Maastricht Manual on Measuring Eco-innovation for a Green Economy

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Innovation for Sustainable Development Network

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CONTACT: **Dr. Fernando J. Díaz López., Inno4sd Director**

fernando.diazlopez@inno4sd.net

DESIGN: **Inge Conde Moreno (www.ingecreative.com)**

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Maastricht Manual on Measuring Eco-Innovation for a Green Economy

Authors

René Kemp
Professorial fellow at UNU-MERIT and Professor of Innovation and Sustainable Development at ICIS, Maastricht University

Anthony Arundel
Professorial Fellow at UNU-MERIT and adjunct professor at the University of Tasmania

Christian Rammer
Senior researcher at ZEW Department of Economics of Innovation and Industrial Dynamics, and director of ZEW annual
innovation survey, the Mannheim Innovation Panel

Michal Miedzinski
Senior Research Associate, University College London, Institute for Sustainable Resources

Carlos Tapia
Senior researcher at TECNALIA Research & Innovation, Energy and Environment Division

Nicolò Barbieri
Researcher at the Department of Economics and Management - University of Ferrara

Serdar Türkeli
Post-doctoral researcher at UNU-MERIT, Lecturer in Science, Technology and Innovation Policy and Coordinator of Innovation, Institutions and Development specialisation at UNU-MERIT/MGSoG, Maastricht University

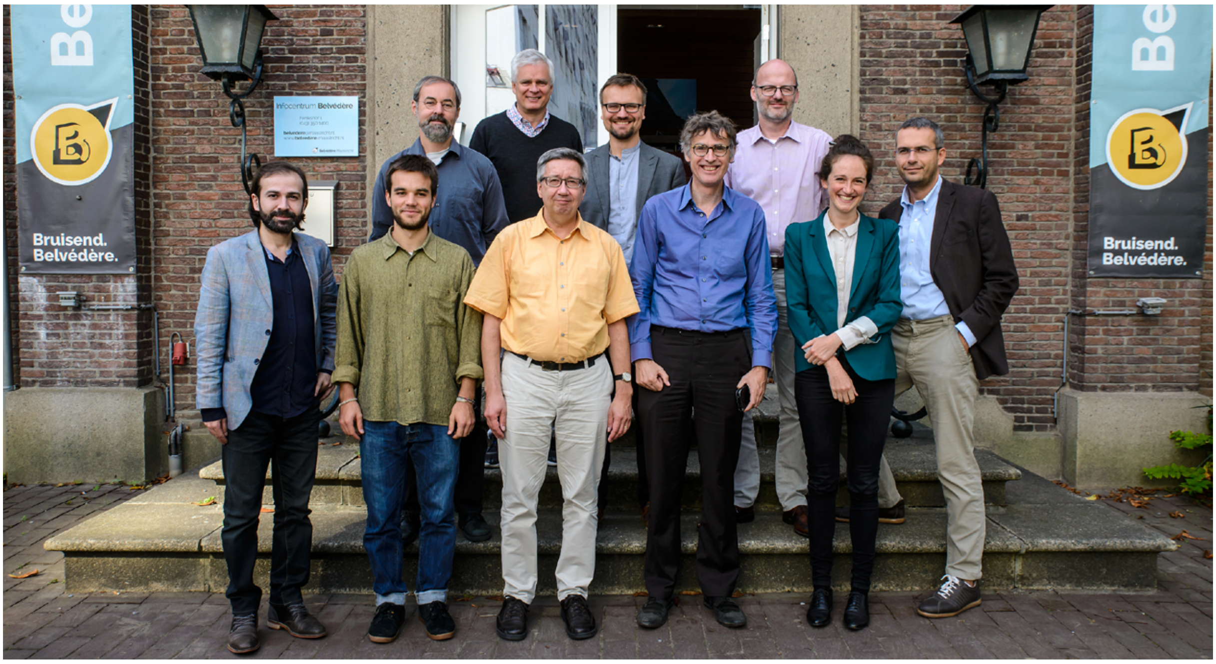
Andrea M. Bassi
Founder and CEO of KnowlEdge Srl, Extraordinary Associate Professor of System Dynamics Modelling at Stellenbosch University, and Associate at the International Institute for Sustainable Development (IISD)

Massimiliano Mazzanti
Professor of Economic Policy, University of Ferrara and Lecturer in Environmental Economics, University of Ferrara

Donald Chapman
PhD research fellow in Ecological Economics and Sustainability Transitions at KU Leuven

Fernando J. Díaz López
Director, Innovation for Sustainable Development Network and Associate Professor Extraordinary on Sustainable Systems, at Stellenbosch University

Will McDowall
Lecturer, Researcher, University College London, Bartlett School Environment, Energy & Resources, Faculty of the Built Environment



Participants at the first workshop about the Maastricht Manual for eco-innovation held in Maastricht on 26-27 September 2016)

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Abbreviations

APEC: Asia-Pacific Economic Cooperation
ASEI: Asia-Europe Meeting Eco-Innovation Index
ASEIC: Asia-Europe Meeting Eco-innovation Centre for Small and Medium-sized Enterprises

ASEM: Asia-Europe Meeting
BEV: Battery Electric Vehicle
BNEF: Bloomberg New Energy Finance
BOD: Biochemical oxygen demand
BRIICS: Brazil, Russia, India, Indonesia, China, South Africa
CAPI: Computer assisted personal interviews
CATI: Computer assisted telephone interviews
CCGT: Combined Cycle Gas Turbine
CCS: Carbon Capture and Storage
CE: Circular Economy
CEM: Clean Energy Ministerial
CH4: Methane
CIS: Community Innovation Survey
CIW: Canadian Index for Well-being
CO: Carbon Monoxide
CO2: Carbon dioxide
COD: Chemical oxygen demand
CPC: Cooperative Patent Classification
CSR: Corporate Social Responsibility
CTG: Cleantech Group
DDT: Dichlorodiphenyltrichloroethane
DMC: Domestic material consumption
DO: Dissolved oxygen
DPSIR: Driving Forces - Pressures - States - Impacts - Responses
EAPI: Energy Architecture Performance Index
EC: European Commission
ECLA: European Classification system
Eco-IS: Eco-Innovation Scoreboard
EEA: European Energy Agency
EGA: Environmental Goods Agreement
EGSS: Environmental goods and services sector
EIO: Eco-innovation Observatory
E-LCA: Environmental Life Cycle Assessment
EMAS: Eco-Management and Audit Scheme
EMInInn: Environmental Macro Indicators of Innovation Project
EPA: Environmental Protection Agency
EPO: European Patent Office
EPR: Extended Producer Responsibility
EPS: Environmental Policy Stringency Index
ERE: Environmental Rebound Effects
ETS: Emissions trading schemes
EU: European Union
EU-SILC: European Union Statistics of Income and Living Conditions
FAO: Food and Agriculture Organization
FDES: Framework for the Development of Environment Statistics
FDI: Foreign Direct Investment
FoEG: Friends of Environmental Goods
GBAORD: Government Budget Appropriations or Outlays Allocated to Research and Development
GCII: Global Cleantech Innovation Index
GDP: Gross Domestic Product

