *windows of opportunity*[4] are needed, e.g. by changing user preferences or external pressures such as climate change or spreading concern about other negative environmental impacts, for these innovations to be adopted and disseminated, i.e. to break through into mass markets, which again will lead to wider changes and restructuring within the socio-technical system (Gale 2004b, Schaltegger &

[2] Following Dosi, Teece (1996, 195) refers to definition of technological paradigms here, which are defined as "pattern of solutions to select technical problems which derives from certain engineering relationships".

[3] A novel fundamental technology can be referred to as revolutionary innovation; secondary development is to be understood as incremental improvement of the fundamental technology.

[4] For further remarks on windows of opportunity see chapter 3.2.5.

Petersen 2001). To take advantage of these windows of opportunity not only are external actors such as users, investors or politicians essential. In this context Schaltegger & Petersen (2001) stress the exceeding role of the *entrepreneur*, whom in case of environmentally oriented innovations they refer to as eco-entrepreneur or ecopreneur. Also Fichter (2005) points out the entrepreneurial role by illustrating the importance of what he calls the interpreneur. Consequently, besides the importance of actors within all domains of the socio-technical system, the relationship between entrepreneurship and eco-innovation can be characterised as one major aspect of eco-innovation performance. In the following this relationship will be exemplified in more detail.

3.1.5 The entrepreneur as engine of change

Traditionally, in neoclassical growth theory, economic growth has been regarded as the result of forces that impinge from outside, as "manna from heaven" (Wennekers & Thurik 1999, 35) in form of *exogenous* technological change and concentrating on *labour* and *capital* identified by Robert Solow as the main contributors to the process of economic expansion (Wennekers & Thurik 1999). This "old" neo-classical growth perspective has changed towards a "new" endogenous growth perspective. In his work on increasing return and long run growth, Romer (1986) identified labour and capital as being not a sufficient explanation of long-term economic growth but accumulation of *knowledge*, typically having been measured in terms of R&D, human capital and patented inventions, as being an additional vital factor in a model of *endogenous* technological change. Lucas (1988) points out that the only exogenous force affecting his economic growth model is that of population growth. He emphasises the importance of endogenous human capital accumulation, which "(...) is taken to be specific to the production of particular goods, and is acquired on-the-job or through learning-by-doing" (Lucas 1988, 40) as endogenous process of knowledge accumulation internally affecting the productivity of its owner as well as resulting in an external effect of *knowledge spillover* from one person to another. This idea stresses the importance of persons as actors for knowledge spillover to take place. Accordingly, Audretsch and Keilbach (2004a) emphasise, although knowledge is to be regarded as important source of competitive advantage, it does not just spill over due to its mere existence, but that there is a need to identify mechanisms generating these knowledge spillovers. Besides factors in the external environment one also has to look for innovation triggers from a business- or micro-perspective, i.e., within the organisation where the innovation is taking place. Thus, Audretsch and Keilbach (2004a) identify *entrepreneurship* as the missing link. According to them, what they call "[e]ntrepreneurship capital (...) can contribute to output and growth by serving as a conduit for knowledge spillovers, increasing competition and by injecting diversity" (Audretsch & Keilbach 2004a, 953). This makes entrepreneurial capital, which is "(...) the capacity to engage in and generate entrepreneurial activity" (Audretsch & Thurik 2004, 144) to another supplementary and main element of innovation, competitiveness and economic growth.

Michelacci (2003) claims that innovating depends on both, "(...) researchers, who produce inventions, and entrepreneurs who implement them" (Michelacci 2003, 207). This idea leads to the assumption that "[w]hen the stock of scientific knowledge is already large while the amount of entrepreneurial skills is low, an increase in research effort reduces the growth rate of the economy, because it misallocates socially useful resources" (Michelacci 2003, 218), which is of high importance for optimal skill allocation in "(...) advanced economies where innovation is so *complex* that a single agent fails to possess both the scientific knowledge and the entrepreneurial ability required to innovate" (Michelacci 2003, 221). Moreover, the significance of entrepreneurship for innovation rests in the assumption that "(...) entrepreneurship is an important source of *diversity* by transforming knowledge into economic knowledge that otherwise would have remained uncommercialised" (Audretsch & Keilbach 2004b, 608). The generation of diversity and spillover through economic knowledge, in turn, provides a basis for the exploration of new innovative approaches.

Apart from being central to the creation of diversity, innovation can be regarded from an evolutionary perspective as playing a crucial role in relation to the concept of selection. *Uncertainty* about whether a potential innovation will be received with sufficient demand or whether a competitor might have a superior idea and *risk* due to the institutional context create the conditional context for recognition and appropriation of economic value of possible opportunities. Greater degree of uncertainty vis-à-vis rivalling enterprises in the industry results in a selection process called *noisy selection*, "(...) where efficient firms grow and survive and inefficient firms decline and fail" (Audretsch & Keilbach 2004b, 608). Here, information about their position in the market results in a company's perception of its fitness, which in turn serves as basis for a company's individual learning process and therefore generates diversity and spillover of knowledge, which again can be "(...) transformed into new approaches that otherwise would have remained unexplored" (Audretsch & Keilbach 2004b, 608). Alternatively, Redding (2002) points out that spillover of secondary knowledge being necessary for incremental sophistication of the fundamental innovation may hinder the development of alternative fundamental innovation due to patterns of path dependent lock in. Thus, spillover should preferably be that of knowledge related to fundamental development.

As mentioned above, the agent possessing the scientific knowledge to invent a novelty, the inventor, does not necessarily have the required capabilities or abilities to commercialise this knowledge. Hence, the *entrepreneur* is identified as the 'engine of change' introducing innovation at the micro-level of the economy with the aim to diffuse it into the market. Entrepreneurs can be understood as agents who realise opportunities: "[... T]hey transform the existing status quo into a future opportunity, and turn ideas into a commercial reality" (Schaper 2005, 5). According to Schaper (2005) entrepreneurs, can be found in all levels of society and can be broadly categorised into four main types:

- *traditional* (Schumpeterian) entrepreneurs starting up a small business that eventually grows and becomes a success;
- *intrapreneurs or* corporate entrepreneurs helping to create new business divisions, products and changes to internal operations;
- *interpreneurs* representing the link between opportunities created by the environment and creative ideas invented within an organisation;
- *social* entrepreneurs working within non-profit organisations and attempting to bring about innovations to resolve community problems.

It is important to notice that entrepreneurs might be represented by both, one individual or a whole firm. Furthermore, innovation does not only take place on the *operant level*, where the entrepreneur realises opportunities, but also at the *generic level*, where knowledge potentials are actualised for operation, i.e. the entrepreneur does not only respond to given opportunities but also creates them. “Economic development relies not only on creative *de*-struction, but also on creative *con*-struction [... requiring] knowledge [to] be a constituent factor of the theory” (Dopfer 2006, 24). Following Dopfer’s line of argument, innovation can be regarded as a process that does not rely either on the creativity of entrepreneurs or the created opportunities by the external environment, but rather emerges from the interplay of opportunities created by the environment and creative ideas invented within an organisation.

3.1.5.1 Ecopreneurship

A fifth category among the identified types of entrepreneurs can be labelled eco-entrepreneurs or *ecopreneurs*. Ecopreneurs are characterized as “[a]ctors and companies making environmental progress to their core business. Ecopreneurs generate new products, services, techniques, and organizational modes which substantially reduce environmental impacts and increase the quality of life” (Schaltegger 2002, 44; Schaltegger & Petersen 2001). Whereas alternative actors keep their novelties for the alternative scene and bioneers introduce their novelties in niche-markets, ecopreneurs link inventions with mass market success (Schaltegger & Petersen 2001). It is important to notice that throughout this text it is not referred to general inventions but *environmentally progressive* inventions linked to market success, either in the alternative, niche or mass market. Regarding the above mentioned broader perspective of eco-innovation, this kind of eco-innovation does not only lead towards improved environmental performance but may also indirectly lead towards social improvement while making a social system more eco-efficient. In this case the entrepreneur or ecopreneur can even be labelled a *sustainable entrepreneur*, because, within his innovative activities, he integrates the three dimensions of sustainable development, i.e. the economic dimension of the entrepreneur, the additional environmental dimension of the ecopreneur and finally the required social dimension of sustainable development (Schaltegger & Wagner 2008; Schaltegger & Wagner 2009). An example for this might be an entrepreneur who finds a profitable solution to produce and sell a certain medicine, which is needed for treatment of a widespread disease, by means of more environmentally friendly technologies in the production process.

3.1.5.2 Eco-innovation through ecopreneurship

Eco-innovations are different from general innovations because they require ecopreneurship, i.e. entrepreneurial actors integrating (not just considering) environmental goals in the core business concept and activities as well as creating an ample influence on the mass market. Nevertheless, it needs to be taken into account that not the ecopreneurial intention is the decisive factor, yet, that the economic and environmental effect of the innovation process’ output determines whether an innovation is eco-efficient and therefore can be regarded as eco-innovation.

Eco-innovations are not neutral with regard to the *nature of their novelty*. Not only is it of relevance that progress is taking place but also that a certain direction and content of progress is created by integrating ecological and economic dimensions of sustainable development into the novel concept. From an ecological economics perspective, eco-innovation can be regarded as an enhancement of Lehr & Löbbe's environmental innovation concept, which is a "technological, economic, social and institutional innovation which contributes to a reduction in anthropogenic overuse of the environment, regardless of whether the innovation offers other – namely economic – benefits" (Lehr & Löbbe 2000, 110f.). This one-dimensional definition of innovation focussing on environmental issues only, would allow for trade-offs reducing economic performance and competitiveness. This view thus considers the existence of *weak eco-innovation* (figure 13). Yet, *environmental effectiveness is a first prerequisite for eco-innovation.* Eco-innovation *does* furthermore pay regard to sustainable economic development. Not any kind of environmental activity by a firm results in a positive effect on the firm's economic performance (Schaltegger & Synnestvedt 2002). Eco-efficiency cannot be regarded as a one-size-fits-all concept. It needs adaptation towards every firm's individual most suitable performance correlation between maximum economic success to be achieved and an optimal amount of environmental protection to be realised (Schaltegger & Wagner 2006).

That is why it is necessary for *strong eco-innovations* contributing strongly to environmental and economic progress to go the *step from the niche market to successful diffusion into the mass market.* Although the niche market may host the best innovations with regard to environmental protection, for the realisation of a strong and sustainable eco-innovation, the bridge between environmental innovation and market success needs to be built. Hence, strong eco-innovations need an entrepreneur who regards environmental performance goals as being a core business strategy and aims at actuating these environmental performance goals within the mass market, i.e. an ecopreneur or sustainable entrepreneur (Schaltegger 2002; Schaltegger & Petersen 2001). Moreover, as mentioned before, it should be considered that eco-innovation is not an isolated process, however, is embedded into a socio-technical system of processes influencing the eco-innovation process as well as being influenced by the innovation process. Here, the idea of interpreneurship ties in.

3.1.5.3 Interpreneurship

The interpreneurship approach banks on Schumpeter's idea of creative response, which is a fundamental change in previously existing modes of behaviour, implying not only the creation of an actor's novel creative accomplishment but also its actual realisation and implementation. Thus, creative response can be distinguished from adaptive response, which merely aims at optimising already existing conditions (Schumpeter, 1976/79). In the creative response approach innovation cannot just be explained by an actor's reactive response to external framework phenomena but by an entrepreneurial discovery of external opportunities recombined with his actor specific and unique abilities and reflective interactions. This interactive recombination leads to a change in perception, evaluation and opinion ultimately resulting in novel schemes of interpretation that in turn retroact on the cognitive and institutional prerequisites for an actors' acceptance of, support of and connectivity to innovations (Fichter 2005). In an environmentally sustainable context, interpreneurs are capable to interactively connect claims raised by the cultural, institutional, political, legal, social and economical dimensions of their societal context with potential solutions in a way never done before and thus create innovations in such a way, that they find acceptance within the societal context without further deteriorating the environment. In general, the interpreneur has indeterminate freedom for creative action. Nevertheless, this action always takes place in relation to his own constantly altering societal and ecological context including his networking and other interaction activities with stakeholders in his environment. The creation of eco-innovations therefore depends on this interactive dynamism between exogenous and endogenous determinants and the interpreneur's entrepreneurial opportunities are objective and subjective at the same time: objective in the real framework conditions coming from the entrepreneur's environment and subjective in the sense that there's an asymmetric distribution of information about the framework conditions among interpreneurs leading to subjective assumptions about how to respond (Fichter 2005).

Bearing in mind that eco-innovations need an ecopreneur who pushes the environmental improved innovation into the mass market due to personal intrinsic or group-related environmental, ethical, or sustainability beliefs (Schaltegger 2002), Fichter (2005) points out that, although there is the need for a driving entrepreneur, this actor primarily aims at reaching economically strategic purposes which then are mixed with normative-ethical motives. Like with entrepreneurs and ecopreneurs in general the interpreneur's sustainability concerns are not 'arising from within' but are to be activated by the social and ecological context within which the interpreneur is acting. That means an innovation process is always influenced by its contextual environment. Innovations can also be characterized according to how and in which sphere of influence they are created by entrepreneurs: Since the term innovation in this context does not appeal to natural evolutions, which is innovation brought about by nature for progress of nature itself and since up to date no artificially intelligent machine exists that can create innovations without human intervention, innovations in this context should be regarded as a process driven by human mind and imagination. The initial triggers and barriers for innovation can therefore be found in the societal system. The societal system can be thought of as general environment within which innovation is taking place. Following the interpreneurship concept, innovations, might they be of technological, social, organisational or business-related nature as defined by Hauschildt (2004), are created only as an evolutionary result of the reciprocally intertwined, dynamic and complex processes taking place in the spheres of influence which constitute the business and corporate environment. In this context Dew & Sarasvaty's (2007, 275) suggest to think of every entrepreneurial venture "(...) as *a network of stakeholders* engaged in an ongoing process of (re)negotiating the design of innovations, a process which continually shapes and alters the consequences of innovations (and thus their externalities)." The stakeholders participating in this entrepreneurial venture may be rooted in several arenas within a firm's external environment.

3.1.6 Dealing with actors outside the firm

As mentioned before, a firm's general external environment is made up of intertwined arenas, which are the socio-cultural arena with its actors from civil society, the economic arena with its market actors, the scientific-technological arena, the political and the legal arena (see chapter 3.1.4). In the firm's external environment, numerous resources as well as at times even contradicting demands from various actors that are influencing and are influenced by a firm's eco-innovation performance, can be identified (figure 6). It is the firm's task to juggle all these different demands and try to internalise those resources to attain the so called social legitimacy or licence to operate from civil society and the political / legal arena and, furthermore, to gain competitive advantage over other actors in the market as well as scientific arena.