GEP: Green Economy Progress Index
GGEI: Global Green Economy Index
GGKP: Green Growth Knowledge Platform
GHG: Greenhouse gas emissions
GSM: Global System for Mobile Communications
HCB: Hexachlorobenzene
HFCs: Hydrocarbons
HM: Heavy metals
ICEV: Internal combustion engine vehicles
ICT: Information Communication Technology
IEA: International Energy Agency
IGEM: Integrated Green Economy Modelling
IP: Intellectual Property
IPC: International Patent Classification
IRES: International Recommendations for Energy Statistics
ISIC: International Standard Industrial Classification
ISO: International Organization for Standardization
MEI: Measuring Eco-Innovation Project
N20: Nitrous oxide
NABS2007: Nomenclature for the Analysis and comparison of Scientific programmes and Budget
NGOs: Non-governmental organisations
NMVOC: Non-methane volatile organic compounds
NO2: Nitrogen dioxide
NPISH: Non-profit institutions serving households
NSO: National Statistical Office
NUTS: Nomenclature of Territorial Units for Statistics
O3: Ozone
OCGT: Open Cycle Gas Turbine
OECD: Organisation for Economic Co-operation and Development
PACE: Pollution Abatement Costs and Expenditures Survey
PAH: Polycyclic aromatic hydrocarbon
PBL: Planbureau voor de Leefomgeving (Netherlands Environmental Assessment Agency)
PFCs: Perfluorocarbons
PM: Particulate matter
POPs: Persistent organic pollutants
PPP: Purchasing Power Parity
R&D: Research and development
RMC: Raw Material Consumption
RREUSE: Reuse and Recycling EU Social Enterprises network
SEEA: System of Environmental-Economic Accounting
SGI: Sustainable Governance Index
SNA: System of National Accounts
SO2: Sulphur dioxide
SOER 2010: The European environment – state and outlook 2010
STEEP: Social, technological, environmental, economic, political
STIR: Sustainability Transitions and Innovation Review
SUV: Sport-utility Vehicle
TH: Total hardness
TPES: Total Primary Energy Supply
UCL: University College London

UN: United Nations
UNEP: United Nations Environment Programme
UNFCCC: United Nations Framework Convention on Climate Change
UNU-MERIT: United Nations University - Maastricht Economic and Social Research Institute on Innovation and Technology
USPC: United States Patent Classification
UU: Utrecht University
VOC: Volatile organic compounds
WBCSD: World Business Council For Sustainable Development
WEF: World Economic Forum
WIPO: World Intellectual Property Organisation
WTO: World Trade Organisation

SUGGESTED CITATION

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The world is facing serious environmental challenges. Addressing them is a matter of urgency.

Eco-innovation is a means of moving towards a greener economy, making the world a better place, but the development of effective policy to make this happen requires robust and internationally comparable statistical indicators to guide policy development and to monitor and evaluate policies that have been implemented. For this to happen there must be guidelines for the statistical measurement of eco-innovation.

The *Maastricht Manual on Measuring Eco-Innovation for a Green Economy* is a significant step towards having official statistics on eco-innovation that can support research on eco-innovation. The outcome of this is 'policy learning' leading to better policy for better green outcomes.

The Manual challenges the measurement community, statistical offices and research institutes, to add statistical measurements of eco-innovations and their outcomes to their official statistics. Official statistics are important because they are credible and support informed public discourse on environmental priorities and the allocation of resources to implementing more effective green policies.

The Manual is more than a statistical guide. In addition to setting standards for data collection and interpretation it educates the reader, encourages the use of the data and indicators and helps to build communities of practice that are trying to contribute to the green economy.

The Manual is not an end but a beginning. This is illustrated by the OECD/*Eurostat Oslo Manual* for the collecting, reporting and using data on innovation. The OECD Working Party of National Experts on Science and Technology Indicators (NESTI) spent fifteen years before its collective knowledge of innovation was first codified in 1992. Once the manual existed, statisticians, researchers, policy analysts, and policy makers learned from collecting and using statistics on innovation and used that knowledge to revise the manual which is now in its fourth edition.

Eco-innovation can happen everywhere, in the public sector, the government sector, the business sector, the private non-profit sector and the household sector. In the past, the interest has been focused on the business sector, but now the *Oslo Manual* provides a general definition of innovation applicable in all sectors. This applies as well to eco-innovation and provides an opportunity to probe eco-innovation everywhere, raising more policy questions, leading to a greener economy.

The Manual is about eco-innovation, a subset of innovation, and it aligns with the *Oslo Manual* which is an international standard. This connects the eco-innovation community to the broader innovation community. What is needed now is an institutional home for ongoing discussion of eco-innovation leading to collective learning and revision of the Maastricht Manual. It is an important subject and the future of the Manual is an urgent issue.

The *Maastricht Manual on Measuring Eco-Innovation for a Green Economy* is a new tool for studying eco-innovation, for learning about this activity, and supporting policy that can lead to a greener economy. The sooner it is brought into use, the better for humanity.

Fred Gault

UNU-MERIT

Tshwane University of Technology / Institute for Economic Research on Innovation, Pretoria, South Africa.

Visiting Professor, South African Research Chair in Industrial Development, University of Johannesburg, South Africa.

Foreword

We are at acrossroads. A hot, dry crossroads.

Economic development and growth over the past 50 years has lifted hundreds of millions of people out of poverty and created unparalleled levels of prosperity. This economic growth, however, has come at a steep environmental and social price.

Our use of natural resources has more than tripled since 1970 and continues to grow largely unabated, threatening the very ecosystems on which our lives and economies depend. Meanwhile, close to 600 million people live in extreme poverty; 2.3 billion lack access to basic sanitation services; 2.1 billion lack access to safe drinking water at home; and around 1.2 billion people have little or no access to electricity.

Almost daily, we are confronted with headlines about record-breaking temperatures, life-threatening weather events, conflicts over diminishing resources, growing inequality, pollution-related public health crises, and the unprecedented decline of plant and animal species. The warnings have been clear and loud for years, and we are now seeing the consequences of inaction to safeguard our natural environment.

One of the most important challenges we face is how to reconcile the imperative to foster economic development with the existential need for stronger environmental stewardship.

At Rio+20, governments from around the world identified a green economy as a powerful pathway for providing economic opportunities for all while preserving the natural assets on which our well-being relies. Building on this momentum, UN Member States unanimously adopted a global agenda to end poverty by 2030, representing an historic opportunity to put sustainability at the heart of economic policies and practices. At the core of this agenda are a set of 17 Sustainable Development Goals (SDGs) for eliminating poverty, protecting the environment, and providing for social inclusion. Our job now is to take these global aspirations and turn to the hard work of creating change on-the-ground.

Innovation across a wide range of areas will be key to delivering on the commitments outlined in the SDGs, whether these innovations reflect new ideas, processes, or technologies.

The Maastricht Manual on Measuring Eco-Innovation for a Green Economy represents a critical step towards effectively harnessing the eco-innovations we need at this critical juncture. The manual reflects a culmination of years of work by many of the world's leading innovation experts and institutions and builds on previous efforts and studies going back more than a decade.

As the head of the Green Growth Knowledge Partnership, I've had the pleasure to closely follow the development of cutting-edge studies and analytical tools produced in support of a green economic transition over many years. The Maastricht Manual fills a critical knowledge gap by providing a comprehensive overview of how we measure the progress and performance of eco-innovation.

Importantly, the manual provides clear and concise recommendations for creating a global, standardized measurement system for eco-innovation. These recommendations are rooted in practicality and are backed up by extensive research and lucid analysis from the authors. They place eco-innovation in a policy and socio-economic context so that its ultimate impact on sustainable development goals and targets can be measured and managed.

The Maastricht Manual should be considered as an indispensable blueprint for catalyzing resources and action towards the development of a global eco-innovation measurement standard. Shifting the focus to eco-innovation is a key stepin the transformation of the global economy to put humanity on a more sustainable path.

Benjamin Simmons
Head of Secretariat
Green Growth Knowledge Partnership

i. Preamble

Purpose of the Manual

The purpose of this manual is to offer guidance on the measurement of eco-innovation in order to provide high quality data for research and policies to support the green economy.

Who this Manual is for

The guidelines for data collection are designed for researchers, policy makers and statisticians from National Statistical Offices (NSOs) and other organisations responsible for collecting and producing indicators. Policy makers can use the manual to identify the types of data that are required to inform policy and consequently to demand and fund the collection of relevant, high quality indicators on eco-innovation.

Box i.1 Reading guidance

For business people, sections 2.2-2.7 on eco-innovation types are of greatest relevance. In particular, it is important to read section 2.7 on business model innovation for sustainability.

Policy makers will particularly benefit from sections 1.3.5 and 1.3.6 on rebound effects and why improvements in relative efficiency are insufficient for achieving a green economy. Policy makers will also benefit from Chapter 3 on drivers and barriers, Chapter 4 on policy capabilities and Chapter 9 on system innovations.

Statisticians from national statistical offices and other agencies should read section 1.5 on eco-innovation as a new concept and the history of its measurement, section 1.3.8 on systems aspects of eco-innovation, Chapter 2 on definitions, Chapter 9 on measurement methodologies and the conclusions in Chapter 10.