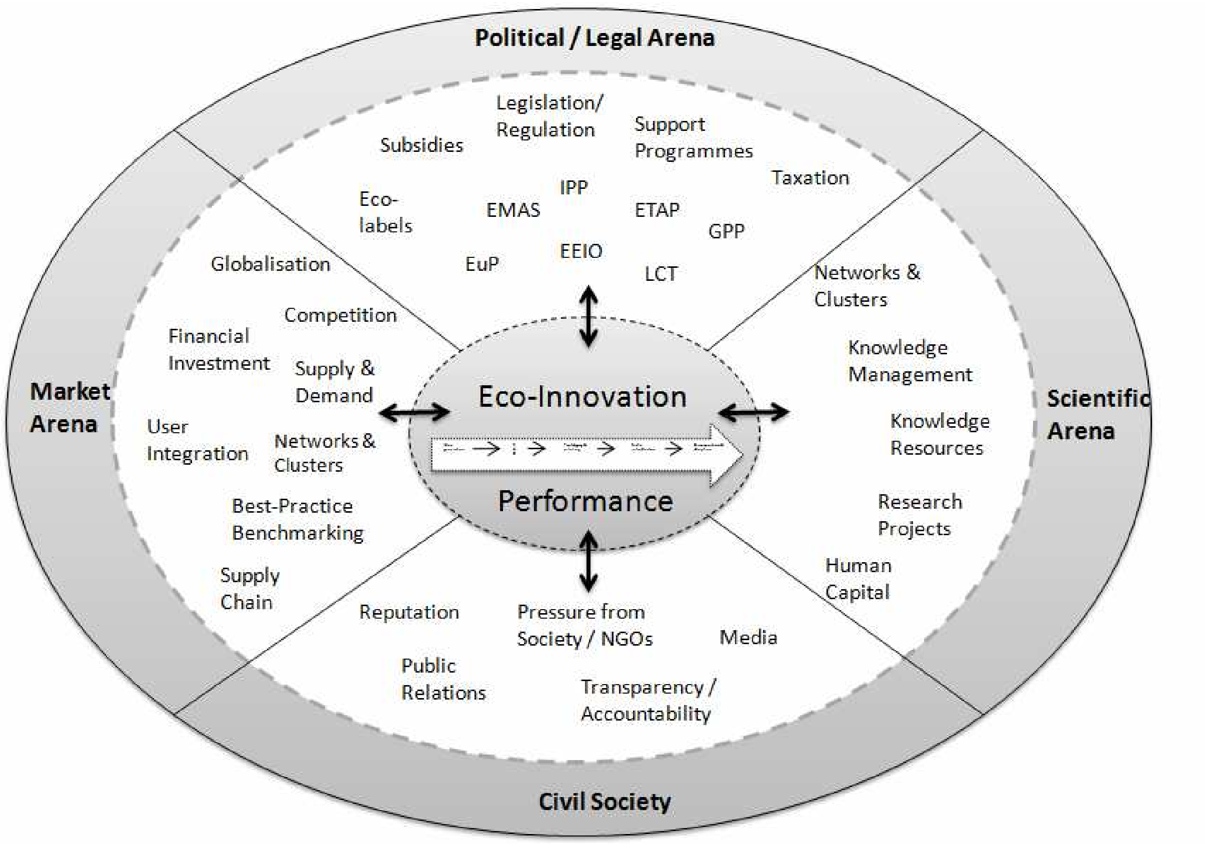

Figure 6: Eco-innovation within its web of external demands and resources

In order to manage this task, a firm can apply several internal organisational mechanisms and instruments that are supporting the firm's approach in coping with external stakeholder demands as well as facilitating the firm's internal capacity building activities towards improved eco-innovation performance (figure 7). Besides a firm's internal activities, such as participation programmes and top management commitment to sustainability and eco-innovation issues, linkages to the external environment need to be build and nourished.

Here, not only one-way engagement with stakeholders, e.g. by means of reporting and awareness raising activities, but interactive stakeholder integration by means of stakeholder dialogues, networking and cooperation activities, is crucial for the successful realisation of eco-innovations.

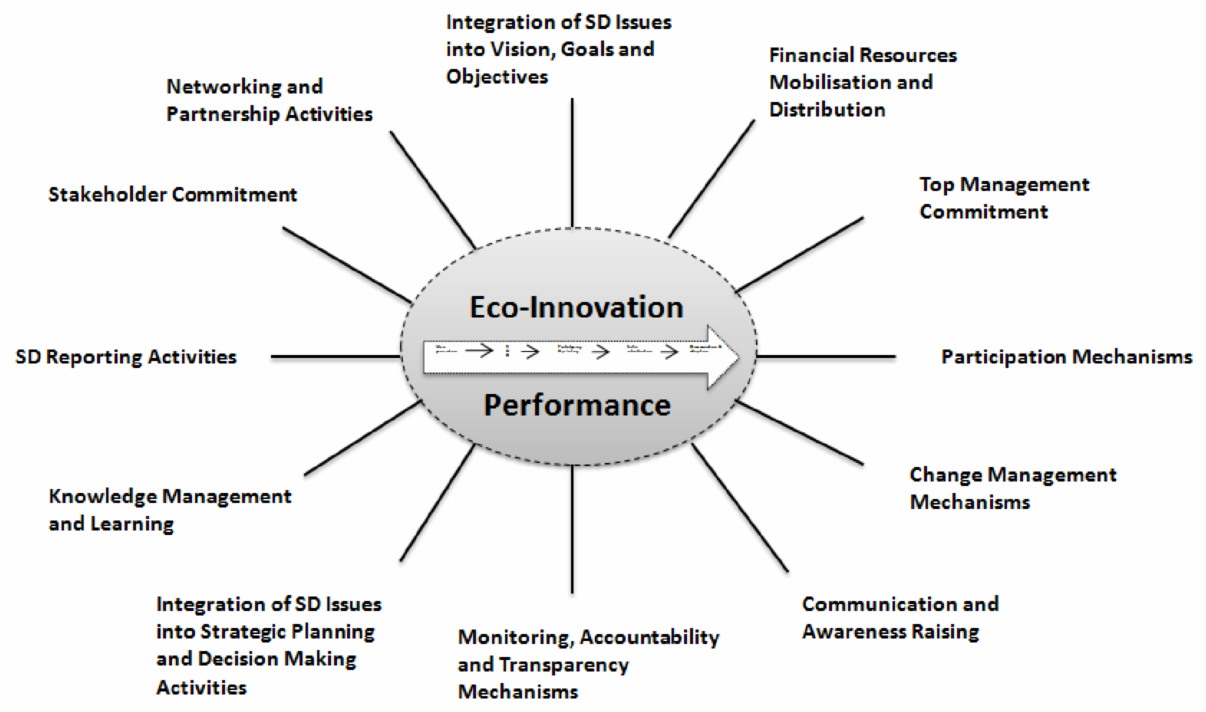

Figure 7: Internal organisational mechanisms contributing to eco-innovation development

3.1.7 The importance of networks, clusters and cooperation for innovation success

As Fukasaku (2005, 253) mentions, "[k]nowledge about environmental changes and their impacts as well as innovations that improve it arise from research and development in different scientific and engineering disciplines. (...) Environmental innovations often require an inter- or multi-disciplinary approach to research as well as inter-firm or inter-institutional co-operation in R&D [...making it to a] 'systemic' difficulty." Also Malerba mentions the importance of *networks* between actors of different disciplines within and across sectors, regions and nations for innovation and industry evolution since these "(...) are highly affected by the interaction of heterogeneous actors with different knowledge, competences and spezialisation, with relationships that may range from competitive to cooperative, from formal to informal, from market to non-market." The innovation process is regarded as being embedded into a network of multiple actors co-shaping the innovation process and conversely being embedded into the innovation process and thus shaped and formed by it themselves (Garud & Karnøe 2003). Innovation is understood not only as a process of transaction but also as a process of *interactive learning* with special emphasis on the generation of *long-term relationships* to build *trust* and facilitate the transmission of *tacit* *knowledge*. Here, the way actors relate to each other is regarded as being shaped by formal and informal institutions, such as laws and regulations (formal institutions) and trust, time horizon of agents and rationality (informal institutions) with regard to operation and decision making (Lundvall et al. 2002).

Via a cooperative or a competitive strategy different innovators, may they be radical innovators, incremental innovators or even imitators, are relating to the innovations of other firms. Thus, if there, e.g., is a quite stable coexistence of these different types of innovators, according to Lundvall et al. (2002) it seems quite obvious to think in terms of an *innovation system* that highlights the importance of further actors, such as governments that might correct and enhance the innovation system by means of intervention. Hence the performance of innovation systems which also influences the performance of firms' innovation activities depends on the system's economic, political and social infrastructures and institutions as well as on past experiences. These aspects provide the capabilities for active and interactive learning by organisations and individuals. Not only sector specific, regional, or national networks are crucial for successful innovation and development, however, as Lundvall et al. (2002, 229 emphasis added) stress "[t]he power games of exclusion and inclusion in relation to *global* knowledge-intensive networks has become of key importance for development". Thus, for knowledge gathering reasons as well as for legitimacy reasons firms should engage in *multi-stakeholder networks and governance* to be able to successfully address complex problems and challenges in a cooperative way, which facilitates coping with various and at times opposing stakeholder demands and enhances the legitimacy of corporate activities. Within these networks "(...) information concerning a problem is gathered from different sources, learning takes place, conflicts between participants are addressed and cooperation is sought" (Roloff 2008, 311).

Here what Porter (2000) defines as *clusters* may play a major role in understanding firms' networking activities on a complex, knowledge intensive and dynamic scale that embraces location from a different perspective. According to Porter (2000, 15f.) "[c]lusters are geographic concentrations of interconnected companies, specialized suppliers, service providers, firms in related industries, and associated institutions (e.g. universities, standard agencies, trade associations) in a particular field that compete but also cooperate [...whereby t]he geographic scope of a cluster relates to the distance over which informational, transactional, incentive, and other efficiencies occur." Hence, a cluster is not bound to a certain geographic scale and may encompass an array of linked industries and other entities important to competition even on a global scale:

> Drawing cluster boundaries is often a matter of degree and involves a creative process informed by understanding the linkages and complementarities across industries and institutions that are most important to competition in a particular field. The strengths of these spillovers and their importance to productivity and innovation often are the ultimate boundary-determining factors (Porter 2000, 17).

In this context Fichter et al. (2006) refer to what is called *innovation communities*, which, divergent to networking aims which are relationship building and information exchange, put a stronger emphasis on pursuing objectives or goals, a group's cohesiveness and collective understanding. Hence, cooperation is targeted at the compensation of resource deficiencies, the realisation of synergies, the acceleration of development processes and the facilitation of marketing and dissemination by means of integration of customers and other stakeholders into the innovation process. Not only material transfer but also communication and understanding between the cooperation promoters within the innovation communities are crucial to the successful realisation of the innovation objectives. According to Fichter (2006) the innovation communities concept is meaningful especially for the performance of sustainability oriented innovation processes when it comes to the integration of life-cycle and system oriented solutions as necessary for eco-innovation.

3.2 The eco-innovation process

3.2.1 Defining the eco-innovation process

Deriving indicators for eco-innovation performance is a process of seeking knowledge about a condition to be assessed within a defined framework, where according to Emblemsvag & Bras (2000, 641) "(...) the knowledge achieved through rational knowledge and intuition is what can be referred to as relative knowledge, which is characterized by its dependency on a framework to have value." Since innovation is change or creative destruction, eco-innovation cannot be regarded as a determinable static object. Emblemsvag & Bras (2000, 649) point out that "(...) change can only be fully described in terms of processes. Thus, science and engineering must be process-oriented. The process-orientation also means that strategies, the usage of methods, implementation of results and the feedback loops must be processes." Hence, when establishing a framework targeting at the derivation of eco-innovation indicators and drivers the relativity of knowledge needs to be taken into account and therefore the *process dimension* of eco-innovation as well, i.e. the different phases, feedback loops, drawbacks, path dependencies within the eco-innovation process. Furthermore, a systems perspective requires taking into account the multiple relationships, networks and change agents involved in the processes of change throughout the eco-innovation process. Considering eco-innovation as not being the mere end-state of an antecedent innovation process, however, as being a process of change in itself, leads to the challenge of defining the process phases, relations, and change agents triggering and being inherent to eco-innovations. When setting up an eco-innovation framework, it seems to be useful to look at the eco-innovation process not from a variance theory perspective, "where change is represented as dependent variable, which is explained with a set of independent variables that statistically explain variations in the dependent variable of change" (Van de Ven & Poole 2005, 1380), however, rather look at it from a process theory and event-driven perspective explaining a "temporal order and sequence, in which change events occur based on a story or historical narrative" (Van de Ven & Poole 2005, 1381). Geels (2004) stresses that from a socio-technical systems of innovation perspective, the supply side (innovations) with its development of knowledge *and* the demand side (user environment) where diffusion and use of technology, impacts and societal transformations play a role, need to be taken into account. According to Geels (2004, 898) "[t]his indicates that the focus is not just on innovations, but also on use and functionality", which shows that there exist several contiguous phases classifying the eco-innovation process. However, before discussing phases of the innovation process, innovations must be distinguished from inventions.

3.2.2 From inventions to innovations

Inventions can be seen as innovation catalyser. "(...) a change is set in motion by a discovery (invention); when an invention is first introduced and commercialised by a firm, an innovation occurs [... followed by] diffusion, which implies the introduction of these new products or processes by other firms in and across industries" (Preissl & Solimene 2003, 9). Required for an invention to become an innovation is that the invention's novel idea is linked to the market, regardless whether the step from the invention to the market introduction has initially been triggered by market pull or scientific push. As Freeman and Soete (1997, 200) state: "The market demand may come from private firms, from government or from domestic consumers, but in its absence, however good the flow of inventions, they cannot be converted into innovations."

Notwithstanding, it is important to notice that "[i]nnovation is a coupling process and the coupling first takes place in the minds of imaginative people" (Freeman & Soete 1997, 202). Although the need for something new might be a trigger to invent a novelty, sometimes a novelty might be created without having known in the first instance that there is a need and thus a market for it. As Popper (1977) has put it, universe is creative and we have the freedom to be creative towards our self-chosen purposes and goals. In addition to market demand and scientific or other inventions, adequate technological, social or organisational infrastructure must have developed insofar as to make feasible the conversion of an inventive idea into a realisable innovation.

According to Rothwell (1994) the definition of the innovation process as *linear technology push model* in the 1950s until mid 1960s, was followed by a more *market oriented*, however, still linear approach from the mid 1960s until the early 1970s. The early 1970s to the mid 1980s brought forward a third generation of the innovation process (figure 8) which regards the process of innovation as an *interactive, coupling model* representing "(...) the confluence of technological capabilities and market-needs within the framework of the innovating firm" (Rothwell 1994, 10).

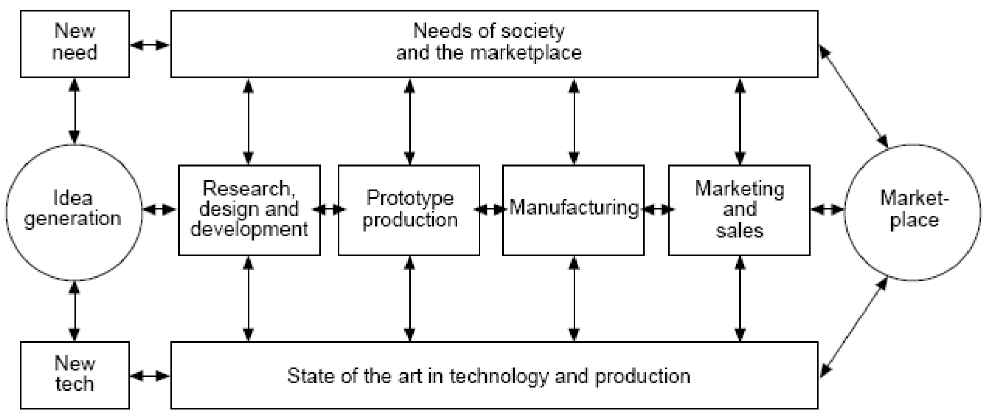

Figure 8: The "coupling" model of innovation

Source: Rothwell (1994, 10).

The model represents the innovation process also as sequential process initiated by a phase of idea generation, followed by R&D, prototyping, manufacturing, marketing and sales and dissemination in the market place, however, in this case feedback loops are included. Besides *feedback loops*, a fourth generation of the innovation process developed from researching Japanese innovation efforts in the early 1980s until the early 1990s accounted for the inclusion of two further aspects into the innovation process: *integration* and *parallel development*. The core idea is that "[e]ven when completely simultaneous development is not possible or, as in the case of science-based sectors such as pharmaceuticals not necessary, a degree of functional overlap with intensive information exchange is essential"(Rothwell 1994, 11). According to Rothwell a subsequent fifth generation of the innovation process has put increasing emphasis on *networking* (mainly directed at exchange of know-how), *systems integration*, *flexibility* and *parallel (real time) information processing* by means of more and more sophisticated IT support throughout the innovation process. Having presented these five generations successively defining the innovation process, it should be noted that, although the linearity of the innovation process model has been heavily criticized (Godin 2006), its simple structure is still helpful to grasp a general understanding of what kind of different phases are existent within the highly complex innovation process. Moreover, according to Godin (2006) a useful analytical framework representing the complex nature of the innovation process with all its feedback-, drawback- and interactive mechanisms has not been established yet.