Researchers should read Chapters 5 and 6 on the limitations of measures of eco-innovation and Chapter 4 on policy evaluation. Other useful sections include 1.3.6 and 1.3.7 on systems aspects and the dynamic nature of eco-innovation as an important issue for measurement and analysis.

Why this Manual is needed

Measuring eco-innovation is important for:
- Improving data collection by national statistical offices and researchers.
- Helping policy makers to understand, analyse, and benchmark trends in eco-innovation activity.
- Assisting policy makers to design better policies to support eco-innovation.
- Helping researchers to study the dynamics of specific eco-innovations and their macro-economic, macro-ecological and social impacts.

The focus of this manual is on data collection at the country level because the relevance of different types of eco-innovation can vary by country and because policy decisions are usually implemented nationally. As an example, reducing water consumption is an important environmental and economic issue in countries with water scarcity, but is less important in countries with abundant fresh water resources. However, this manual's guidelines for data collection can also be applied to measurement at the regional and local (municipal) levels. For instance, pollution from road vehicles is particularly important in urban areas, especially for people living near heavily-trafficked roads. Furthermore, the consequences for human well-being depend on the natural ability of eco-systems (complexes of geology and biotic communities) to absorb and neutralise these pressures. These eco-systems vary in scale from local, regional, supranational to global areas.

The Manual

This manual contains ten chapters: Chapter 1, Introduction; Chapter 2, Definitions and types of Eco-innovation; Chapter 3, Eco-innovation drivers and barriers; Chapter 4, Policies for eco-innovation and green economy; Chapter 5, Inputs to eco-innovation and green economy; Chapter 6, Output and outcome indicators for Eco-innovation; Chapter 7, Green Economy and Growth; Chapter 8, Methodologies for Data Collection; Chapter 9, System innovation and eco-innovation measurement; Chapter 10, Conclusions.

1

INTRODUCTION

René Kemp and Anthony Arundel

This chapter gives a short overview of the changing focus of eco-innovation (towards preventive and systemic solutions), describes the genesis and measurement of eco-innovation, and delineates eleven important issues for understanding.

The purpose of this introduction is to describe the social, environmental and economic context for eco-innovation. Eco-innovation involves production, distribution, consumption and recycling of goods and services in a way that is less harmful than existing practices (see **Chapter 2** for a full definition).

Eco-innovation is necessary in order to achieve a green economy, defined by the United Nations Environment Programme (UNEP) as *"an economy where growth in income and employment is driven by investments that reduce carbon emissions and pollution, enhance energy and resource efficiency, and prevent the loss of biodiversity and ecosystem services"*. Ecosystem services supply the basics of life such as water, air and food and are consequently essential for humanity (SEEA, 2012). The concept of a green economy rests on long-term economic and environmental sustainability.

All sectors of an economy contribute to environmental degradation through production, consumption and waste and consequently eco-innovation is relevant to all sectors. The System of National Accounts (SNA) identifies five national sectors (see **Chapter 8**), but for the purposes of this manual these can be reduced to four: private businesses, government, non-profit institutes serving households (NPISHs), and households.

1.1. From environmental technology to eco-innovation and green system innovation

Until recently, eco-innovation was dominated by a focus on the adoption of environmental technology in the business sector in order to meet regulations. One benefit noticed by businesses was that regulations to prevent pollution could also reduce costs by improving resource efficiency. Over time, business strategy also adapted to regulation and customer demand for greener goods and services by modifying the design of products to reduce their environmental impacts during use. Many businesses shifted towards a pro-active environmental strategy, with important roles for product stewardship and pollution prevention. Resource efficiency was also improved through reuse and better management of waste. Bans on landfilling and end-of-life regulations created incentives for businesses to minimize waste and to find markets for their waste. Policy to encourage eco-innovation was directed at the actors (such as through R&D subsidies) or at framework conditions (regulation, anti-trust, finance rules, intellectual property rights, etc.).

Recognition that sustainability requires the active involvement of all sectors led to more systemic approaches to environmental issues, such as the concepts of a green economy and a circular economy. The latter involves "cradle to cradle" approaches whereby all waste becomes an input into other economic activities. The European Commission adopted an ambitious Circular Economy Package, with legislative proposals on waste and a detailed action plan with measures covering the material cycle of production, consumption and waste management and the market for secondary raw materials (EEA, 2016, p. 7). The circular economy replaces a linear model of take, make and dispose.

The circular economy draws on ideas of industrial ecology and industrial metabolism formulated in the 1970s and 1980s, but there are different interpretations of the term (see Box 1.1 for a discussion of different understandings of a concept). The government in China adopted the circular economy as a key aspect of environmental policy, but the Chinese and European perspectives differ. Europe's conception of the circular economy focuses on opportunities for businesses to minimize waste and to turn waste into a resource. In contrast, the Chinese perspective is very broad and incorporates pollution, industrial ecoparks, and ecological civilization (Weng et al., 2015) along with waste and resource concerns (McDowall et al., 2017).

The circular economy is a potential example of a green system innovation, based on technological and non-technological changes that allow societal functions (such as mobility or nutrition) to be met in a fundamentally different way. The circular economy is not yet an innovation because only parts of it exist, whereas all parts must function for it to be fully implemented.

System innovations usually require new organisational capabilities and changes to business models, infrastructure, institutions, and cultural perspectives. Due to this complexity, system innovations cannot be designed and implemented from the top down because no single decision maker has sufficient knowledge, financial means, and a social license to undertake it. Consequently, system innovations evolve slowly out of short-term possibilities used by innovation actors and changing circumstances. Complex systems innovation can require transition management to steer the processes of co-evolution and ensure feedback into societal decision processes and investment decisions, with learning, maintaining variety (through portfolio management) and institutional change as important policy aims (Kemp et al., 2007; Loorbach, 2010).

Eco-innovation comprises a wide range of activities, including organisational changes and green technology. Some of the activities are part of wider system innovations such as the circular economy discussed above, the bio-economy, and the low-carbon economy.

The bio-economy is about the use of bio-based substitutes from forestry and agriculture to replace non-renewables. The low-carbon economy is about reducing CO_2 and other greenhouse gas (GHG) emissions through renewable zero emission energy, low-carbon products, energy-efficient buildings, and carbon capture. To summarize, the circular economy focuses on how resources are used, the bio-economy is about what resources are used (D'Amato et al., 2017), while the low carbon economy is about the near total elimination of anthropogenic CO2 and other GHG emissions. The concept of a green economy covers all of these concepts: resource-efficiency, circularity, the use of renewables, and the elimination of GHG emissions in all sectors of an economy and in all economic activities (production, distribution, consumption and waste recycling). Importantly, the green economy also includes social inclusiveness and social equity, which are largely absent from the other concepts (see D'Amato et al., 2017).

Box 1.1. Different understandings of a concept

People often have different understandings of a concept, in part due to cultural and other differences across countries.

This holds especially true for general concepts such as the bio-economy or the circular economy. From a statistical perspective, it is important to define a concept as clearly as possible and ensure that all respondents to a data collection exercise understand the concept in the same way.

Concepts also evolve over time. Before 2012, the circular economy was associated with reduce, reuse, recycle. After 2012, it is viewed in terms of an alternative economic system (Kirchherr et al., 2017).

Lay people's understanding will differ from those of scholars, practitioners and policy makers, but even scholars can have different understandings. A bibliometric analysis identified 114 different definitions of the circular economy in scholarly articles (Kirchherr et al., 2017).

The concept of the green economy is also relevant to many, but not all, of the United Nation's Sustainable Development Goals (SDGs). The SDGs for Quality Education and Gender Equality are not part of the Green Economy concept, although they are indirectly supported by the Green Economy goals of inclusiveness and social equity.

The negative side-effects of a large part of economic growth, gave rise to advocacy for degrowth advocates the end of economic growth as a social objective (Mastini, 2017). The goal is to reduce pollution, psychological costs related to work stress and consumerism, and over exploitation of natural resources[1]. Degrowth may pertain to GDP growth, consumption growth and work-time growth (van den Bergh, 2010). The concept of degrowth is not included in the green, circular bio-, and low carbon concepts of an economy, all of which assume that green growth (economic growth that achieves the goal of environmental sustainability) is possible and desirable.

The recognition of oceans as a source of resources and a place for economic activities, including renewable energy, led to the concept of Blue Economy[2]. The use of green or non-polluting technologies is highly desirable and relevant to Blue Economy industries including fishing, shipping, ports, shipbuilding and repairs, renewable energy, marine biotechnology, ocean mining, extraction and commercialisation of marine resources, ecosystem services, and coastal protection. There is a need for deeper analysis into the green aspects of the Blue Economy and the eco-innovation element of Blue economy innovation activities. Offshore wind qualifies as an eco-innovation on account of its carbon emissions (which are higher than those of onshore wind (Bonou et al., 2016) but below those of coal-based power).

Figure 1.1 maps the different "economies" and the position of environmental technologies, green products and resource efficiency, together with the location of de-growth. Eco-innovations need to move further to the right in order to contribute to a green economy and the SDGs. Degrowth is not an activity as such but an ideology. It helps to reduce environmental burdens but negative economic growth conflicts with SDG 8 which calls for "at least 7% GDP growth per annum in the least developed countries" and "*higher levels of economic productivity"* across the board[3].

Eco-innovations that address sustainability and ethical values are known as sustainable innovations. Charter and Clark (2007) define sustainable innovation as a *"process where sustainability considerations (environmental, social, financial) are integrated into company systems from idea generation through to research and development (R&D) and commercialisation. This applies to products, services and technologies, as well as new business and organisation models".* A better term is sustainability-oriented innovations.

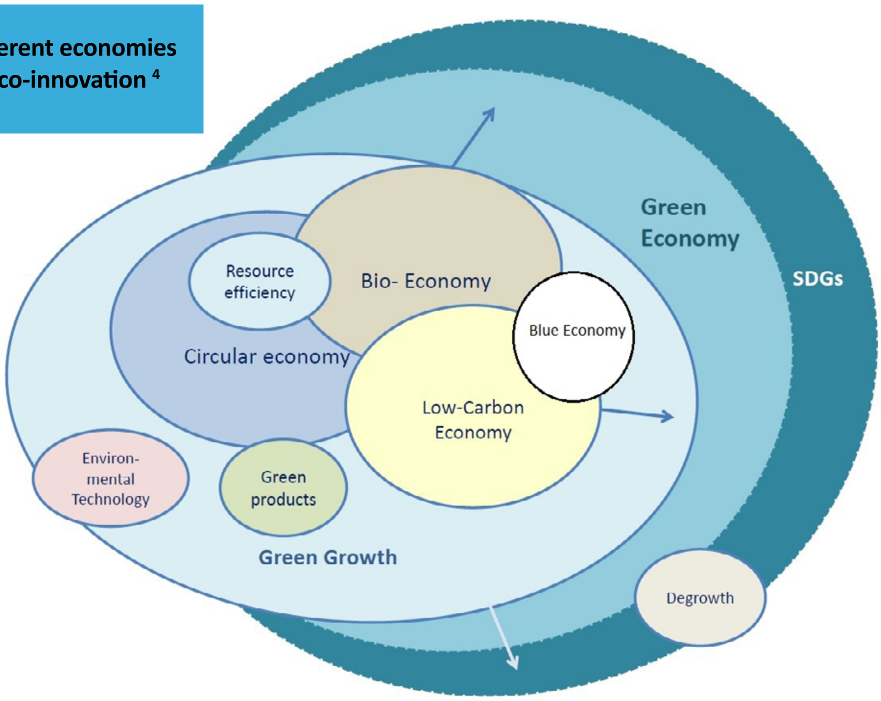
The social dimension of sustainability requires better clarity and consensus. Increasingly, measurable social sustainability factors such as employment and poverty alleviation are complemented or replaced by constructs that are more difficult to measure, as happiness and a sense of place (Colantonio and Dixon, 2011), equity and democracy (Sachs and Warner, 1999), or social justice, human dignity and participation (Griessler and Littig, 2005). In Vancouver, municipal authorities enacted a social assessment framework based on the principles of equity, inclusion, adaptability and security (Colantonio and Dixon, 2011, p. 32-34).

1.2. The genesis and measurement of eco-innovation

The term 'eco-innovation' entered the public debate in the second half of the 1990s on the wave of the sustainable development debates preceding and following the Rio Earth Summit in 1992 (Fussler and James, 1996; Rennings, 1998; Rennings, 2000). The debate on eco-innovation picked up after the Rio Summit and has attracted increasing policy attention over the last decade, notably in Europe and the OECD. The debate was reinforced by the explicit recognition of the role of innovation in meeting sustainable development goals (UN, 2015).

The novelty of the concept of eco-innovation was a dual emphasis on the business and environmental features of eco-innovations for products and processes, as well as positioning eco-innovation as a major driver of socio-technical shifts (Fussler and James, 1996). A win-win narrative for businesses and the environment remained a key part of eco-innovation debates, which in the 2000s focused on businesses and other actors in research and innovation systems. More recently, the debate moved to the role of sys-

Figure 1.1. Different economies and types of eco-innovation [4]



tem eco-innovations as part of wider societal transitions to green socio-technical regimes (Geels, 2005; Kemp, 2011).

Eco-innovation contributes to a political agenda in support of the green economy and green growth. The OECD defines green growth as *"fostering economic growth and development, while ensuring that natural assets continue to provide the resources and environmental services on which our well-being relies"* (OECD, 2011).

Eco-innovation can 'green' existing sectors through the replacement of outdated technologies by new and more efficient ones and is the essential component of growth in the emerging "cleantech" sectors. The availability of affordable eco-innovation makes it easier for regulators to introduce environmental regulations. Environmental policy thus benefits from an active innovation policy for eco-innovation (Janicke and Lindemann, 2010). In developing countries, eco-innovations can provide social benefits through improved access to energy, water and sanitation.

Many definitions of eco-innovation have been proposed since the mid-1990s (see Box 1.2 below). The definitions are implicitly optimistic by not recognising trade-offs between improvements to various environmental dimensions (Miedzinski et al., 2017). Economic and social impacts are either mentioned in general terms or not mentioned at all.

Most definitions do not include an explicit baseline, target or benchmark that must be exceeded in order to qualify as eco-innovation. An exception is the MEI definition (Kemp and Pearson, 2007), which uses "relevant existing alternatives" as the baseline for determining whether an innovation is an eco-innovation.

The requirement of economic gains in some definitions implies (Huppes et al., 2008) that cost-increasing environmental protection measures adopted in response to regulation do not qualify as eco-innovation.

The prevalence of different types of eco-innovations was measured in Europe by the 2008 and 2014 and Community Innovation Surveys (CIS). The 2014 survey asked respondents if their business had one or more innovations between 2012 and 2014 that provided environmental benefits during its use within the enterprise or during its consumption or use by

Box 1.2. Selected definitions of eco-innovation[5]

Claude Fussler and Peter James (1996) were the first to use the notion of eco-innovation as "innovation for sustainability" and linked it to the WBCSD's definition of eco-efficiency: "the delivery of competitively priced goods and services that satisfy human needs and bring quality of life while progressively reducing ecological impacts and resource intensity, through the life cycle, to a level at least in line with the earth's estimated carrier capacity."

The EU FP6 MEI project (Kemp and Pearson, 2007) defined "eco-innovation as the production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organisation (developing or adopting it) and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives."

The EU FP6 ECODRIVE project (Huppes et al., 2008) defined eco-innovation as "a change in economic activities that improves both the economic performance and the environmental performance of society."

The EU CIP-funded Eco-Innovation Observatory (EIO, 2010; EIO, 2012) defined eco-innovation as "the introduction of any new or significantly improved product (good or service), process, organisational change or marketing solution that reduces the use of natural resources (including materials, energy, water and land) and decreases the release of harmful substances across the whole life-cycle."

UNEP (2014a, 2014b) defined eco-innovation as "the development and application of a business model, shaped by a new business strategy, which incorporates sustainability throughout all business operations based on life cycle thinking and in cooperation with partners across the value chain."