Noticing that an invention should be realised, i.e., be adopted within an organisation (e.g. a process innovation) or be diffused into the market, to become an innovation, this kind of demand necessary for an invention to become and innovation should not be confused with an economic calculation or assessment. As mentioned before, besides consumers also governments may create demand for an innovation by promoting the dispersion of inventions. Thus, an innovation may be a market success and even a business success for a company but does not necessarily have to be economically beneficial in the more general view of public economics. Respective legislation or subsidies might support the spread of an environmentally novel invention that does not seem to be economically profitable at first glance. Here, regulative intervention can trigger consumers' attention, create business success and promote the acceptance of an environmentally progressive innovation that fulfils certain societal and ecological goals. Therefore, it is not essential that an innovation is economically profitable right from the start of its market introduction. Also a subsidised innovation captures a certain market share although not being profitable from an overall economic perspective. What is of importance here, is that the innovation is understood (e.g. by scientists) and increasingly accepted in the market, may it be by customers or political demand, as ground-breaking development that leads to a more sustainable future.

3.2.3 Phases of the eco-innovation process

In order to operationalise eco-innovation indicators it is important to determine what kind of eco-innovation phases exist, what progress means and which triggers exist at which stage of the eco-innovation process. Going along with Rothwell's fifth generation of the innovation process, it should be understood as "(…) systemic, dynamic, non-linear process, involving a diverse range of actors, giving rise to both positive and negative feedback” (Foxon et al. 2004, 97) including networking, system integration, flexibility and parallel information processing. Various frameworks and approaches exist towards innovation processes and associated actors, institutions, expectations, market and policy developments and risks.

In order to make the determination of appropriate eco-innovation key performance drivers and indicators not too complex, this study also makes use of a simplified illustration of the process from potential eco-innovations towards actually realised eco-innovations. Being mainly oriented towards product innovations, the sequence of phases defined for the innovation process in Rothwell’s coupling model (figure 8) will be used in a modified version as general reference throughout this paper.

Idea generation → R&D → Prototyping → Manufacturing → Marketing & Sales → Market dissemination

Figure 9: Innovation Phases

Source: adapted from Rothwell (1994).

To make it more straightforward, the two phases R&D and prototyping will be combined into one phase. Furthermore, there will be another phase upstream of market dissemination, namely market introduction. The two phases manufacturing and marketing and sales will be understood as being inherent to the market introduction and market dissemination phases since they are important functions within these two realisation phases (figure 10). Nevertheless, it will be kept in mind that the innovation process is much more complex, nonlinear, interactive and prone to error and drawbacks taking into consideration the existence of multiple feedback loops, affiliated networks, parallel developments and rebound effects.

The understanding of eco-innovation referred to throughout this paper is not limited to product innovations but extended to other forms of innovation, such as process innovation and system innovation (see chapter 3.1.1). Another aspect to mention is that throughout innovation literature there is a strong focus on technological progress. However, it should be taken into account that eco-innovations are not exclusively bound to technological innovations, but that organisational innovations, institutional innovations and social innovations need to be considered as well. That is why the model representing the different innovation phases will be altered to a more general one that can be applied not only to product innovations, but also to other rather non-product oriented forms of innovation mentioned before. Keeping in mind Geels’ dynamic multi-level perspective (figure 5), the innovation process breaking through from niche via regime towards landscape can be thought of as illustrated in figure 10.

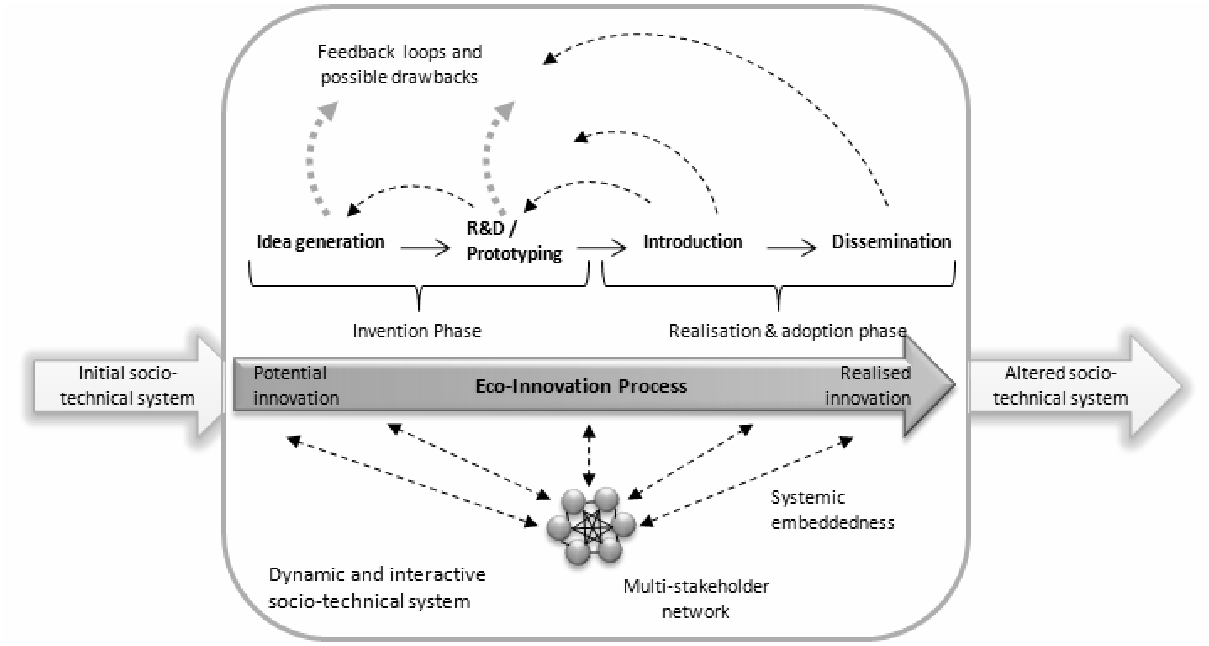

Figure 10: Eco-innovation process within the socio-technical innovation system

From a business perspective (e.g., Hauschildt 2004, 8) intra-organisational or market realisation is crucial to the innovation concept (see chapter 3.2.2). Therefore, it should be noticed that the phases defined within the innovation process can be associated to an *invention phase* and to a subsequent *realisation phase*. The phase of realising an innovation in the market (e.g. product or service innovation) or throughout an organisation (e.g. process or organisational innovation) is a significant aspect of the innovation process. Innovations can only be called innovations ex post their realisation, i.e. when they have been introduced, adopted and their dissemination has successfully commenced. Before the realisation has taken place, innovations are mere ideas or inventions, i.e. potential innovations that may perhaps never be realised and thus grow old as patented ideas in an organisation's shelves.

The eco-innovation process itself should be understood as being divided into four main phases (figure 11) starting off the invention phase with an *idea generation phase*, which is followed by *research and development* activities that may result into a *prototyping phase* followed by a piloting and marketing research that subsequently may realise the invention by *introducing* it into a (niche) market and finally *disseminating* it into the mass market. Alternatively to a product innovation being disseminated into the market, one can think of a process innovation as being disseminated and adopted throughout an organisation.

Although this simplified model of an eco-innovation process will be used for further research on indicators and drivers throughout this paper, for the sake of completeness and accurateness the complexity of innovation processes shall be referred to in the following paragraphs.

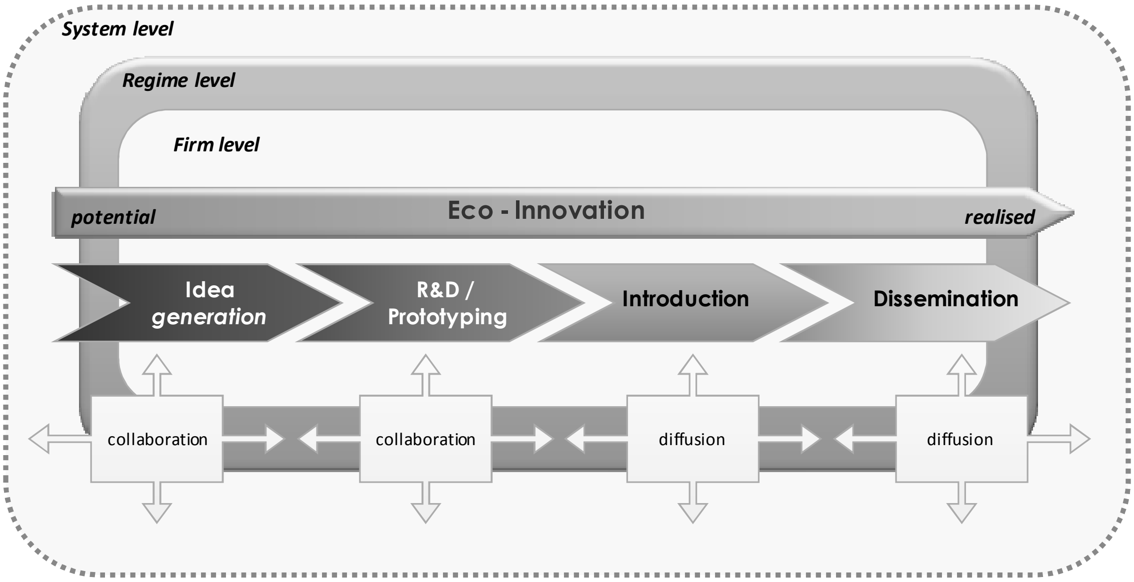

Figure 11: Simplified eco-innovation process

To bring some structure into the complex picture, different phases of eco-innovations can be defined according to Hauschildt's (2004) procedural dimensions of innovation. Here, the phases of an innovation even start before the invention phase. According to Hauschildt the initial phase is that of *idea* generation and *initiative*, followed by the phase of *discovery* and *observation*, which then passes into the phases of *research* and *development*. According to the open innovation approach (Chesbrough 2003) not only do ideas need to be generated within a firm but can also originate outside a firm's own labs and be brought inside for commercialisation where internal R&D is needed to claim some portion of the value created by external R&D, i.e. external and internal ideas are combined for innovation purposes. Following the R&D phase is that of *invention* of an alternative to what has been existent so far including a definition of its components and a detailed description of its patentable and publishable characteristics. This phase is followed by a so called *realisation-attempt*, i.e. the invention's conversion into an economically utilisable *prototype*, which will generally be followed by a *marketing research* or *piloting* phase before the next phase, its actual realisation, i.e. its final *market introduction*, may begin. In order to become a strong eco-innovation (for a categorisation of strong and weak eco-innovations see chapter 4.1.2) an innovation does not only need to be introduced into the market but it also has to be *adopted* and *diffused* successfully. Afterwards, a phase of *routine and continuous maintenance* is following the innovation process. This phase is not to be regarded as part of the innovation procedure itself but rather as subsequent task to be performed by functional or divisional management (Hauschildt 2004).

Fichter (2005) mentions that there is a *framing* phase prior to the innovation process which is crucial for triggering the innovation process. In this framing phase a person that will later come up with a novel idea is equipped with the specific knowledge, expertise, expectations, imagination and interpretation capabilities required for a deviant cognitive frame that at the pivotal point of time gives him or her the opportunity to see reality from a different perspective, to draw alternative connections and come up with a novel idea.

Schroeder et al. (1986) describe innovation as a process model initiated by *shocks* that arouse someone's awareness of a discrepancy between what is and what should be and therefore stimulate "(...) people's action thresholds to pay attention and initiate novel action" (Schroeder et al. 1986, 513). According to them an initial idea tends to proliferate into several ideas during the innovation process, which then is characterised by various *setbacks*, *integration* and *restructuring* procedures and dependent on the participation of different actors in the innovation context as well as an appropriate infrastructure development. It is to be noticed that the individual phases of innovation should not be treated as separate entities since they illustrate a complex and dynamic chain of causes and effects going through various feedback loops and being externally influenced by all kinds of actors. Smits & Kuhlmann (2004, 7) point out "(...) that more and very heterogeneous actors, often at very different levels and operating in various arenas, are involved in (the management of) innovation processes." Parallel co-evolutionary and systemic activities may take place within the different phases along the innovation process due to feedback loops and systemic dynamism. Although the discussion of innovation processes usually stops with the adoption and dissemination, for eco-efficiency reasons and to determine whether an innovation is an eco-innovation, it is of importance to look a step further along the life-cycle.

3.2.4 Eco-innovations and life-cycle effects

From a *life-cycle-assessment* (LCA) perspective not only is an innovation's invention phase of importance but also its *adoption* and thus *consumption* and *waste processing* phase. The LCA perspective on eco-innovation emphasises that eco-efficiency should be implemented along the entire value chain of an eco-innovative product or process and not just within the processes happening within the physical boundaries of the plant. For some industries substantial harmful environmental effects occur in upstream (raw material generation and supplier processing) or downstream processes (product use and disposal) (WBCSD 2006).

Evaluating whether an innovation is an eco-innovation over its entire product life cycle is a prerequisite to measure the ecological leverage effect and may be quite a challenge given the many steps and diverted paths products and side-products may have. Whether an innovation is an eco-innovation can only be definitely determined ex post. One can never say that something will be an innovation as long as it has not been accepted as an innovation in a broader context and as long as its real effects are not known for the entire life cycle, yet. That is why an innovation can only be said to be an innovation as soon as it has reached the stage of adoption and realisation, be it within the scientific community, the consumer market or within organisations for internal process innovations. However, it remains arguable whether an innovation can be determined as being or not being eco-efficient in advance, because in the long run *rebound effects* might emerge which had not been anticipated before.

Moreover, apart from arguing that an eco-innovation is eco-efficient over its entire life-cycle, i.e., from cradle to grave, there exists a further standpoint looking at eco-innovation from a cradle to cradle perspective. The idea behind the *cradle to cradle* perspective is to avoid waste in total and to restore continuous cycles. Thus cradle to cradle does not focus on the principles of eco-efficiency but applies the eco-effectiveness approach (McDonough & Braungart 2002). The cradle to cradle perspective expands the LCA-perspective with a qualitative perspective, which in this context means a fundamental demand on fully recyclable and renewable products and processes, from research phase until disposal. This idea differs from eco-efficiency where the relation between value added and ecological leverage effect needs to be optimised, which, however, in the result still implies a negative absolute ecological effect. Cradle to cradle aims at developing closed-loop systems in which product design is completely renewable and in which any disposal is fed into a process of recycling and generating new value by transferring the used resources into new production processes. Ideally this consideration contains all process-related inputs and outputs along upstream and downstream processes, for instance the energy used throughout a production process as well as social working conditions. According to McDonough & Braungart (2002) the archetype of this model is nature itself, which has always been producing absolutely inefficiently but effectively. The example of a cherry tree producing thousands of blooms and fruits without causing negative environmental impact is mentioned. As soon as the fruits are ripe and have fallen down they are not wasted, however, fed back into the system as nutrients for animals, plants and the ground surrounding the tree. Although this perspective is ideal with regard to environmental impact, there remains the question whether it is actually realisable in today's global industries. It will be hard to make firms deviating from their old habits and rethink the way they make things by choosing a totally new perspective that does not focus on efficiency. Theory on path dependence may be able to give further insights.

3.2.5 Directing pathways towards a more sustainable future

Since innovation development tends to be influenced by path dependence (see chapter 3.1.4), it is important to choose an eco-innovation path increasing the probability for environmentally and economically sound decisions According to North (1994) there exists a

> (…) powerful influence of the past on the present and future. The current learning of any generation takes place within the context of the perceptions derived from collective learning […with] no guarantee that the cumulative past experience of a society will necessarily fit them to solve new problems. Societies that get "stuck" embody belief systems and institutions that fail to confront and solve new problems of societal complexity.