UNIDO (2015) defined eco-innovation as "products that reduce their overall life-cycle environmental impacts by favouring reparability, disassembly, recyclability and recoverability."

the end user. Descriptions of specific types of benefits were provided, including reductions in material and energy use per unit of output and in total CO2 emissions. Table A1.2 (in the Annex of chapter 1) includes the eco-innovation questions in the similar CIS 2008 survey.
Three dedicated indicator systems have been created in the last seven years to measure eco-innovation inputs, activities and outcomes on a regular basis: the Eco-innovation Observatory (EIO) established in 2010 by the European Commission (EC) for the 28 European Union (EU) countries; the Asia-Europe Meeting (ASEM) Eco-Innovation Index (ASEI), established by the ASEM SME Eco-innovation Center (ASEIC) for small and medium sized enterprises (SMEs) in South Korea) for 50 countries in Europe and Asia; and the Global Cleantech Innovation Index (GCII) established by the Cleantech Group for 40 countries including non-European countries and non-Asian Countries such as Argentina, Australia, Brazil, Canada and USA. The ASEM Eco-Innovation Index uses questions from the CIS and questions from the GCII, in addition to data from other sources Table A1.3- A1.5 (in the annex of chapter 1) provide details for the EIO, ASEI, and GCII indicator systems).

Eco-innovation has also been measured in sectoral and specialised studies, such as the study by Bocken et al. (2014) on the front-end of eco-innovation by Dutch SMEs and the IMPRESS study of eco-innovation in 5 European countries (Rennings and Zwick, 2003).

Earlier guidelines for measuring eco-innovation were developed in the Measuring Eco-Innovation (MEI) project funded by the European Commission (Kemp and Pearson, 2008; Arundel et al., 2009). Relevant experience with measurement was also obtained from the Environmental Macro Indicators of Innovation (EMInInn) project about the micro-macro link between eco-innovation performance and macro environmental data (McDowall, Diaz-Lopez, Seiffert, 2015).

This manual draws on the above studies, research from environmental science and earlier deliverables of green.eu (Miedzinski 2017, Arundel et al., 2017).

1.3. Important issues for understanding

This section offers important background information about eco-innovation, in terms of eleven issues for understanding.

1.3.1. About innovation

Innovation involves new ways of doing things, but it does not need to be new to the world. According to the fourth edition of the Oslo Manual (OECD / Eurostat, 2018), an innovation is a new or improved product or process (or combination thereof) that differs significantly from the unit's previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process). Innovation includes both the first-time development of new or improved products or processes and the adoption of others' innovations. Innovation can also rest on ideas, processes or technologies that have been acquired from other entities (businesses, governments, households, etc.).

An innovation must be used by the innovative unit or made available to potential users. This separates an innovation from an invention. Innovations can be based on applied R&D, combining existing knowledge in new ways, or, as noted above, by imitating, adopting, or modifying what already exits. R&D is not necessary and is uncommon for many service and organisational innovations. Approximately half of European businesses and two-thirds of Australian businesses innovate without performing R&D. Innovation involves learning and the alignment of various activities: research, production, sourcing, distribution and marketing. Many actors can be involved: managers, marketers, technicians, graphic artists, researchers, front-line staff, designers, and users. Users are an important source of information. According to the Community Innovation Survey (CIS), customers are the most important source of information for product innovations by businesses.

The novelty of an innovation can increase over time from complementary innovations. Incremental innovations are an important source of efficiency, usability, and other types of improvements. Radical innovation can open up new avenues for incremental innovation and subsequent radical innovations[6]. System innovation involves major changes in market organization, new companies, mergers, and market exits. They are often held back by regulation and the power of incumbents. Market liberalisation, for instance, was needed for the mobile phone revolution.

Innovation involves complex interactions between an entity and its environment. Innovations are often developed through collaboration or "quasi-cooperative relationships which shape learning and technology creation". The environment involves broader factors that can shape the behaviour of governments, households or firms: the social and cultural contexts; the institutional and organizational framework; infrastructures; and "the processes which create and distribute scientific knowledge" (Smith, 2000, p. 73). Policy can be directed at the actors (subsidies) or at the framework conditions (regulation, etc.).[7]

Innovation is driven by opportunities that are exploited by willing and capable actors. Firms, governments and households are typically restricted in what they can do because of gaps in their knowledge base or a lack of complementary technologies or infrastructure. Firms and governments can be restricted by longstanding mindsets.

Once a stable techno-institutional system is in place, it acquires a stability and resistance to disruptive change. Unruh (2000) argues that fossil-fuel based energy systems have undergone a process of co-evolution, leading to the current dominance of carbon-based technologies and the accumulated knowledge, capital outlays, infrastructure, available skills, production routines, social norms, regulations and lifestyles which support “carbon lock-in”. Similar arguments apply to systems with lower environmental impacts which leads to the conclusion that eco-innovation requires not only technological change, but also institutional enablers. The measurement of eco-innovation consequently needs to cover both technological and institutional factors.

1.3.2. Eco-innovation and the SDGs

Policies for the sustainable development goals (SDGs) need to be more concerned with eco-innovation than currently is the case (Andersen, 2016). Conversely, the SDG framework could be a core target of eco-innovation for a green economy. Eco-innovation can contributes to at least nine of the SDGs on a global level if diffused and adopted effectively; industry, innovation and infrastructure (9), responsible consumption and production (12), good health and well-being (3), affordable and clean energy (7), sustainable cities and communities (11), climate action across the world (13), life below water (14), life on land (15), and partnerships for the goals (17). Moreover, eco-innovation can have a significant impact on additional goals in low- and middle-income countries: clean water and sanitation (6), zero hunger (2), and no poverty (1). Under some conditions it could contribute to ‘decent work and economic growth (8).

Of specific interest to developing countries are grass root innovations and frugal innovations. Grass root innovators are community based, co-created innovations, founded upon grassroots knowledge, values, and institutions, offering a good fit to the local sustainability needs (Gupta, 2010). That said, by their very nature, they are dispersed and often below the radar of policy makers and hence difficult to standardize and diffuse, in both developed and developing countries (Gill and Smith, 2007). Frugal innovations aim to provide “affordable, no-frills, good (enough) quality products and services for resource-constrained consumers” (Hyvärinen et al., 2016). Fuel-efficient biomass cooking stoves, small-scale PV systems and pico-grids are examples of frugal energy technologies (Numminen and Lund, 2016). However, their diffusion has been limited due to diverse problems even when made affordable. On the supply side, often the challenges are: varying and unknown quality, short life, discontinuities in the supply chain and the lack of maintenance and repair agencies; and on the demand side, competing non-green aspirational products and services as well as lack of fit to local capabilities, skills and norms that can thwart adoption (Ramani et al., 2017), Thus, their success as green technologies is not guaranteed.
To do so, Policies for the sustainable development goals (SDGs) need to be more concerned with eco-innovation than currently is the case (Andersen, 2016). Conversely, the SDG framework could be a core target of eco-innovation for a green economy.

1.3.3. Stylized facts about eco-innovation

As for all types of innovation, eco-innovation requires skills and capabilities and a positive motivation for the innovator to devote effort and money to an innovation project. Innovators can be motivated by various factors: market-based pressures for cost-reduction, commercialisation prospects (demand from customers), and pressures from regulation, NGOs, clients or affiliated businesses. Decisions to eco-innovate benefit from the presence of internal capabilities, a green ethos, positive managerial expectations for potential gains compared to costs, and low expectations for risks. Such aspects may constitute necessary conditions.

Stylized facts about eco-innovation include:

- Eco-innovation requires identification of opportunity, capability and positive expectations about economic gains and reduced environmental impacts. Each of these is a necessary element.

- Pro-environmental behaviour depends on managerial responsiveness to regulations and environmental groups, effort to identify win-win solutions, and the criteria used to evaluate the benefits of investment in environmental innovations (Gunningham et al., 2003).

- Eco-innovation is influenced by framework conditions such as regulations, informal institutions and current market prices.

- The anticipation of regulation, such as a future product or substance ban, can drive eco-innovation.

- Incremental innovations with environmental benefits are less driven by regulation and less likely to be the result of dedicated innovation projects.

- Weak regulations foster the diffusion of existing technologies and incremental innovations.

- Reasons for a problem sector not to eco-innovate (more) include the absence of an economic incentive to go beyond standards required by law; poor innovation capabilities of the problem sector; and the problem sector's preference for non-disruptive technology responses (Kemp and Pontoglio, 2011).

- Businesses with positive experiences with eco-innovation are more likely to eco-innovate than those without positive experiences (Horbach, 2008).

1.3.4. Eco-innovation impacts are location-specific and co-produced

It is common practice to label certain technologies as eco-innovations. Examples are renewable energy technologies, water treatment technologies and non-motorised forms of transport. However, a product or process is an eco-innovation **in a relative sense,** in comparison to an alternative. An electric bike is an eco-innovation when it substitutes for car trips, but not when it substitutes for normal bike trips or walking. Eco-innovations can have negative environmental impacts, depending on the state of production and how they are used.

The way in which emissions have impacts are complex and **location-specific.** In contrast to what is commonly assumed, environmental and economic benefits are not inherent to specific technologies, but **co-produced by the behaviours of all actors in an economy and boundary conditions.** Products that are repaired and re-used will have lower environmental impacts than products that are not. If the energy system relies heavily on fossil fuels, energy consumption in the transport, manufacture and recycling of a product eco-innovation will produce greenhouse gases, NOx and particulate emissions. These need to be considered when evaluating the environmental impacts of a presumed product eco-innovation. Carbon emissions from off-shore wind are higher than those from onshore wind as a result of the extra infrastructure and fuel requirements (Bonou et al., 2016).

1.3.5. Environmental rebound effects

Eco-innovations can create environmental rebound effects in response to cost savings or increases (Font Vivanco et al., 2014, 2016). An Environmental Rebound Effects analysis tracks the environmental pressures as a result of demand changes and other second round effects of money saved due to the adoption of an eco-innovation. Font Vivanco et al. (2014) estimated that the 35% lower transport costs per kilometre for diesel cars, compared to petrol vehicles, "liberated on average 1200 euro per user a year, money which was spent on goods with CO_2 emissions". The environmental rebound effect was so strong as to cause an absolute increase in emissions. Conversely, the high price for electric vehicles creates a negative rebound effect (Font Vivanco et al., 2015), but the high price discourages adoption.

The presence of rebound effects underscores the importance of reducing environmental impacts in all sectors. Possible ways to achieve this are carbon prices, resource taxes, and anti-landfill policies that promote recycling. Global carbon pricing could curtail carbon emission leakages between countries (Baranzini et al., 2017). The rebound effect also draws attention to the environmental performance of higher levels of consumption, such as higher levels of car mobility and increases in the consumption of meat in emerging economies.

In addition to the rebound effects for low-cost eco-innovations, other problems are associated with the use of green technologies. Examples of negative side-effects are visual intrusion and noise from wind turbines, health and safety hazards associated with unprotected forms of recycling, and the danger of carbon leaks in the case of carbon capture and sequestering (van den Bergh, 2012).

In general, any major change will have effects in other parts of a system. Such effects cannot be fully predicted because they involve behavioural reactions. Policy interventions will often have unanticipated effects.

1.3.6. Relative efficiency versus absolute efficiency

Resource intensity indicators can be misleading in respect to goals to achieve an absolute reduction in environmental pressures. For example, the energy and carbon intensity of the Group of Twenty (G20) economies declined since 1990 by 18% and 27% respectively, but energy related CO_2 emissions grew by 56% (Climate Transparency, 2016). In addition, measures based on resource and emissions productivity can hide upstream impacts due to imports (Wiedmann et al., 2015). Calculations on material intensity showed that “with every 10% increase in gross domestic product, the average national material footprint (MF) increases by 6%”. This indicates that the widespread use in policy of relative indicators for resource efficiency is seriously misleading. Instead, it is important to implement “consumption based accounting for natural resource use” (Wiedmann et al., 2015, p. 6271) as well as absolute measures of resource use.

1.3.7. Innovations are dynamic and interrelated

Eco-innovations are **dynamic,** such that their characteristics change over time. The price-performance ratio tends to improve over time thanks to dynamic scale and learning economies (Kemp, 1994) and price competition. Progress rates and learning curves are important issues for measurement.

Behavioural change is usually distinguished from technical change, but technology can facilitate behavioural change. Smart meters can assist in behavioural change by making households more aware of their energy consumption and by providing continuous feedback that can be tailored to each household’s individual requirements[8]. Evidence from the United States and Norway on smart meter systems finds that households who receive feedback on their energy consumption reduce energy use by 10%-15% (Darby, 2006)[9].

Eco-innovations are interrelated. For example, a product change can require a process change and draw on eco-design tools as a design innovation. Furthermore, the introduction of environmental management systems helps companies to identify and implement measures for achieving environmental improvements.

Eco-innovations in a sector can compete with one another. Solar energy competes with wind power. When practiced on a large scale, recycling can hinder repair, remanufacturing and re-use. Product manufacturers can prefer recycling if product repair and re-use cause a decline in product sales.

1.3.8. Systems aspects of innovation chains

A common scheme for understanding the environment-economy relationship is the Driving Forces - Pressures - States - Impacts - Responses (DPSIR) model (Figure 1.2). According to the DPSIR system analysis view, social and economic developments drive changes that exert pressure on eco-systems in the form of pollution and waste. Depending on the natural assimilation capacity of eco-systems, pressure can lead to changes in the state of the environment that cause impacts on human health, ecosystem functions, materials (such as historic buildings), and the economy. These dynamics are intermediated by responses in the form of regulation and eco-innovation that directly or indirectly affect earlier parts of the system (Stanners et al., 2007).

Figure 1.3 illustrates the DPSIR model for eco-innovation and rebound effects. The graph includes a policy making model of how environmental degradation leads to eco-policies via media articles on environmental problems, capable agencies for environmental protection, international treaties, and eco-innovation organisations lobbying for pro-environment policies. In order to analyse the influence of actors in the eco-innovation sector on policies for eco-innovation, and the role of capable agencies for making effective policies in a world of asymmetric information and stakeholder influence, we need to measure stakeholder influence, policy capabilities, policy mixes and policy effects. These are discussed in chapter 4.

A weakness of the DPSIR framework is that stakeholder interests, politics and policy intelligence are backgrounded (together with rebound effects). In econometric analysis policy is an exogenous variable, whereas in practice it is an outcome of policy making processes[10]. Figure 1.3 depicts an important loop: from eco-innovation policy to (material) eco-innovation responses. This also occurs in reverse, such as when eco-innovation suppliers influence environmental policy via sector organisations. National environmental policies are also affected by international treaties, competent agencies and the general discourse about green growth and public environmental concerns.

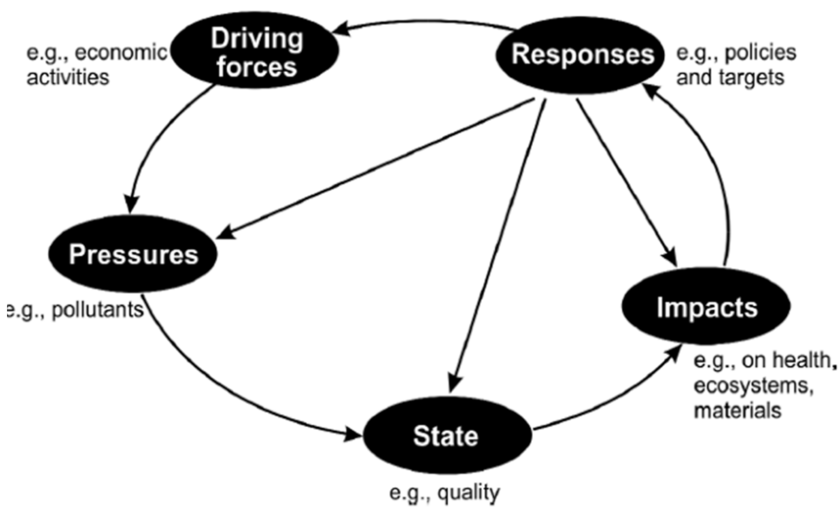
1.3.9. Environmental life cycle assessment

Environmental Life Cycle Assessment (E-LCA) evaluates the environmental impacts from producing, transporting, using, recycling and discarding a product or service. Producing includes all stages of the value chain, including the extraction of resources and the production of intermediary products and equipment to produce the product.