Anex (2000) mentions that technology development pathways may *lock in* a certain technology not always because it is the best alternative but because of a series of small, perhaps random events. Nevertheless, there exist *windows of opportunity* for influencing the trajectory of development. Created by occasional periods of large social, economic, or political change, these windows of opportunity facilitate substitution of incumbent technologies. North (1994) calls for an institutional/cognitive approach that provides for flexible institutional structures created by successful political/economic systems leading to adaptive efficiency in the long run. This leads to two conclusions for eco-innovations:

- *Windows of opportunity*: In times of major debates about the importance of sustainable development and the impact of climate change throughout multiple media channels and in lively political discussions, it is important to focus on an ecological market development strategy in order to take advantage of the window of opportunity for development towards more eco-efficient innovations. Windows of opportunity, once missed, may not appear again very quickly and may be quite different.
- *Consideration of the creation of new path dependencies*: Moreover, eco-innovations can create new path dependencies. The consideration of path fixation effects (such as by high sunk costs, etc.) is recommendable in order to prevent new path developments which may not be entirely convincing in terms of eco-efficiency or which may prevent even more superior eco-innovations in the future.

Hence, it is crucial to the successful improvement of firms' eco-innovation performance to understand the context they are operating in, may it be in terms of the interdependencies with actors in their surrounding environment or socio-technical system (e.g. by getting involved into multi-stakeholder networks and governance as mentioned in chapter 3.1.7), decisions having been taken in the past and influencing the present or present decision making procedures and strategic choices influencing the near and long-term future. Only then a window of opportunity can be realised and it is possible to create new path dependencies being oriented towards a more eco-innovative future.

4 STEP TWO: IDENTIFYING ECO-INNOVATION KEY PERFORMANCE INDICATORS AND DRIVERS (EI-KPIS)

What needs to be done next is the identification of the appropriate key performance indicators and drivers of eco-innovation performance within the eco-innovation framework presented throughout the previous chapters. Eco-innovation like any other innovation contributes to economic growth by "(…) the economic realisation of new ideas or knowledge in terms of products, processes, services, or even concepts and structures" (Beroggi et al. 2006, 201). Furthermore, being directed towards the improvement of the environmental system attributes five further characteristics to eco-innovations, which are summarised by Weber & Hemmelskamp (2005, 1) as: "functional changes with a jump in eco-efficiency; a combination of technological, organisational and institutional innovations; the involvement of a multitude of actors; the existence of new guiding principles and sets of goals; and long-term change at micro- and meso-level". The eco-innovation framework outlined in this paper regards eco-innovation as being eco-efficient with regard to its process and output level. Therefore it is useful to determine appropriate environmental impact indicators and relate those to appropriate economic performance indicators as to determine the ratio between environmental impact and economic performance, i.e. the *eco-efficiency* of the eco-innovation process and output. Besides the environmental and economic aspects to be accounted for, further aspects of innovativeness and the involved organisational management orientation towards sustainability issues (i.e. sustainability management) should be determined by appropriate indicators. Bearing in mind the eco-innovation framework, a categorisation of drivers and indicators of eco-innovation results into the following main dimensions to be analysed:

- an ecological impact dimension and an economic performance dimension (resulting in eco-efficiency as main lag indicator);
- an innovation performance dimension; and
- a dimension of sustainability orientation.

4.1 Eco-efficiency as lag indicator of eco-innovation performance

4.1.1 Mapping eco-efficiency improvements

Eco-efficiency measures are to be utilised for deriving lag indicators of eco-innovation performance. As discussed earlier eco-efficiency is an inherent concept of eco-innovation because of the nature of those innovations as successful offers in the market with beneficial environmental effects. A more detailed mapping and measuring of the progress of eco-innovation can only be executed on basis of the measurement of eco-efficiency and eco-efficiency progress at the different stages of the innovation process. This in turn, requires to further define the term eco-efficiency in the context of corporate sustainability as well as indicators and measures of eco-efficiency (Schaltegger & Burritt 2005; Schaltegger et al. 2002). Eco-efficiency is the conceptual integration of eco-effectiveness and economic effectiveness and thus part of the overarching concept of corporate sustainability as displayed in figure 12:

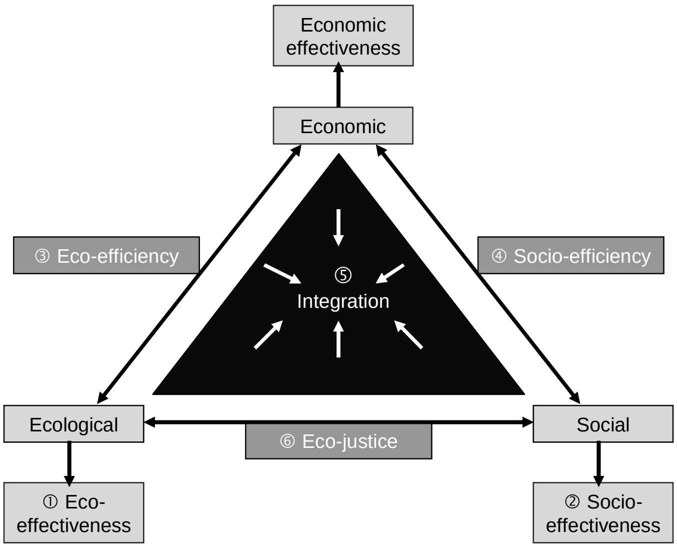

Figure 12: Corproate sustainability challenges

Source: Schaltegger & Burritt (2005, 189); BMU et al. (2002; 2007).

Eco-effectiveness stands for ecological effectiveness or environmental effectiveness and "measures the absolute environmental performance (e.g. tonnes of CO_2 emissions reduced last period) and is a general description of the extent to which the targeted objective of minimizing environmental impacts has actually been achieved" (Schaltegger & Burritt 2005, 190f.). *Economic effectiveness* simply means achieving the best possible economic result in terms of creating corporate and shareholder value. Integrating economic effectiveness and eco-effectiveness thus results in *economic-ecological efficiency*, which is the ratio of monetary efficiency supplemented with physical, ecological aspects. In other words it can be regarded "(...) as the ratio of value added to environmental impact added per unit, where environmental impact added is equivalent to the sum of all environmental impacts generated directly or indirectly by a product or activity" (Schaltegger & Burritt 2005, 192). Eco-efficiency can be represented as ratio with EVA as numerator and EIA as denumerator (Schaltegger & Sturm 1990):

$$\text{Eco-efficiency} = \frac{\text{Economic value added (EVA)}}{\text{Environmental impact added (EIA)}}$$

The ratio is a helpful tool for distinguishing eco-efficiency trends over a period of time. An increasing efficiency ratio reflects a positive performance improvement. Next to eco-justice and socio efficiency, eco-efficiency is a central element for progressing towards sustainable development. Eco-efficiency can be determined as lag indicator for all business activities and be improved over time. Environmental impact added is measured by considering calculations of material flows which can be found in environmental accounting methods and environmental performance evaluation (Schaltegger et al. 2003). Eco-efficiency can be applied as measure of the ratio between the provision of a unit of product and the environmental impact added by that product's life-cycle (ecological product efficiency) and as measure of how much environmental impact is associated with the provision of a specific function in each period of time (ecological function efficiency). Progress in an innovation's eco-efficiency thus can be obtained by providing more value per unit of environmental impact. A more detailed explanation on eco-efficiency can be found in Schaltegger et al. (2003).

It is important to notice that "[b]oth product or service value and environmental influence include many different indicators which cannot be merged into one single number" (WBCSD 2000, 8) but need to be represented by *ratios* that best serve the needs of individual decision makers. Effectiveness – whether economic, environmental or social effectiveness – can be measured in absolute figures. Efficiency, by contrast, describes the relation between different dimensions such as the environmental and economic dimension for eco-efficiency, or the social and economic dimension for socio –efficiency (even economic efficiency reflects the relation between different economic issues such as assets, profit, time, etc.). Efficiency is therefore measured in relative indicators or ratios. Efficiency indicators are cross-indicators which incorporate two separate units of measure, unless both dimensions of an efficiency analysis are measured in monetary terms" (Schaltegger et al. 2006, 7).

This way it is possible to measure economic value and environmental impact "(…) for different entities, such as production lines, manufacturing sites, or entire corporations, as well as for single products, market segments or entire economies. In the same way, eco-efficiency ratios can be calculated and used for many of these entities" (WBCSD 2000, 8f.) and thus are providing adaptable stakeholder specific ratios that are meaningful and useful to the stakeholders' differing and specific information needs. The calculated ratios then can be used as lag indicator for improving or declining performance of innovations' eco-efficiency.

4.1.2 Eco-efficiency benchmarking and comparability of eco-innovations

Out of the ecological market development strategy, innovations might be classified into one of the four dimensions provided by a so called *eco-efficiency portfolio matrix* (Ilinitch & Schaltegger 1995; Schaltegger & Sturm 1995; Schaltegger & Burritt 2000; figure 4.2). The eco-efficiency portfolio matrix (figure 13) allows for benchmarking of eco-innovations. In order to find out whether in eco-efficiency terms an innovation is an eco-innovation it should be benchmarked among alternative already existing innovations in terms of economic value added (EVA) and environmental impact added (EIA) (see Ilinitch & Schaltegger 1995; Schaltegger & Sturm 1992; ibid 1995). This kind of evaluation will show whether the analysed innovation can be categorised as *strong* eco-innovation, *weak* eco-innovation (with improving environmental performance and decreasing economic performance or vice versa) or *negative* eco-innovation, where environmental and economic performance are low. This way it can also be determined whether an eco-innovation can be termed a more eco-efficient innovation than its benchmark. An innovation to be termed eco-innovation at least should be on or above (i.e. to the right of) the dashed diagonal eco-efficiency line. Therefore, the diagonal eco-efficiency line represents the minimum threshold necessary for the ratio between EVA and EIA in order to label innovations as eco-innovations. The eco-efficiency portfolio matrix acknowledges dirty cash cows that highly perform on the economic side, however show poor environmental performance, to be called weak eco-innovations as long as they reach a minimum of environmental performance above the dashed eco-efficiency line.

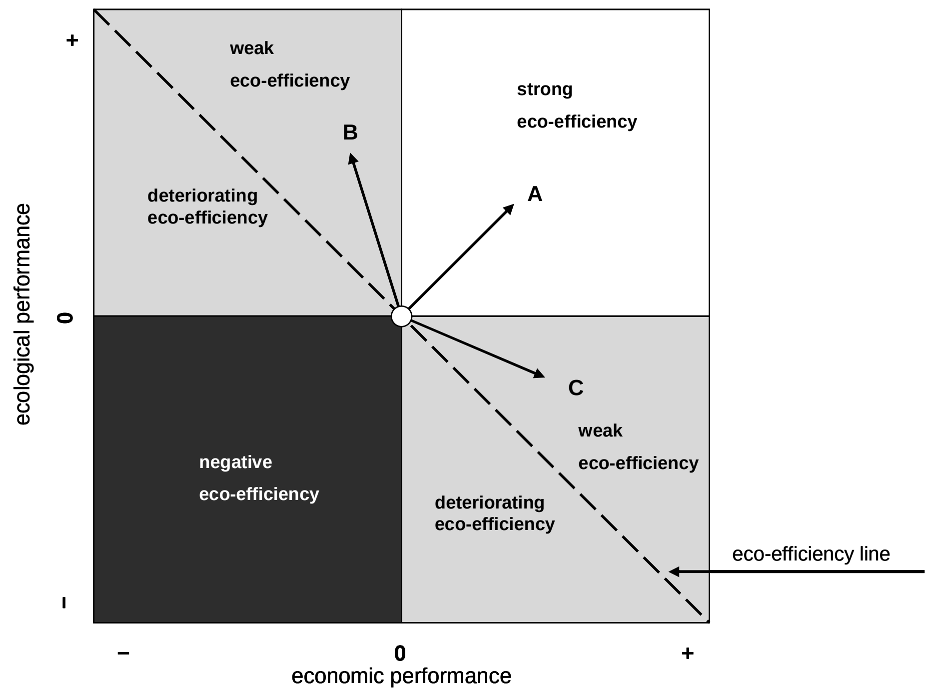

Figure 13: Eco-efficiency portfolio matrix

Source: adapted from Schaltegger (2000); Schaltegger & Burritt (2000, 53, 391).

The same counts for weak eco-innovations that highly perform in environmental terms and show very poor performance on the economic side. The question here is, how to improve the ratio between EVA and EIA since any movement further above the diagonal eco-efficiency line indicates that the ratio between EVA and EIA has improved, i.e., the innovation can be said to be more eco-efficient than an innovation closer to the dashed line. An innovation improving towards the direction of arrow B is that of an eco-innovation growing stronger in economically sustainable terms whereas its environmental aspects are deteriorating. An eco-innovation improving towards the direction of arrow C is that of an eco-innovation growing stronger in environmentally sustainable terms whereas its economic aspects are deteriorating. Since development towards these two directions (B and C) from an eco-efficiency perspective is weaker than development towards the optimum direction of arrow A where both the environmental and the economic aspects are improving development towards arrow A can be called *strong eco-innovation*. Development towards the direction of arrows B or C is that of *weak eco-innovation*.

To focus on a strong sustainable improvement of corporate eco-efficiency can be seen as a mutually beneficial *'no-regrets strategy'* for corporate environmental protection because measures taken result in an improvement in economic and environmental performance. Weak improvements in eco-efficiency imply either an improving economic situation that is *traded off* against lower environmental performance, or an improving environmental performance that is traded off against a lower economic level of performance (Schaltegger & Burritt 2000).

Categorising eco-innovations' performance in this kind of matrix is necessary due to the fact that there does not exist *the* ultimate eco-innovation but eco-innovativeness must always be regarded in *relative* terms. Eco-efficiency is not a stable achievable end-goal but rather a comparative goal and innovation is an open-ended process with an indefinite future where one might regard a certain eco-innovation as the best available for the moment. However, it is never certain that this benchmark might not become obsolete in the future due to a new eco-innovation that is more eco-efficient, whether in terms of improved economic performance (arrow B), improved environmental performance (arrow C) or even both (arrow A) and thus creating a new benchmark.

Not only does *benchmarking* of eco-innovations enable categorisation of eco-innovations into strong and weak eco-innovations, i.e., eco-innovations with a relatively strong and weak eco-efficiency ratio (figure 13; Schaltegger 2000) but also into average and leading benchmarks with regard to eco-efficiency. The *best eco-innovations available* in the market are those with the highest eco-efficiency ratio (closest to arrow A) and thus representing the *leading eco-innovation benchmark*, whereas eco-innovations with a lower eco-efficiency ratio, either in terms of environmental performance, economic performance or both, however still on or above the dashed eco-efficiency threshold, represent the *average eco-innovation benchmark*. Setting these benchmarks is of such importance since they provide the standard against which the performance of competing innovations is judged and therefore serve as basis for future action and further improvement towards best practice (Schaltegger & Burritt 2000). Here, it should be considered the systemic nature of eco-innovations being embedded into the micro and macro features of their societal context, which again is embedded and dependent on ecological resources. Strong eco-innovations show high economic performance and are decoupled from environmental depletion.

When analysing eco-innovations in this kind of eco-innovation portfolio matrix, the *comparability* of innovations needs to be verified (see chapter 2). Having determined that an innovation is above (or at the margin also on) the eco-efficiency line and thus can be categorised as an eco-innovation, does not make its eco-efficiency comparable to that of any kind of eco-innovation. Here, for instance, industrial sector differences need to be taken into account. Companies operate in sectors with different environmental sensitivity such as mining, energy and chemicals, where in absolute terms these companies are usually rated into the category of poor environmental performance. However, within the scope of the same industry, such a company might still do better relative to their competitors dealing with the same environmental challenges.

Three perspectives of eco-efficiency are crucial for any kind of comparison with regard to eco-innovations and sustainable development (Schaltegger & Burritt 2000):

- *product eco-efficiency:* different versions or production systems of a product such as a mud guard of a car are compared (e.g. should the mud guard be made of steel, aluminium, plastic or magnesium?)
- *functional eco-efficiency:* different products or services fulfilling the same function are compared (e.g. is the car or the motorbike or the train more eco-efficient in transporting a person from one end of the town to the other?)
- *needs related eco-efficiency:* different products and services are compared regarding their effect in fulfilling the needs behind a consumption activity (e.g. if the person wants to communicate over distance email, video conferencing, etc. may fulfil the needs more eco-efficiently rather than the transportation of the person from one place to the other)

The analysis of these dimensions of eco-efficiency is necessary to make sure that comparisons are made on a truly comparable basis (for further information on different types of eco-efficiency refer to Schaltegger et al. 2006; Schaltegger et al. 2008; Schaltegger & Burritt 2006). Furthermore, this analysis may not only help to determine what concept or business offer is most eco-efficient but also stimulate competition and therefore the creation of new eco-innovations and a long-term dynamic innovation process towards sustainability.

For most questions and applications it does not make sense to compare whether an innovative production process, e.g., of a certain pharmaceutical product, is more eco-efficient than, e.g., the production process of a novel and innovative packaging alternative for mineral water. However, it might make sense to have a look at what has stimulated the novel idea of an eco-innovation and compare this stimulus to those of other eco-innovations in order to find out whether there might be some kind of pattern or catalyser that stimulates an increase in the amount of eco-innovations developed. This implies that there might be a difference in eco-efficiency perspectives as well as in eco-innovation indicators to be applied in different phases of the innovation life-cycle as well as throughout different branches.

The measurement of eco-efficiency as output oriented lag indicator for eco-innovation performance mainly comes into play in the rear part of the eco-innovation process. Whereas throughout the invention phase the necessary creative steps are taken to increase an innovation's eco-efficiency (e.g. in terms of user integrated research or eco-design), the realisation phase, where the novelty actually is produced, implemented, adopted and disseminated, provides the main platform for eco-efficiency measurements. Here, the eco-efficiency analysis should not only concentrate on firm internal processes but also activities throughout the value chain, i.e. the activities taking place throughout the company's supply chain and other related areas up to the production of the eco-innovation should be integrated. When it comes to market introduction, affiliated value chain processes, such as logistics and distribution into the market as well as recycling activities should be integrated into the eco-efficiency analysis. In the final phase, where the eco-innovation is disseminated to the mass market, the holistic picture, i.e. the entire value chain should be considered. The eco-efficiency analysis should capture an innovation's *entire life-cycle*, i.e. all resources dedicated from cradle to grave or cradle to cradle respectively. That means, in case of a product innovation, the supply chain, production, distribution, logistics, consumption and recycling processes need to be taken into account.

Having said this, it is important to realise that already in the invention phase of the eco-innovation process, eco-efficiency should be considered as crucial issue. For instance, the first phase of idea generation could bear an indicator which determines the eco-efficiency of generated and/or patented ideas. Therefore, by means of estimation the potential environmental impact added pEIA and the potential economic value added pEVA could already be determined at this early stage. For the EIA determination the environmental condition indicators (ECIs) suggested by the European Environmental Agency (EEA) could be utilised. That means it should be investigated which impact the potential eco-innovations, i.e. eco-innovative ideas, might have on the environmental themes and sectors covered by the EEA's ECIs, such as air pollution and ozone depletion, climate change, waste, water, biodiversity, terrestrial environment, agriculture, energy, transport and fisheries before they are realised in the market. On the other side of the equation economic measures, such as suggested by Burritt & Schaltegger (2000) should be made use of. These could be, e.g., NPV, ROCE, SHV, or value added depending on the specific stakeholder needs.

4.1.3 Stakeholder specific eco-efficiency measurement

As mentioned in chapter 2.5 different stakeholders may have different needs for information or detail with regard to eco-innovation indicators. Having in mind figure 3 showing different aggregation levels for different innovations, one can identify different levels and units that may have specific information needs. If we are, e.g., dealing with an innovative process, its eco-efficiency could be analysed for the business unit where the innovative process is taking place (micro-perspective). Is the eco-innovation business related, e.g., changing the management system of an entire organisation, top management will be interested in an indicator assessing the innovation's annual eco-efficiency performance with regard to the entire organisation (micro-perspective). A production manager could be interested in what eco-efficiency indicator can be attributed to her product thoroughout the supply chain taking into account the eco-efficiency of the product's entire life-cycle (meso-perspective). Is the eco-innovation of functional nature the analysis level could be on the functional service or industry level (meso-perspective). Government as stakeholder will be interested in the eco-innovation's impact on society as a whole (macro-perspective).

In order to avoid a messy overload of eco-innovation drivers and indicators it is important to ensure that the set is *purpose-oriented* and *focused* on the special interests and activities of specific and relevant stakeholders (Schaltegger & Burritt 2000). Therefore, one should have a look at who are the actual agents and stakeholders in the different phases of the innovation process having an interest in and a main influence on the development and performance of eco-innovations throughout the different process phases. One key aspect for determining the appropriate eco-innovation drivers and indicators is to define relevant actors or agents within the innovating organisation and its contextual environment and to look at what drives them to be interested in eco-innovation performance.

With different stakeholder groups asking for different information, a list of exemplary eco-efficiency indicators could look as shown in table 2. The selection of appropriate environmental performance indicators, economic performance indicators as well as eco-efficiency indicators should be determined separately for every eco-innovation product, product group, and other innovative function depending on the addressed stakeholder's information needs and the activity or aggregation level the indicators are referring to.

Table 2: Examples of eco-efficiency indicators

Source: Burritt & Schaltegger (2000, 364).

Stakeholder group	Example of eco-efficiency indicator	Focus
Shareholders	SHV / NPEIA	Assessment of financial investment into innovative company
Government, top management	VA / EIA	Assessment of eco-innovation impacts on society as a whole
Government, top management	(corporate taxes) / EIA	Assessment of impacts relevant for the government and the tax agency
Top management	Income / EIA	Assessment of annual performance
Site management	ROCE / EIA	Assessment of site
Project management	NPV / NPEIA	Assessment of capital investment project
Divisional management	CM / EIA	Assessment of innovative product group
Product management	CM / EIA	Assessment of innovative product

CM = contribution margin; EIA = environmental impact added; NPEIA = net present environmental impact added; NPV = net present value; ROCE = return on capital employed; SHV = shareholder value; VA = value added

4.1.4 Integrating environmental and economic performance indicators

With regard to the level of analysis it is important to take into consideration that environmental and economic data must be *consistent*, i.e., "[i]f an enterprise expands its eco-efficiency reporting to include the life-cycle of its products and services, it has to ensure that, if the environmental item includes activities up- and/or downstream, the financial item used as a reference figure also covers these activities" (UNCTAD 2003, 12). Eco-efficiency ratios can help to provide an insight into the decoupling of eco-innovations' environmental pressure from economic performance. Hence, the appropriate EVA and EIA indicators of the eco-efficiency ratio for eco-innovations depending on the stakeholder needs are to be defined.

Derivation of eco-efficiency indicators takes place according what is called the eco-efficiency path procedure (figure 14).

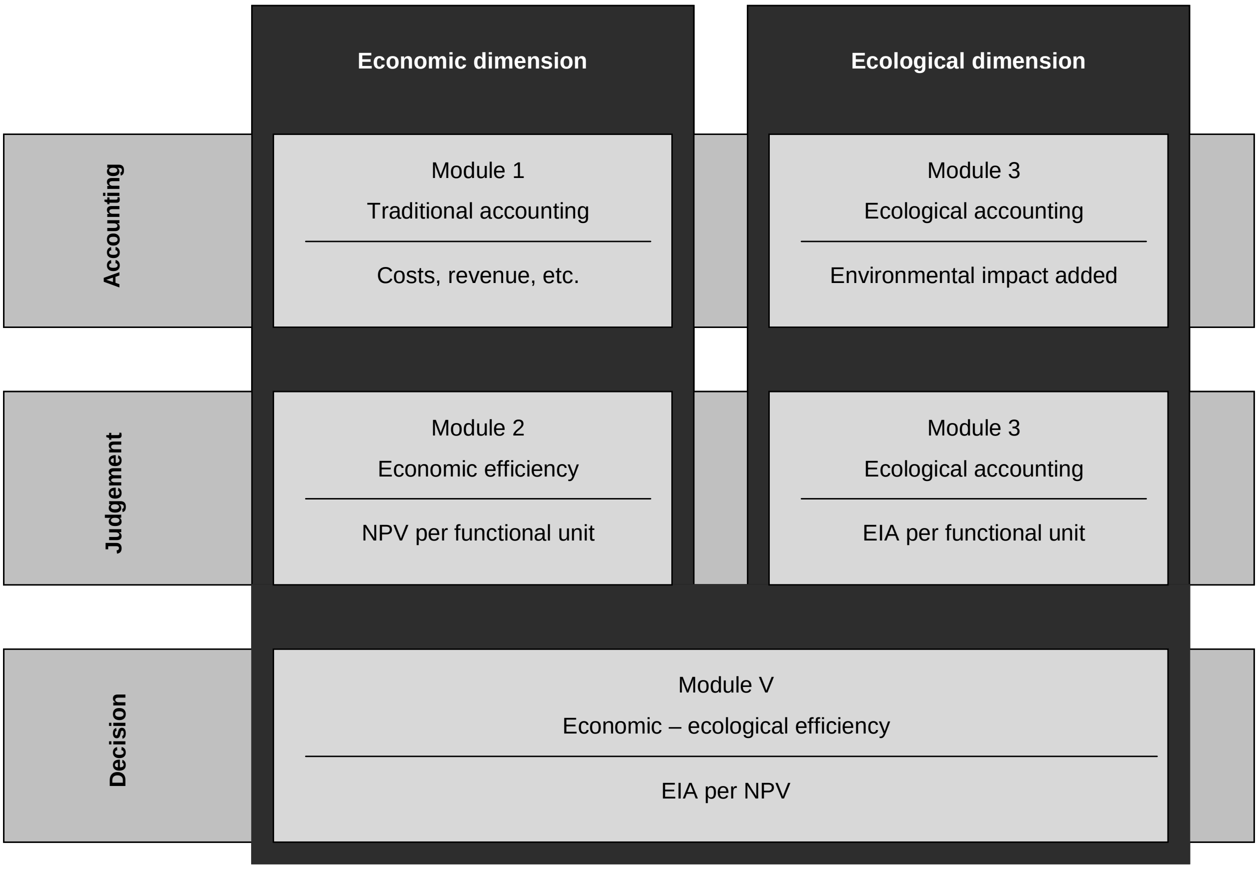

Figure 14: The eco-efficiency path procedure

Source: adapted from Schaltegger & Burritt (2000, 359); Schaltegger & Sturm (1992, 207).

Due to a great diversity of applications, industries and stakeholders, many diverse and diverging approaches determining environmental performance, economic performance and innovation activities are existing (e.g. see ISO 14031, EEA-CSI, OECD key environmental indicators, OECD decoupling indicators, SETAC, EMAS, ACCA, GRI, WBCSD, CIS). Olsthoorn et al. (2001) mention that information needs of many different stakeholders should be served by *normalised* and, in a separate step, *aggregated* or *standardised* sets of indicators. In order to conduct an eco-efficiency analysis of eco-innovations, it is wise not to create an entirely new set of indicators to be added to the already existing ideas. Rather a set of environmental performance indicators should be chosen from those sets already existing. Indicators suggested by the ISO 14000 series could serve as reference here. Applied to innovative products and innovative functions, environmental performance analysis of eco-innovations could be executed with ISO 14031 indicators as basis. ISO 14031 provides for a set of environmental performance indicators that are suitable for the assessment of the environmental performance of operations related to eco-innovations (operational performance indicators OPI). These OPIs could be used to fill the environmental performance dimension of the eco-efficiency equation (CEN 1999).

Furthermore, the appropriate economic performance indicators for eco-efficiency assessment need to be identified. Here, it is important to stick to the same *system boundary* used for an eco-innovation's environmental performance determination. If we, e.g., decide to analyse an eco-innovation from a life-cycle perspective, a life-cycle perspective should be applied for the derivation of environmental as well as economic performance indicators. Recently, efforts have been made to integrate life cycle costing (LCC) into eco-efficiency analysis (Kicherer et al. 2007; Norris 2001). Given that life cycle assessment of environmental performance and LCC differ in purpose and approach (table 3), it needs to be ensured that the applied "(...) ecological and economical figures are derived from the same starting point, i.e. cover the same scope and are comparable" (Kircherer et al. 2007, 2) for instance with regard to system boundaries and time scale.

Table 3: How LCA and LCC differ in purpose and approach

Source: Norris (2001, 118).

Tool/Method	LCA	LCC
Purpose	Compare relative environmental performance of alternative product systems for meeting the same end-use function, from a broad, societal perspective	Determine cost-effectiveness of alternative investments and business decisions, from the perspective of an economic decision maker such as a manufacturing firm or a consumer
Activities which are considered part of the 'Life Cycle'	All processes causally connected to the physical life cycle of the product; including the entire pre-usage supply chain; use and the processes supplying use; end-of-life and the processes supplying end-of-life steps	Activities causing direct costs or benefits to the decision maker during the economic life of the investment, as a result of the investment
Flows considered	Pollutants, resources, and inter-process flows of materials and energy	Cost and benefit monetary flows directly impacting decision maker
Units for tracking flows	Primarily mass and energy; occasionally volume, other physical units	Monetary units (e.g., dollars, euro, etc.)
Time treatment and scope	The timing of processes and their release or consumption flows is traditionally ignored; impact assessment may address a fixed time window of impacts (e.g., 100-year time horizon for assessing global warming potentials) but future impacts are generally not discounted	Timing is critical. Present valuing (discounting) of costs and benefits. Specific time horizon scope is adopted, and any costs or benefits occurring outside that scope are ignored

An LCA of the environmental performance of operations related to eco-innovations should include OPIs that cover the following categories (CEN 1999):

- Input categories: materials, energy, services supporting the organisation's operation
- Physical facilities and equipment used
- Output categories: products, services provided by the organisation, wastes, emissions

An innovation's entire life-cycle should be assessed according to the input used, physical facilities and equipment used and output used. The environmental performance indicators derived through the assessment of the eco-innovation process then should be correlated with the costs occurring throughout the eco-innovation process. That way an eco-efficiency ratio with regard to an innovation's operational performance can be derived. Kircherer et al. (2007) suggest that for the relation between environmental impact derived from LCA analysis and economic costs derived from LCC analysis a *normalisation procedure* as described in ISO 14042 should be applied. By means of a normalisation procedure comparability can be ensured, complexity be reduced and thus decision-making be simplified. Being able to link LCA with LCC figures of innovative products and processes allows for the determination of their eco-efficiency, i.e. the ratio of an environmental impact unit (derived from LCA) per monetary unit earned (derived from LCC) and therefore makes them comparable to benchmarks. Furthermore, the normalised costs of an eco-innovation calculated by means of financial life cycle costing can be set into relation to the gross domestic product of a considered region, which then shows the magnitude the eco-innovation in question contributes to the GDP of that certain region (Kicherer et al. 2007). However, it has to be noticed that LCA is confronted with major drawbacks, such as the high costs to carry out an all-embracing LCA including all pre- and post-steps of all suppliers, suppliers of suppliers, distributors, customers and activities of disposal involved. Here, “the uncertainty and lack of precision of inventory data increase with the distance from the information collector (the firm)” (Schaltegger 1997, 4). Furthermore, the aggregation of environmental information with different spatial impact is problematic since an

> (...) aggregated number of local emissions do not provide any valuable information as they do not tell anything about the potential or even actual environmental impacts. One kilogram of mercury emitted on one hour at one place may kill many people, but the same amount emitted over a year at a hundred places may be without considerable impact. (...) Ecologically it therefore does not make any sense to aggregate interventions with local impacts that occur in different ecosystems. Such a life cycle perspective does not impede, but it rather creates, ecological suboptimization! (Schaltegger 1997, 4f.).