An E-LCA requires data on the material inputs and outputs of a unit process, including waste streams that are required for every process in the life-cycle of the product. Databases are available that contain information on a number of processes common to many products (e.g. a country's electricity production). However, bespoke processes require primary data collection, and thus E-LCA can often take a great deal of time and effort. This can result in the use of simplifying assumptions and an analysis that ignores processes for which there are limited data. A poorly formulated E-LCA can thus produce erroneous conclusions on a product's environmental impacts (Lenzen, 2000; Suh, 2004).

Hybrid methods of E-LCA can correct for some data collection issues by combining the use of economic input/output tables with traditional process-based

Figure 1.2. The DPSIR framework



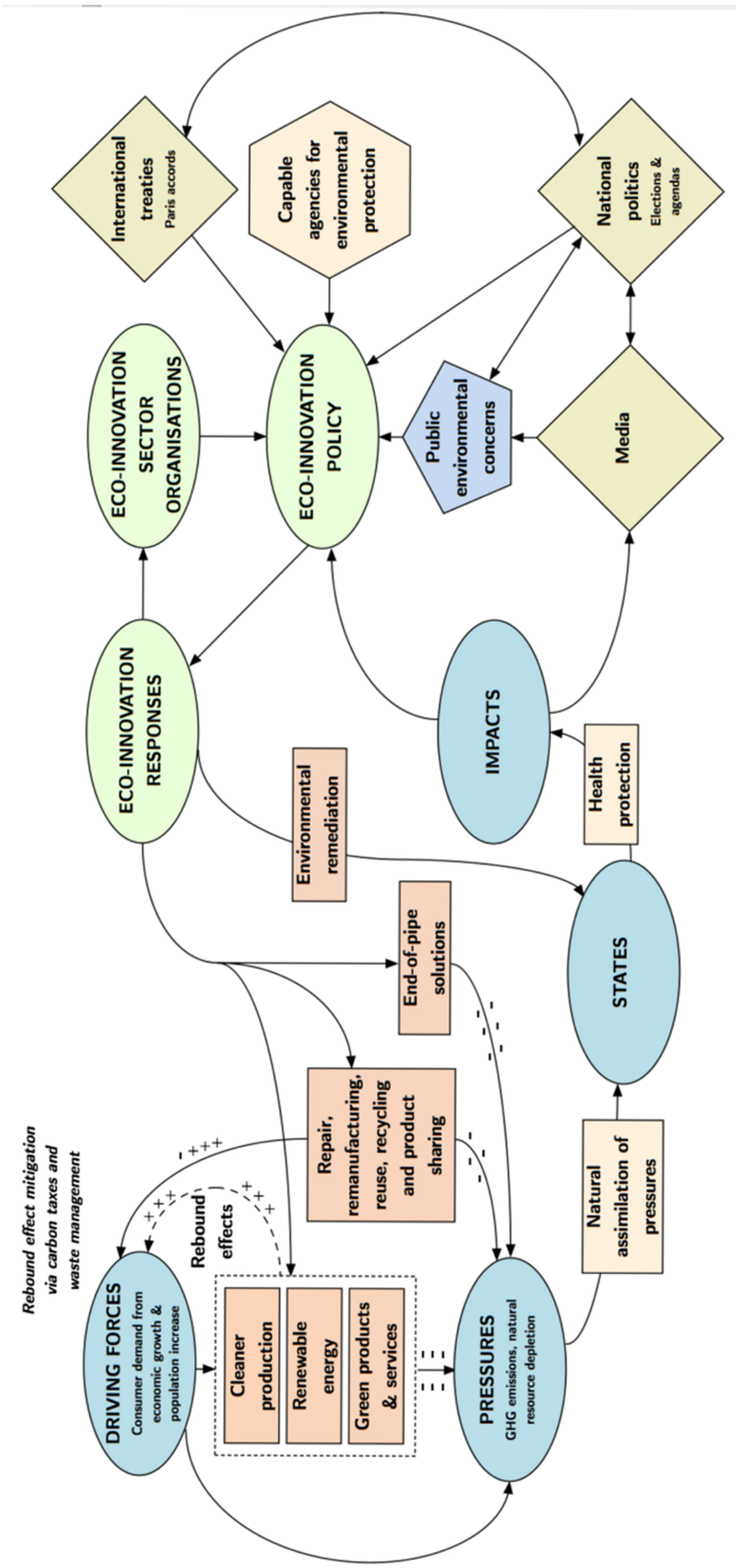


Figure 1.3. DPSIR Framework and Eco-Innovation

data (known as "hybrid" or "(E)IO" LCA). Input/output tables map the economic flows between different sectors in an economy and can be converted into physical flows using relevant unit prices. The data are often aggregated at a level that is not useful for assessing specific products. EIO-LCA is used to extend traditional product E-LCAs to upstream and downstream processes in sectors that would otherwise be ignored (Suh and Huppes, 2005).

Consequential E-LCA can be relevant to eco-innovation. Whereas attributional LCA seeks an answer to the question *"how do pollutants, resources, and process exchanges flow within the chosen temporal window"?*, consequential LCA answers the question *"how will flows change in response to decisions"?* (Weidema et al., 2018, p. 308).

Consequential LCA thus looks at the consequences of the change of a product or the introduction of a new product. Consequential LCA can more accurately measure the impact of an eco-innovation on the economy from as changes in supply, demand, and substitution effects impact (Zamagni et al., 2012). However, consequential E-LCA is more demanding for the analyst because economic behaviour needs to be modelled. It also requires info on potential constraints: resource stocks, capital scarcity, etc.

From the point of view of macro-impacts, it is important to know whether an innovation replaces an existing process or product and whether the less environmentally beneficial process or product is removed from use or not. If not, there will not be an absolute decoupling of environmental impacts from economic growth, at least not for a while. It is thus very important to have information on the capital stock that is used for production and the product stock in use.

1.3.10. Country specificity

Data collection requirements differ across countries. For some countries water use is a critical issue, calling for water saving technologies and for water treatment to turn wastewater into drinking water or water for irrigation or sanitation. For research purposes and international comparability, it is highly desirable that countries **harmonise** the data collected.

1.3.11. A four-pillar indicator system

Ideally, the measurement of eco-innovation and the green economy should cover four types of indicators, although all four **types of indicators** are unlikely to be collected through the same instrument.

- Environmental indicators
- Eco-innovation indicators
- Eco-policy indicators
- Socio-economic well-being indicators

The logic behind the 4-pillar system is as follows. Environmental indicators provide **the baseline** for measuring the effects (with suitable time lags) of eco-innovation activities and eco-policies. Measures of eco-policies are needed to determine the influence of policies on environmental performance via eco-innovation and **for identifying policy gaps** (areas where policy action is needed). Indicators on socio-economic well-being constitute a fourth type that do not cover the innovation-outcome chain, but which play a valuable role in ensuring that shifts to a sustainable economy do not result in undesirable side-effects such as greater inequality.

Absolute environmental indicators are necessary to track progress in achieving sustainable (or acceptable) emission levels. **Direct indicators** of eco-innovation are strongly preferred over indirect measures and input indicators. An example of a direct indicator is the number of battery electric vehicles (BEV) in the car fleet and the share of BEV in total vehicle kilometres.