4.1.5 Environmental condition indicators as impact reference

Moreover, ISO 14031 suggests to have a set of environmental condition indicators (ECIs) that can give information about an eco-innovation’s actual impact or potential impact on the surrounding environment (CEN 1999). In order to analyse the determination of a certain eco-innovation’s contribution to the regional, national or global environmental conditions, e.g. of the ozone layer, air pollution, biodiversity, energy consumption, the core set of environmental indicators developed by the EEA (2005) could be used as reference environmental condition indicators (ECIs). This information should be integrated into the EIA side of the eco-efficiency equation. So far, the European Union’s work on indicator derivation has resulted in a core set of indicators.[5] The European Environment Agency (EEA) has selected a core set of 37 environmental indicators from a much larger set on the basis of the following criteria (EEA 2005): policy relevance, progress towards targets, availability and routinely collected data, spatial coverage, temporal coverage, national scale and representativeness of data, understandability of indicators, methodologically well founded and EU priority policy issues.

The EEA stresses that the selected set of indicators is policy relevant and stable, however not static and therefore still subject to further future development. The indicators cover ten environmental themes:

1) air pollution and ozone depletion,
2) climate change,

[5] See http://themes.eaa.europa.eu/IMS/CSI.

3) waste,
4) water,
5) biodiversity and
6) terrestrial environment,
7) agriculture,
8) energy,
9) transport and
10) fisheries.

Though it is good to have such an already established set of reference indicators that can be used by all kind of different stakeholders with differing information needs, this set does not yet sufficiently cover all aspects to be considered and therefore is open to further indicator development (EEA 2005). EEA mentions that more research needs to be done on indicators covering other relevant priorities, such as chemicals, noise, industry, consumption, material flows (EEA 2005). Bearing in mind the above mentioned obstacles of data aggregation, it has to be taken into account that "only those interventions which impact the same ecosystems are considered, aggregated and assessed" (Schaltegger 1997, 5) giving privilege to decentralist and site-specific collection, recording and auditing of data, which in turn results in higher quality assessment.

Two further important aspects that require consideration in relation to eco-efficient innovations are *demand* and *function*. If there is no demand for a certain function or product then there is no market and consequently the product or service will not sell regardless of how eco-efficient it might be. Furthermore, if an innovation is more eco-efficient but does not serve the function as well as another less eco-efficient product or service, it will have a hard time to capture market share and not to remain in inferior position. Keeping these aspects in mind, ecological market development strategies should improve the prospects for the successful introduction of environmental innovations in the long term by reaching beyond the economic marketplace and by influencing the public and political spheres in an attempt to align legal frameworks with desired and desirable environmental solutions (Schaltegger et al. 2003, 193).

4.1.6 Tools and instruments driving the improvement of eco-efficiency performance

Performance measurement of eco-innovation should not stop by utilising lag indicators. Lead indicators need to be defined that emphasise how the eco-efficiency of the lag indicators could be influenced or improved. These lead indicators or drivers can be found within a firm but also outside the firm. From a business perspective these drivers of eco-innovation performance should be identified throughout the company's entire value chain, including the supply chain from the production side towards the distribution side, as well as supporting activities, such as finance, marketing and IT infrastructure. Moreover, drivers can be found in the political, institutional, cultural, social, legal and economic dimension of the firm (micro) as well as the innovation regimes (meso) and dynamic socio-technical landscapes (macro).

Since this chapter focuses on an analysis from a business perspective, all drivers identified should be business related. These drivers trigger and support the development or improvement of eco-innovations within organisations. They might be a relevant factor for an eco-innovation to master the step from one phase to the next throughout the eco-innovation process. That means these drivers facilitate the steps to be taken from an idea for a potential eco-innovation towards the actual realisation of an eco-innovation in the mass market.

According to the WBCSD (2000) eco-efficiency can be achieved by means of seven key elements. These elements should be applied throughout the eco-innovation process to ensure its improving eco-efficiency:

1) Reduced material intensity (of innovative goods and services)

2) Reduced energy intensity (of innovative goods and services)

3) Reduced dispersion of toxic substances

4) Enhanced recyclability (of materials used throughout the eco-innovation life-cycle)

5) Maximized use of renewables (throughout the eco-innovation life-cycle)

6) Extended product life cycle (in terms of durability)

7) Increased service intensity (of innovative goods and services).

The EU's integrated product policy approach, which is regarded as a cooperative instrument of industry and policy, aims at promotion and progress "(...) towards a continuous improvement of products and product related services, with the aim of reducing their impact on man and the environment during all stages of the product life-cycle" (IHK München & StMUGV 2001). Towards achieving this goal, several life-cycle oriented tools and methods supporting ecological assessment and optimisation are promoted by IPP. In the following paragraphs a list of instruments and tools shall be provided to give a brief overview on how to approach and improve eco-efficiency and its measurement.

4.1.6.1 EMAS and the ISO 14000 series

Several tools and instruments for the management and analysis of eco-efficiency have been developed. Among these are voluntary environmental management systems (EMS) such as the EU Eco-Management and Audit Scheme (EMAS), which is a tool that supports companies and other organisations to evaluate, improve and report their environmental performance. According to Rennings et al. (2006) implementation of an EMS is primarily aiming at promoting process innovations towards improved environmental performance while decreasing costs, and indirectly also at stimulating product innovations towards more eco-efficient products and services. So far, EMS have mainly resulted in companies focussing their environmental management on production processes and firm organisation, however, the inclusion of product planning and prior assessment of environmental consequences of new products are increasingly demanded (Rennings et al. 2006).

The ISO 14001 standards, which serve as basis for EMAS and unlike EMAS are applicable on an international level, provide the requirements for EMS. ISO 14004 provides the general EMS guidelines. The intention of the standards is to provide a framework for a holistic, strategic approach that can serve as common reference for communicating about environmental management issues and that can be certified. Being certified according to the ISO 14001 standard can be regarded as a steppingstone towards EMAS certification.

Within the ISO 14000 series various additional aspects of environmental management are addressed. For instance, the ISO 14031 standard provides guidelines for environmental performance evaluation, ISO 14040 describes the principles and framework for life-cycle assessment (LCA) and ISO 14062 describes concepts and current practices relating to the integration of environmental aspects into product design and development.

4.1.6.2 The cleaner production approach

The cleaner production concept was introduced by the United Nations Environment Program (UNEP) in 1989 as "the continuous application of an integrated preventive environmental strategy applied to processes, products and services to increase eco-efficiency and reduce risks to humans and the environment" (IISD 2007). According to IISD (2007) four elements of cleaner production are

1) The precautionary approach - potential polluters must prove that a substance or activity will do no harm;
2) The preventive approach - preventing pollution at the source rather than after it has been created;
3) Democratic control - workers, consumers, and communities all have access to information and are involved in decision-making;
4) Integrated and holistic approach - addressing all material, energy and water flows using life-cycle analyses.

4.1.6.3 Life-cycle assessment

Integration of life-cycle thinking into environmental system management has brought up the approach of life-cycle assessment, which "(...) is a technique for assessing the environmental performance of a product, process or activity from 'cradle to grave', i.e. from extraction of raw materials to final disposal" (Azapagic 1999, 2). According to Azapagic (1999, 3) the main advantage of this approach "(...) lies in broadening the system boundaries to include all burdens and impacts in the life cycle of a product or process, and not focusing on the emissions and wastes generated by the plant or manufacturing site only." Via a framework comprised of four phases that are 1) goal definition and scoping, 2) inventory analysis, 3) impact assessment and 4) improvement assessment, LCA has been used as instrument for both corporate and public decision making. According to Azapagic (1999, 4) LCA has been mainly but not only utilised for the following purposes:

- strategic planning or environmental strategy development,
- product and process optimisation, design, and innovation,
- identification of environmental improvements opportunities,
- environmental reporting and marketing,
- creating a framework for environmental audits.

Kicherer et al. (2007) have shown that combining LCA with life cycle costing (LCC) via normalisation allows for the determination of eco-efficiency (see chapter 4.1.4).

4.1.6.4 Environmental management accounting

Environmental management accounting (EMA) is composed of two major components, monetary environmental accounting (MEMA) and physical environmental accounting (PEMA) (Burritt et al. 2002). By means of these two components different stakeholders may be served with different kinds of information about the impact of a company's environmental impact:

> For example, top managers are interested in monetary information that shows material effects on shareholder value, including environmentally related impacts on the economic situation of companies. Corporate environment manager (...), on the other hand, are interested in various waste and pollution figures expressed in physical units and generally have no direct interest in, for example, whether the costs of pollution abatement or waste reduction measures are capitalised or considered as expenses in the monetary account (Burritt et al. 2002, 40).

Whereas monetary environmental information reflects environmentally related impacts on the economic situation of companies or even broader economic systems, physical environmental information reflects company-related impacts on environmental systems. According to the multi-dimensional framework of EMA developed by Burritt et al. (2002) a distinction between five dimensions needs to be taken into account:

- internal versus external;
- physical versus monetary;
- past and future timeframes;
- short and long terms; and
- ad hoc versus routine information gathering.

Within the proposed framework[6] different techniques of EMA, such as environmental life-cycle costing or physical environmental budgeting, can be placed and assigned. Hereupon, management can choose appropriate EMA tools to be applied according to their information needs. EMA is necessary to avoid the unnoticed increase of costs related to environmental

[6] For more detailed information on the proposed comprehensive framework on EMA see Burritt et al. (2002); Herzig et al. (2006, 493ff.).

activities or impact. By means of EMA those costs can be identified, monitored and reduced to the best possible extent.

4.1.6.5 Sustainability reporting and the Global Reporting Initiative (GRI)

Many companies have started to publish their activities towards sustainability in so called sustainability reports or corporate responsibility reports. As environmental reporting is part of this reporting process, this effort has a major impact on companies' efforts to increase their eco-efficiency. Many of those published reports are based on a sustainability reporting framework such as provided by the Global Reporting Initiative (GRI). On the one hand, the GRI framework provides guidance on how organization can disclose their sustainability performance; on the other hand, it provides stakeholders a universally applicable, framework ensuring the comparability of information (Morhardt et al. 2002). The standard disclosures of the GRI include reporting an organisation's

- strategy and profile;
- management approach; and
- performance indicators on economic environmental and social (labour practices and decent work, human rights, society, product responsibility) issues.

Furthermore, some sector specific guidelines to be used additionally to the core guidelines are provided. Within the environmental management disclosure, the following environmental categories, which differ from the environmental themes covered by the EEAs indicators (see chapter 4.1.5), are listed:

- Materials;
- Energy;
- Water;
- Biodiversity;
- Emissions, Effluents, and Waste;
- Products and Services;
- Compliance;
- Transport; and
- Overall.

4.1.6.6 Extra-financial issues and responsible investment

Already in 1989 the Social Investment Forum introduced the Coalition for Environmentally Responsible Economies (CERES), a non-for profit network of investors, environmental organisations and other public interest groups working with companies and investors, which then published the ten-point CERES Principles (formerly Valdez principles) aimed at the integration of environmental aspects into investment decision making. Developments at

European and international level show that there is a trend towards increasing importance of extra-financial issues within investment activities. The Social Investment Forum (2006) reports that on a global scale there is growth in the number of socially responsible investment (SRI) funds including a global increase in awareness of SRI and growing demand for information and resources driving its development in markets around the world. Also the European Social Investment Forum (Eurosif) identifies a substantial growth in SRI in Europe. This trend is also reflected in two sets of principles recently created:

- In 2005 the UN Global Compact and the United Nations Environment Programme Finance Initiative (UNEP FI) coordinated the development of the so called principles for responsible investment (PRI), providing a framework for investors on environmental, social and corporate governance (ESG) issues that can affect the performance of investment portfolios. The main aim is to influence investment decision making and owner practices in order to improve long-term returns and beneficiaries. The three main categories of signatory are asset owners, investment managers and professional service partners (UNEP FI & UN Global Compact 2005). Signing the PRI means adhering to six leading principles and being provided support activities.
- At European level Eurosif aims at expanding and developing sustainable investment in the financial industry as well as increasing public awareness on the topic. Eurosif launched the European SRI Transparency Guidelines covering seven principle categories to be followed.

Mirroring the increasing interest in SRI issues, several indices have been established that track the performance of companies regarding sustainability issues. Examples are:

- the Dow Jones Sustainability Index (DJSI) established by a cooperation of Dow Jones Indexes, STOXX Limited and SAM,
- the Ethibel Sustainability Indices (ESI) owned by Vigeo and Forum Ethibel,
- the FTSE4Good Index Series provided by FTSE Group,
- the FTSE Environmental Opportunities All-Share Index,
- the CDP Reports provided by the Carbon Disclosure Project,
- the NASDAQ Clean Edge U.S. Index (CLEN) and the NASDAQ Clean Edge U.S. Liquid Series Index (CELS) sponsored by First Trust Advisors L.P.
- the Claymore/MAC Global Solar Energy Index ETF installed by Claymore Securities Inc.
- the DAXglobal Sarasin Sustainability Germany Index and the DAXglobal Sarasin Sustainability Switzerland Index provided by German stock exchange and Sarasin,
- the Global Challenges Index (GCX) provided by stock exchange Hannover and oekom research AG
- the KLD Sustainability Indices provided by KLD Research & Analytics and Standard and Poors, which also has brought out the
- S&P ESG India Index provided by KLD Research & Analytics, CRISIL and Standard and Poor’s,

and there are more and more to come. All these indices evaluate and benchmark companies' performance with regard to sustainability issues. They provide socially and environmentally concerned investors to match their personal and institutional values to their investment decisions. Thus companies that are targeted on being listed within these indices are better off increasing their eco-efficiency performance.

4.2 Lag and lead indicators of eco-innovation performance

For eco-innovation to be successful it needs to combine both approaches being eco-efficient and being innovative. By means of quantitative analysis Wagner (2008, 25) has found "no association of environmental management with environmental innovation." Thus, although tools and instruments of environmental management can improve a company's eco-efficiency ratios, their application will not necessarily result into increasing environmental or eco-innovativeness. The eco-efficiency assessment and benchmarking procedures described above are suggested as outcome measures within the latter part of the eco-innovation process, where eco-innovations are realised by means of adoption and dissemination. If an EMS does not have a significant effect on innovation, this may be due to the reason that an EMS, although it might have an influence on the improvement of environmental impact measures within the different phases of the eco-innovation process, it does not have the capability to open the stage gates between the different innovation phases. Besides looking at how environmental issues can be integrated into the eco-innovation phases, it also needs to be considered what actually drives and indicates *innovativeness*, i.e. the effective performance within each innovation phase and the successful overcoming of the steps from one innovation phase to the next to transform ideas into actual eco-innovations being adopted and disseminated.

There exist several studies on innovation performance, however, there has not yet been established a commonly accepted set of indicators. Usually R&D inputs, patent measures, patent citations and new product announcements have been used as indicators of innovation performance (Haagedorn & Clodt 2003). These measures prove to be supportive but not satisfactory for setting up a list of eco-innovation performance indicators. The lead and lag indicators derived shall serve management as benchmarking tool for assessing a firm's eco-innovation performance. Since the indicator set characterises the firm's competitiveness in terms of eco-innovation performance, it may turn out to be of interest not only for the eco-innovating firm itself, but also for competitors and investors in the financial market as well as high potentials in the labour market, governments interested in companies' eco-innovation performance within their nation states or even at the EU or global level, and for other actors in an innovator's external environment. Nevertheless, the main idea behind the set of indicators developed here is to look at eco-innovation performance from a firm perspective so as to give the firm the possibility to benchmark its performance, define strategies and carry out continuous improvement of its eco-innovation activities.

4.2.1 Lag indicators of eco-innovation performance

In total 31 lag indicators reflecting eco-innovation performance have been identified (see Appendix I). The aim is to define a set of indicators that is stable but not static. The choice of this set of indicators rests in the theoretical foundation provided before. However, real life application might prove that some indicators need alteration and others may be removed or added. The indicators will be allocated to the according eco-innovation phases utilizing the following abbreviations:

IG = idea generation phase; RD = R&D and prototyping phase; INV = Invention phase (combining idea generation and R&D phase); INTRO = Introduction phase; DISS = Dissemination phase; REAL = realisation phase (combining introduction and dissemination phase); EI = covering entire eco-innovation process; lag = lag indicator; lead = lead indicator; R = Ratio; Eco = environmentally related; E/E = eco-efficiency; SS = sector specific.

According to Hagedoorn and Clodt (2003) innovative performance of high-tech firms can be measured by means of the following indicators: R&D inputs, patent counts, patent citations and new product announcements. Therefore, regarding eco-innovation, these indicators transformed towards environmentally related novelties should be considered as lag indicators of eco-innovation performance as well. Thus, the following lag indicators of eco-innovation can be identified:

- IG-lag1) Eco-patent counts: amount of patents linked to novelties that bring about some kind of environmental performance improvement and thus bear the potential to create a more eco-efficient innovation. Eco-patent counts can be used to create the further following two ratios relevant to the firm:
- IG-lag2) Eco-patent counts in relation to other firm patents (%): ratio of eco-patent counts to other firm patent counts;
- IG-lag3) Eco-patent counts in relation to industry eco-patent counts (%): ratio of eco-patent counts to industry-wide eco-patent counts. An additional indicator are
- IG-lag4) Eco-patent citation counts: following the basic assumption that there is a positive relationship between the importance of a patent and the degree to which a patent is cited in later patents (Hagedoorn & Clodt 2003), which also gives an indication of the quality of patents in contrast to the purely quantitative measure of patent counts.

If the patents created by the firm are decided upon to be realised, the creation of prototypes within the R&D and prototyping phase of eco-innovation may be followed by a firm's press announcement about its novelty, which should be accounted for by the following indicator:

- RD-lag1) Eco-product/process announcement counts, which are to be regarded as being mainly an indicator of relevance on the industry level counting the number of novelties announced by firms and thus "showing off" their competitiveness to rivals. Since this is mainly done by marketing departments' press releases, the originality of the announced novelties needs to be checked due to validity reasons.

Hollenstein (1996) mentions that R&D or patent intensity cover only part of the innovation process. Thus, further innovation performance indicators that do not only cover high-tech firms need to be identified. When looking at the R&D phase of eco-innovation, it needs to be noticed that efforts are targeted at the creation of products or processes with reduced material intensity. By means of eco-design efforts, the material intensity is to be decreased leading to an increase in the eco-efficiency of potential eco-innovations, which at this stage of the eco-innovation process are to be identified as prototypes or projects. Thus, the following two indicators can be identified:

- RD-lag2) Count of eco-prototypes, which are prototypes with potential improved eco-efficiency to be realised as soon as the prototype is introduced and disseminated, and
- RD-lag3) Count of eco-projects throughout the firm, which could for example be eco-design projects aiming at the realisation of more eco-efficient products, projects and processes.

Since, as with patents, the size of a company should be taken into consideration when setting up such indicators, two further indicators are to be identified,

- RD-lag4) Count of eco-prototypes in relation to sales (%)
- RD-lag5) Count of eco-projects in relation to sales (%).

As soon as the novelty is realised by its introduction and adoption and hopefully also disseminated, life-cycle assessment, environmental accounting and other EMS instruments come into play in order to assess the eco-efficiency of the innovation's entire value chain from cradle to grave. Thus,

- REAL-lag1) Eco-efficiency of the innovation throughout its entire life-cycle is an important indicator to be considered.

This overall E/E indicator should be broken down into components that separately examine the eco-innovation's E/E performance related to the supply chain, production, distribution, consumption and recycling processes. Thus, the following lag indicators can be identified:

- REAL-lag2) E/E of supply chain processes, where the eco-efficiency of all activities related to the generation of the novelty within the firms entire supply chain needs to be assessed,
- REAL-lag3) E/E of production processes, where the eco-efficiency of all activities related to the production of the novelty within the firm needs to be examined,
- REAL-lag4) E/E of distribution processes, where the E/E of all activities related to logistics and distribution processes with regard to the novel product or process needs to be assessed,
- REAL-lag5) E/E of consumption processes, where the E/E of all activities related to the consumption of the novelty needs to be identified (e.g. energy use of a coffee machine while in operation *and* in stand-by modus),
- REAL-lag6) E/E of recycling processes, where the E/E of all recycling processes related to the novelty needs to be determined.

When assessing these eco-efficiency measures a firm's eco-innovation impact (e.g. by means of emissions or material intensity) on the environmental themes (see chapter 4.1.5) identified by the EEA for assessment of countries' environmental performance should be covered. By assessing the eco-efficiency of innovations with regard to the environmental themes suggested by the EEA's core set of indicators, it will be possible to link up the eco-innovation's contribution to the national environmental performance. Keeping in mind the WBCSD's (2000) suggestion on how to improve eco-efficiency (see chapter 4.1.6), the following seven indicators should be given special attention with regard to eco-innovation performance:

- REAL-lag7) Material intensity indicating the extent of used materials throughout the eco-innovation life-cycle. Here the eco-innovations impact on the CSI themes biodiversity, climate change, fisheries, terrestrial, transport, waste and water play a role.
- REAL-lag8) Energy intensity of eco-innovation life-cycle, where mainly the CSI theme energy is affected.
- REAL-lag9) Dispersion of toxic substances throughout the entire eco-innovation life-cycle, where CSI themes agriculture, air pollution, climate change, terrestrial and water play a main role.
- REAL-lag10) Recyclability of materials and substances used, which should be enhanced to achieve environmental effectiveness most ideally according to the cradle to cradle idea mentioned in chapter 3.2.4. Here, mainly CSI theme waste comes into play.
- REAL-lag11) Intensity of renewable use, which should be maximised throughout the eco-innovation life-cycle and could be categorised according to the nature of renewable resources used, such as wind, solar, photovoltaic, rain, tides and geothermal heat and is mainly related to CSI themes air pollution, biodiversity, climate change, energy, transport and water.
- REAL-lag12) Durability of eco-innovation life cycle, which should be extended to the longest time span possible (for example by increasing component durability by means of increasing reparability) in order to decrease environmental as well as economic cost of recycling and remanufacturing processes.
- REAL-lag13) Service intensity of a product service system (PSS), which should be augmented by increasingly concentrating on innovative functional aspects of a PSS in order to go the step from incremental via functional towards system innovation. Here, the three perspectives of eco-efficiency (product eco-efficiency, functional eco-efficiency and needs related eco-efficiency) mentioned in chapter 4.1.2 should be taken into consideration.

If the eco-innovation is a product or service innovation, the effect it has on the customer market as well as on the labour market and financial market are good indicators of its realisation progress. Process innovations may also have an effect on the labour or the financial market, however, usually they are not introduced into a customer market but within a firm and then sold and diffused to other firms so that those can buy and adopt the eco-innovative process and thus upgrade the performance of their processes. Hence, in the introduction phase and after its diffusion in the dissemination phase the following indicators should be assessed:

- INTRO-lag1) Niche market share indicating the eco-innovation's market success when introduced into a niche market;
- INTRO-lag2) Rate of adoption throughout organisational processes, in order to determine the adoption rate of eco-innovative processes throughout the innovating firm;
- DISS-lag1) Market share indicating the eco-innovation's market success when being diffused into the mass market;
- REAL-lag14) Share of firm sales in order to determine the eco-innovation's fraction of entire firm sales.

Furthermore, the eco-innovation's effect on the labour market with its "high-potentials" should be assessed, for example by means of determining the amount of employees who have been attracted due to the firm's eco-innovation efforts. An indicator here could be

- REAL-lag15) High-potentials attraction, where job applications that can be linked to a firm's eco-innovation efforts should be taken into consideration.

Moreover, the effect on the financial market should be determined (see chapter 4.1.6.6), such as the firm's inclusion in rankings targeted at extra-financial aspects and the amount of investment attracted due to the firm's eco-innovation efforts leading to the following indicators:

- REAL-lag16) Inclusion in SRI-rankings and other extra-financial rankings and
- REAL-lag17) External investment earnings due to eco-innovation efforts.

Moreover, firms may prove the competitiveness of their eco-innovation efforts by applying for prizes or awards initiated by external institutions such as governments to foster eco-innovativeness and sustainability orientation of companies:

- EI-lag1) Count of awards/prizes gained for eco-innovative performance.

As described in chapter three, eco-innovations can vary in their degree of novelty or impact (figure 4). Although any kind of eco-innovation is a good step in the direction towards sustainable development and economic growth, those with the greater degree of novelty and impact should be looked upon more favourable than those with less impact and degree of novelty. If a firm imitates an eco-innovation invented by a competitor, it certainly improves the firm's eco-innovation performance, however, if a firm comes up with an innovation in its own R&D department that leads to improvement, radical change or even societal change this should certainly be honoured in the performance assessment carried out. Thus, it is necessary to categorise a firm's eco-innovation activities into that of an imitator, incremental innovator, functional innovator or system innovator due to the innovation's effect on society:

- EI-lag2) Degree of novelty and societal impact of eco-innovation.

It is assumed that companies engaging most in the various innovation driving activities mentioned above and in the following chapter are those ones bringing about the most innovative novelties. Nevertheless, as soon as a novelty is released into the market, it should be assessed regarding the impact it may have on society with imitators being rated the lowest and system innovators being rated the highest rank of eco-innovation performance.

4.2.2 Lead indicators of eco-innovation performance

As mentioned before, eco-innovation performance should be understood as a cause and effect chain where not only output oriented indicators are sufficient means of measurement, however, drivers or lead indicators need to be taken into consideration as formative measures of eco-innovation performance as well. As has been explained earlier, there are barriers within the innovation process that need to be overcome in order to realise an eco-innovative idea into a dispersed success. Thus, drivers of eco-innovation rooted within all spheres of the socio-technical system as well as residing inside the innovating firm are indispensable for successful eco-innovation performance. In this course 32 lead indicators driving eco-innovation performance have been identified (see Appendix I). A first lead indicator of eco-innovation performance residing within the innovating firm and being relevant throughout the entire eco-innovation process is top-management commitment determined by the indicator:

- EI-lead1) Top management commitment to eco-innovation throughout the entirety of eco-innovation related activities.

If a firm's management does not show the leadership and entrepreneurship efforts needed for eco-innovation development (see chapter 3.1.5), eco-innovation will not be part of the firm's core strategy. As Arundel & Hollanders (2005) state, strategic innovators see innovation as a core component of their competitive strategy. Thus, eco-innovation should be regarded as core component of the competitive strategy for highly performing eco-innovators:

- EI-lead2) Strategic integration of eco-innovation.

Integrating eco-innovation into the core competitive strategy makes it to a corporate wide task. There should be a culture where all of the company's departments and value chain activities should be involved in improving eco-innovation performance as early as possible via functional integration efforts. Eco-innovation should be "lived" by the company. Ahmed (1998, 48) states that "[f]ormal structures, as captured by the stage gate innovation funnels enhance innovation performance but they cannot substitute soft aspects of innovations, such as those encapsulated by organisational culture, leadership, people." The company should have a corporate philosophy and mission of innovation. Hence, instruments and tools (e.g. employee suggestion systems) that allow any employee to come up with innovative ideas to get involved into eco-innovation development should be utilised, since "[i]nnovation primarily arises from a corporate culture which encourages its people to engage in entrepreneurial behaviour" (Ahmed 1998, 48). Indicators are:

- EI-lead3) Corporate philosophy and mission of eco-innovation;
- EI-lead4) Multifunctional collaboration efforts that support the integration of all functional units towards eco-innovation development. Eco-innovation is not regarded as only being a topic for the R&D department but for all functions throughout the organisation's value chain that should collaborate for this purpose;
- INV-lead1) Existence of corporate wide participation programmes towards employee involvement into eco-innovation development, for example by means of employee

suggestion schemes, workshops, trainings, job rotations, etc. These efforts may build human capital within the organisation and support the idea generation and R&D phase by utilising all means available throughout the company to come up with new eco-innovative ideas and developments.

Furthermore, corporate commitment towards the generation of eco-innovative ideas can be fostered by corporate wide communication efforts about the meaningfulness of innovations that support sustainable development, leading to the following indicator:

- IG-lead1) Corporate wide communication on sustainability issues.

Besides the pure communication efforts on sustainability issues, the company should also display integrated sustainability management, which helps the company to strategically integrate an economically, environmentally and socially responsible long-term dimension into its corporate processes and activities:

- EI-lead5) Integrated sustainability management.

The existence of reporting structures and idea channels help the innovating company to "pick up on ideas that often get cut out through the normal screening process" (Ahmed 1998, 52) leading to the following indicator:

- IG-lead2) Existence of idea reporting structures and idea channels.

Moreover, incentive and rewarding schemes may help to promote the eco-innovative culture throughout the entire organisation:

- INV-lead2) Existence of internal reward and incentive programmes for the generation of eco-innovative ideas and developments.

A further aspect identified by Arundel & Hollanders (2005) with top innovators is R&D performance on a continuous basis to develop novel product or process innovations. Eco-R&D input represents the actual R&D efforts related to environmental impact reduction by both current expenditure as well as successes related to previous R&D expenditure, since previous R&D expenditure affects subsequent R&D input. Thus the following three components of this indicator can be identified:

- RD-lead1) Sales share of eco-research input (%);
- RD-lead2) Sales share of eco-development input (%);
- RD-lead3) Eco-follow-up investment in relation to overall R&D input (%) due to success of previous eco-R&D expenditure.

Besides R&D expenditure directed at the purpose to develop eco-innovation, eco-innovation might be generated coincidentally, without having been intended to. Thus, general R&D input should be regarded as lag indicator of eco-innovation performance as well, creating the following two indicators:

- RD-lead4) Sales share of research input (%) and
- RD-lead5) Sales share of development input (%).

Having the sustainability approach in mind one aspect of this idea is that principles of eco-design are applied strategically in the R&D and prototyping phase of eco-innovation leading to the following indicator:

- RD-lead6) Integration of eco-design approach.

Applying an eco-design approach might for example lead to a change in supplied components used towards employment of more environmentally friendly options or the development of improvements that may reduce environmental impact throughout a product or process life-cycle, for example the removal of stand-by modes on machines or the development of cars that replace fuel consumption by renewable energy modes (e.g. hybrid engine car or electric car).

Here, also the functional integration comes into play, since it is important not only to design eco-friendly novelties, however, to also take into consideration the marketability / adoptability of the designed novelties. Therefore, a designing for marketability / adoptability approach should be followed in the R&D phase of eco-innovation, which will support the successful introduction and dissemination of the novelty:

- REAL-lead1) Design for marketability / adoptability efforts.

Although innovation efforts are directed towards realising mass market success, Ahmed (1998) mentions that it is important that an innovating firm provides its employees the freedom and space to innovate, thus risk taking and resource slack should be allowed for. The importance should lie with “trying”, even if that means that some efforts might result in failures, which should be accepted as belonging to the innovation process and not be discarded immediately but stored for later adaptation efforts:

- INV-lead3) Willingness to take risk and acceptance of failure.

Another important aspect throughout the R&D phase is that the company should be able to access newest equipment of highest quality. It should be avoided to get stuck in old, obsolete modes of behaviour due to equipment incapability:

- RD-lead7) Access to and utilisation of high-quality equipment and technologies.

Besides the lead indicators identifiable within the company’s internal innovation system, the external socio-technical system of innovation should be investigated as well. Here actors, institutions and processes within the five intertwined arenas of the general environment, i.e. the socio-cultural, economic, scientific-technological, legal and political arena (Schaltegger et al. 2003), need to be taken into account (see chapter 3.1.4). Within these arenas various lead indicators of eco-innovation performance can be identified. First of all, the company should bear in mind that the external environment can serve as source for innovative resources. As proposed by Chesbrough (2003), the company should follow an open-innovation approach, where, via customer integration efforts, external knowledge and ideas can be internalised into a firm’s innovation efforts. The integration not only of customers, however, of various stakeholders into the eco-innovation process, especially into the idea generation phase, by means of multi-stakeholder dialogues, competitive tenders, user feedback systems, etc., will certainly proof helpful for identifying aspects that facilitate increasing eco-innovation performance:

- o INV-lead4) A policy or approach of collaborative multi-stakeholder integration should be followed to be able to filter relevant knowledge from the arenas in the external environment that may be useful for idea generation purposes as well as research and development efforts.

This interactive approach or willingness to accept and adopt external ideas can be supported by instruments such as stakeholder dialogues or the set up of user feedback systems in order to support learning by using efforts:

- o INV-lead5) Engagement in stakeholder dialogues;
- o INV-lead6) Utilisation of user feedback systems for interactive learning purposes.

Within their study on the development of innovations in the wind energy sector, Garud & Karnøe (2003) identify what they call a bricolage approach as driver of innovation performance, where the emphasis lies on continuous step-by-step recombination of the existing and on interaction and networking between multiple actors. Innovators are enabled to pursue opportunities by embedding multiple actors into the innovation process, which is regarded as a process of co-shaping and interaction. Here, collaborative networking efforts and clustering, interactive communication and learning, and a participative style towards innovation are highlighted (see also chapter 3.1.7). Thus, further indicators are:

- o INV-lead7) Efforts to establish effective linkages / networks for instance with external institutions and bodies of know-how for sustainability and eco-innovation, such as research institutes, universities and knowledge centres.

Moreover, Stern et al. (2000) and Cooke (2001) among others identified clustering efforts with competitors and other actors as important driver of innovation:

- o INV-lead8) Clustering activities with competitors and research institutes active in the same or similar research fields as the innovating firm.

Additionally to clustering efforts, firms should emphasise integration of suppliers into eco-innovation efforts, for instance by means of trainings, workshops and environmental assessment/auditing activities:

- o INV-lead9) Integration of suppliers into eco-innovation efforts.

Besides efforts to establish networks and linkages with external institutions, a highly innovative company should make use of knowledge provided by the labour market. Being attractive to the labour market certainly is a characteristic an innovating company should not neglect. Graduates with a background in environmental engineering, sustainability management, sustainable marketing and other eco-innovation related disciplines should be regarded as valuable pool to be capitalised on. They may bring ideas and knowledge into the company that may otherwise be lost to competitors. However, these high-potentials do not just choose their employers by the toss of a coin. They increasingly deliberate about their employer’s impact on the environment, the environmental impact of products and services sold as well as the employer’s attitude towards taking on corporate social responsibility. Thus, labour market pressure towards increasing corporate social responsibility may certainly be a factor driving firms to increase their eco-innovation performance:

- INV-lead10) Pressure from high-potentials, who most suitable have a background in eco-innovation related disciplines.

Besides being attractive to the labour market, also the financial market needs to be impressed. Extra-financials gain increasing importance in the financial market. The growing investments in sustainability oriented technologies, projects and companies increase the pressure to eco-innovate successfully and thus internalise these investments for further eco-innovation activities. Hence, a company's ability to capitalise on increasing financial market pressure due to ESG and responsible investment initiatives leads to the following lead indicator:

- EI-lead6) Intake of financial support due to eco-innovation efforts.

In addition to pressure from the labour and the financial market, competitive pressure from rivals is another significant aspect that drives firms to increase their eco-innovation performance:

- EI-lead7) Ability to utilise competitive pressure from rivals for eco-innovation purposes.

Certainly this competitive environment is fostered by prizes and awards such as the German Sustainability Award or Awards initiated by other institutions and political actors such as the European Union or global actors. Participation in these competitions may certainly support the improvement of eco-innovation performance:

- EI-lead8) Participation in award/prize competitions directed at eco-innovation performance.

Besides awarding prizes, political actors fulfil another important role. Laws, regulations, tax and incentive systems aiming at reducing the environmental impact of corporate activities are forcing companies to integrate the reduction of environmental impacts throughout their entire supply chain and value chain processes. Thus, firms' obligation to obey to laws and regulations as well as taxes targeting at environmental impact reduction should certainly be regarded a driver for a firm's decision to improve its eco-innovation performance:

- EI-lead9) Obedience of "green" laws and regulations targeting at environmental impact reduction;
- EI-lead10) Ability to handle "green" tax policy targeting at environmental impact reduction.

Then again, incentive systems, such as subsidies provided by governments for eco-innovative activities, prove to be a helpful tool that might allow small and medium sized eco-innovators to release and keep their products or services in niche markets in order to increase market share whilst being less vulnerable to competitive, however less environmentally friendly, products or services:

- REAL-lead2) Intake of incentives and subsidies granted for eco-innovative activities.

Of course, by and by, subsidies need to be replaced by increasing market demand. Thus change of business customers' as well as consumers' attitude towards sustainability issues, e.g. in terms of changing production processes or changes in life-style are necessary. Here, besides marketing efforts, customer or user education programmes may be a helpful tool to raise awareness and utilisation of eco-innovations and thus their adoption rate:

- REAL-lead3) Customer / user education programmes;
- REAL-lead4) Marketing efforts, e.g. in term of sustainability marketing campaigns.

4.2.3 Sector specific assessment

Based on the derived 31 lag and 32 lead indicators provided in the previous chapters a comprehensive assessment of a firm's eco-innovation performance may be conducted. Additionally, sector specific issues need to be taken into account. Hence, with regard to eco-innovation performance, indicators need to be identified that assess firms' performance in their particular, sector-specific critical environmental impact areas. Hesse (2007) and Beatge & Hesse (2008) have provided a profound set of sector-specific sustainable development key performance indicators (SD-KPIs), which may increase comparability of firms' performance within a particular sector. The following indicators can be identified for ten sectors analysed by Hesse and Beatge:

Automobile sector:

- SS-auto1) Average fleet consumption
- SS-auto2) Energy and GHG intensity of production activities

Banking sector:

- SS-bank1) Environmental and social credit risk in commercial / investment banking sector
- SS-bank2) Environmental and social credit risk in retail banking sector
- SS-bank3) Integration of environmental and social issues into asset management

Chemical sector:

- SS-chem1) Energy and GHG intensity of production activities
- SS-chem2) Mitigation / avoidance of hazardous substances
- SS-chem3) Mitigation / avoidance of toxicity

Industrial goods sector:

- SS-ind1) Corporate wide energy and GHG intensity of production activities
- SS-ind2) Energy efficiency of products

- SS-ind3) Working conditions (for eco-innovation purposes the emphasis lies more on the avoidance of harmful substances with environmental impact than on social conditions, however, eco-innovation should have no negative impact on social issues, either)

ITC sector:

- SS-ict1) Corporate wide energy and GHG intensity of production activities and of products
- SS-ict2) Integration of eco-design approach
- SS-ict3) Working conditions (especially with regard to harmful substances)

Consumer goods and retail sector:

- SS-cgr1) Integration of environmental and social standards (ISO14001 series) into the entire supply chain
- SS-cgr2) Count of eco-labelled products
- SS-cgr3) Mitigation / avoidance of hazardous and toxic substances

Pharmaceuticals sector:

- SS-pharm1) Accession policy/strategy for products, especially in emerging and developing countries
- SS-pharm2) Integration of ethical considerations into R&D activities
- SS-pharm3) Integration of ethical considerations into marketing activities

Transport and Logistics:

- SS-log1) Corporate wide energy and GHG efficiency of transportation and distribution services
- SS-log2) Average fleet consumption

Insurance sector:

- SS-ins1) Integration of environmental and social issues into asset management
- SS-ins2) Existence of ecological premium stimuli

Utilities sector:

- SS-util1) Corporate wide GHG intensity of energy production activities
- SS-util2) Raise of share of renewables in energy mix

- SS-util3) Transparency of energy mix

Certainly, efforts should be taken up to identify main SD-KPIs for other sectors, for instance those which have a difficult standing on the sustainable development agenda due to their nature of business, such as the extracting industry, tobacco industry, etc. Nevertheless, this list of sector specific most relevant indicators regarding sustainable development is a helpful tool to give credit to sector specific differences when conducting an eco-innovation performance assessment.

5 ECO-INNOVATION PERFORMANCE ASSESSMENT – AN OUTLOOK

In “Step One” having conceptualised eco-innovation and eco-innovation performance as complex constructs measurable only by means of approaching it from a dynamic systems and process perspective has resulted in “Step Two”, which is the development of a set of eco-innovation KPIs comprised of 31 lag indicators, 32 lead indicators and 27 sector specific indicators. This set of indicators may be used as foundation for “Step Three”, which is the development of a structured assessment tool capable to capture and reflect a firm’s capabilities with regard to eco-innovation performance. Thereby, differences between various sectors and between varying institutions need to be taken into account. The most challenging task is to ensure that the set of indicators is comprehensive, however, at the same time not too complex and complicated for actual assessment and benchmarking purposes. Moreover, a detailed analysis of the validity of the proposed indicators needs to be conducted to assure that the proposed lag, lead and sector specific indicators can effectively measure the latent variable they are intended to measure. If so, the set of eco-innovation indicators can certainly be used as eco-innovation KPIs and therfore supplementary to systems of general innovation performance indicators.

By means of an assessment tool based on these eco-innovation KPIs, assessors may gain access to the relevant data about firms’ eco-innovation performance. Having gathered all relevant data enables the assessor to draw a detailed picture of a firm’s strength and weaknesses with regard to eco-innovation. In that way a company can benchmark its activities and work out an adaptation and improvement plan necessary for future strategic decision making with regard to the improvement of eco-innovation performance and sustainable competitive advantage. Moreover, an industry wide benchmarking analysis provides information on how successful a company operates in comparison to its competitors. This may enable the assessor to benchmark towards identifying the best-practice innovator in the particular field. In total, eco-innovation performance assessment helps management to prioritise resource allocation to maximise return on eco-innovation investment. Furthermore, it provide external stakeholders with information on firms’ actual eco-innovation performance, may it be on micro (e.g. firm specific), meso (e.g. sector specific) or macro level (e.g. with regard to national performance).

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APPENDIX I

List of Eco-Innovation KPIs

EI-Indicators

EI-lag1) Count of awards/prizes gained for eco-innovative performance
EI-lag2) Degree of novelty and societal impact of eco-innovation
EI-lead1) Top management commitment to eco-innovation
EI-lead2) Strategic integration of eco-innovation
EI-lead3) Corporate philosophy and mission of eco-innovation
EI-lead4) Multifunctional collaboration efforts
EI-lead5) Integrated sustainability management
EI-lead6) Intake of financial support due to eco-innovation efforts
EI-lead7) Ability to utilise competitive pressure from rivals
EI-lead8) Participation in award/prize competitions
EI-lead9) Obedience of "green" laws and regulations
EI-lead10) Ability to handle "green" tax policy

INV-Indicators	REAL-Indicators
INV-lead1) Existence of corporate wide participation programmes	REAL-lag1) E/E of the innovation throughout the entire life-cycle
INV-lead2) Existence of internal reward and incentive programmes	REAL-lag2) E/E of supply chain processes
INV-lead3) Willingness to take risk and acceptance of failure	REAL-lag3) E/E of production processes
INV-lead4) Policy/approach of collaborative multi-stakeholder integration	REAL-lag4) E/E of distribution processes
INV-lead5) Frequency of engagement in stakeholder dialogues / workshops	REAL-lag5) E/E of consumption processes
INV-lead6) Utilisation of user feedback systems	REAL-lag6) E/E of recycling processes
INV-lead7) Efforts to establish effective linkages / networks	REAL-lag7) Materials intensity
INV-lead8) Clustering activities	REAL-lag8) Energy intensity
INV-lead9) Integration of suppliers into eco-innovation efforts	REAL-lag9) Dispersion of toxic substances
INV-lead10) Pressure from high-potentials with related background	REAL-lag10) Recyclability of materials and substances used

		REAL-lag11) Intensity of renewables use REAL-lag12) Durability of eco-innovation life-cycle REAL-lag13) Service intensity of a PSS REAL-lag14) Share of firm sales REAL-lag15) High-potentials attraction REAL-lag16) Inclusion in SRI rankings REAL-lag17) External investment earnings REAL-lead1) Design for marketability / adoptability efforts REAL-lead2) Intake of incentives and subsidies REAL-lead3) Customer / user education programmes REAL-lead4) Marketing efforts	
IG-Indicators	**RD-Indicators**	**INTRO-Indicators**	**DISS-Indicators**
IG-lag1) Eco-patent counts IG-lag2) Eco-patent counts in relation to other firm patents IG-lag3) Eco-patent counts in relation to industry eco-patent counts IG-lag4) Eco-patent citation counts IG-lead1) Corporate wide communication on sustainability issues IG-lead2) Existence of idea reporting structures and idea channels	RD-lag1) Eco-product/process announcements RD-lag2) Count of eco-prototypes RD-lag3) Count of eco-projects RD-lag4) Count of eco-prototypes in relation to sales RD-lag5) Count of eco-projects in relation to sales RD-lead1) Sales share of eco-research input RD-lead2) Sales share of eco-development input RD-lead 3) Eco-follow-up investment in relation to overall R&D input RD-lead4) Sales share of research input RD-lead5) Sales share of development input RD-lead6) Integration of eco-design approach RD-lead7) Access to and utilisation of high-quality equipment and technology	INTRO-lag1) Niche market share INTRO-lag2) Rate of adoption throughout organizational processes	DISS-lag1) Market share

SS-Indicators

SS-auto1) Average fleet consumption
SS-auto2) Energy and GHG intensity of production activities
SS-bank1) Environmental and social credit risk in commercial / investment banking sector
SS-bank2) Environmental and social credit risk in retail banking sector
SS-bank3) Integration of environmental and social issues into asset management
SS-chem1) Energy and GHG intensity of production activities
SS-chem2) Mitigation / avoidance of hazardous substances
SS-chem3) Mitigation / avoidance of toxicity
SS-ind1) Corporate wide energy and GHG intensity of production activities
SS-ind2) Energy efficiency of products
SS-ind3) Working conditions (for eco-innovation purposes the emphasis lies more on the avoidance of harmful substances with environmental impact than on social conditions, however, eco-innovation should have no negative impact on social issues, either)
SS-ict1) Corporate wide energy and GHG intensity of production activities and of products
SS-ict2) Integration of eco-design approach
SS-ict3) Working conditions (especially with regard to harmful substances)
SS-cgr1) Integration of environmental and social standards (ISO14001 series) into the entire supply chain
SS-cgr2) Count of eco-labelled products
SS-cgr3) Mitigation / avoidance of hazardous and toxic substances
SS-pharm1) Accession policy/strategy for products, especially in emerging and developing countries
SS-pharm2) Integration of ethical considerations into R&D activities
SS-pharm3) Integration of ethical considerations into marketing activities
SS-log1) Corporate wide energy and GHG efficiency of transportation and distribution services
SS-log2) Average fleet consumption
SS-ins1) Integration of environmental and social issues into asset management
SS-ins2) Existence of ecological premium stimuli
SS-util1) Corporate wide GHG intensity of energy production activities
SS-util2) Raise of share of renewables in energy mix
SS-util3) Transparency of energy mix

EI = covering the entire eco-innovation process; INV = Invention phase (combining idea generation and R&D phase); IG = idea generation phase; RD = R&D and prototyping phase; REAL = realisation phase (combining introduction and dissemination phase); INTRO = Introduction phase; DISS = Dissemination phase; lag = lag indicator; lead = lead indicator; R = ratio; Eco = environmentally related; E/E = eco-efficiency; SS = sector specific.

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