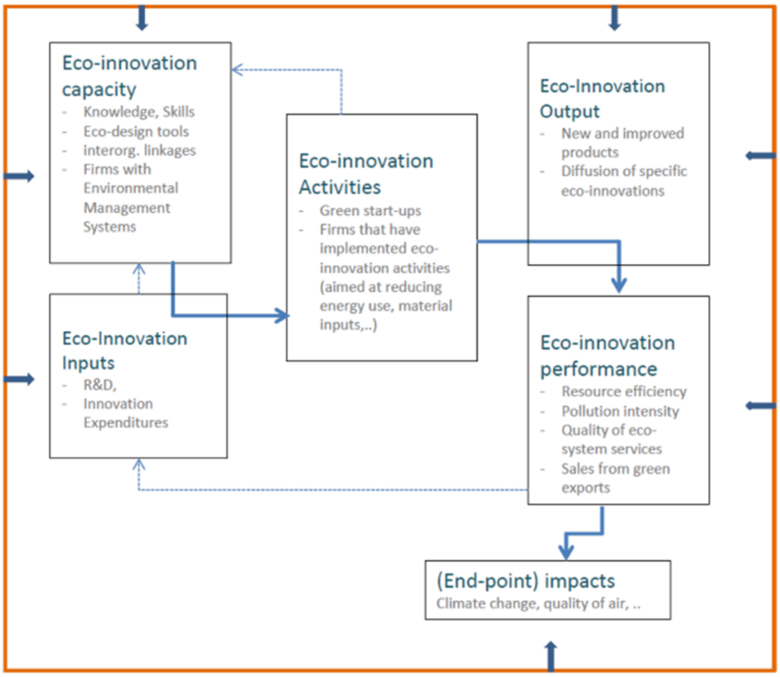
Figure 1.4 shows the forward and backward linkages between eco-innovation inputs, capacity, outputs and performance. Eco-innovation performance depends on eco-innovation outputs from eco-innovation activities. All elements are affected by boundary conditions (framework conditions) which include global influences. The different feedback loops make the system non-linear and complex.

Eco-innovation can only achieve an absolute decoupling between economic growth and emissions if environmentally harmful activities are discontinued and if the eco-innovations diffuse widely. This requires policies to discourage harmful activities in addition to eco-innovation promotion policies.

Socio-economic well-being depends on other factors unrelated to eco-innovation.

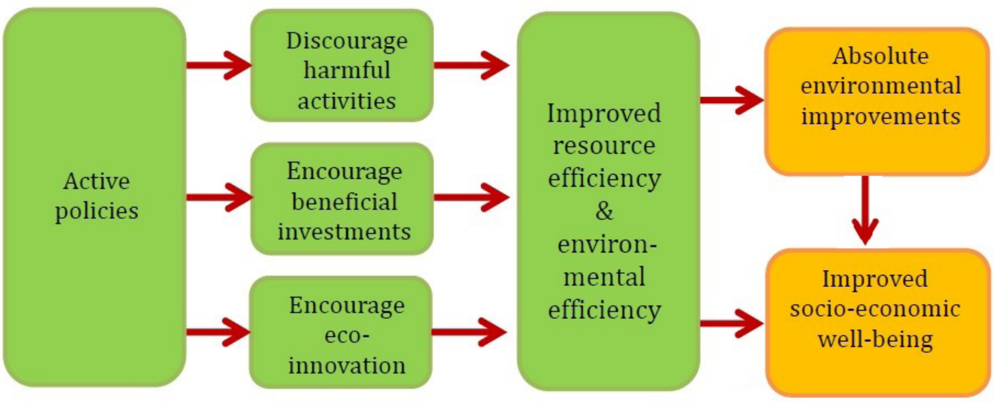
Figure 1.5 identifies four possible reasons for the frequently observed outcome that eco-innovations do not result in absolute environmental improvements. The reasons (which usually operate simultaneously) are: 1) too low green investments, 2) many harmful activities are continued, 3) the eco-innovation gains (compared to relevant alternatives) are relatively low, and 4) eco-innovation gains are negated by environmental rebound effects and the negative environmental impacts associated with growth. In the case of passenger road transport, overall GHG emissions have increased, despite the massive diffusion of low-carbon technologies (diesel cars, direct fuel injection, car sharing and bicycle sharing).

Figure 1.4. The eco-innovation impact causal chain



Boundary conditions in orange
Source: Authors' elaboration

Figure 1.5. Eco-innovation and absolute environmental improvements



2

DEFINITIONS AND TYPES OF ECO-INNOVATION

Christian Rammer, Anthony Arundel,
René Kemp and Michal Miedzinski

This chapter defines eco-innovation and delineates different types of eco-innovations. Eco-innovation refers to the actions of individuals, organisations and groups of individuals (such as local initiatives) to reduce the environmental impacts of their activities.

Eco-innovations can result from the activities of many different types of organisations and individuals, including coordinated actions by several organisations or groups of individuals. This chapter defines different types of eco-innovation and describes methods for measuring them.

The definitions and recommendations for measurement in this chapter are aligned with the fourth edition of the Oslo Manual guidelines for measuring innovation in the business sector. This facilitates the measurement of eco-innovation in data collection activities based on the Oslo Manual, such as the Community Innovation Survey in Europe and national innovation surveys in Argentina, Australia, Brazil, Canada, Chile, China, Japan, Korea, New Zealand, the United States and many other countries.

In addition to the business sector, this manual is designed to cover data collection in all economic sectors, as defined by the System of National Accounts (SNA) (UN, 2008). Following the Oslo Manual, the two corporate sectors in the SNA are combined into a single business sector. Other relevant sectors are the general government sector, including all government owned or controlled organisations at the local, regional and national level; non-profit institutions serving households (NPISHs) such as many environmental NGOs; and households, which includes individuals and unincorporated enterprises. This manual covers all sectors because of the importance to environmental outcomes of not only businesses as producers and users of eco-innovations, but the role of other sectors as both producers and consumers of eco-innovations. The NPISH sector, for instance, is very active in supporting systemic social innovations with environmental benefits, while the outcomes of many eco-innovations produced by the other sectors, including electric vehicles, zero-carbon domestic heating technologies and recycling, depends on their adoption by households. Households can also be active in producing eco-innovations, as when users modify technology to better meet their own needs (von Hippel, 2017).

The four sectors of an economy contain different types of entities: establishments, kind of activity units, enterprises, and enterprise groups in the business sector; agencies, departments, ministries, municipalities, hospitals, universities and more in the government sector; and individuals, the self-employed and unincorporated enterprises in the household sector. All of these different entities are referred to as ‘units’ in the SNA, with all economic activities assigned to only one unit within the national accounts, to permit aggregation (or disaggregation) of data without double-counting. Data on eco-innovation can be collected from all types of units, but National Statistical Offices collect innovation and administrative data (profits, employment, value-added etc.) for the business sector at the enterprise level. Similarly, this manual recommends collecting data on eco-innovation in the business sector for enterprises **(see Chapter 8).**

2.1. Definition of eco-innovation

An eco-innovation is a new or improved product or practice of a unit that generates lower environmental impacts, compared to the unit’s previous products or practices, and that has been made available to potential users or brought into use by the unit.

A **product** comprises both goods and services, including digital goods and digital services. A practice refers to any activity performed by a unit, including processes to produce goods and services and distribute them to potential users, as well as all auxiliary processes to support the activities of the unit. Practices include the activities described as ‘processes’ in the Oslo Manual as well as any activities of individuals.

Lower environmental impacts can refer to the **use of fewer natural resources** (energy, material, water, land), **the substitution of environmentally harmful substances** by less harmful ones, or **lower environmental risk, pollution or other negative envi-**

ronmental impacts. Whether a product or practice results in a reduction in environmental impacts needs to be based on the environmental impacts associated with all stages of a product's life, from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling[11]. A lower environmental impact can either result from a higher environmental efficiency or from a reduction of activities with a negative environmental impact. Higher environmental efficiency of a product or practice refers to fewer environmental impacts by unit of activity or output. Examples are a vehicle that consumes less energy per unit of distance, a production process that consumes less material per product produced, or a new production system that re-uses waste, wastewater or waste heat. Reducing activities with a negative environmental impact refer to changes in behaviour such as sourcing inputs from regional suppliers (hence reducing the average supply distance) or replacing long-distance holidays with destinations closer to home.

An eco-innovation only needs to be **new or improved for the unit that offers or uses the product or practice.** Eco-innovations hence include the adoption of products or practices that have previously been used by others. An eco-innovation also includes the introduction of products or practices which are inferior in terms of their environmental performance compared to other products or practices available in the market, but which are superior over the products and practices used by the innovating organisation or individual so far. For example, if a household buys a new refrigerator of eco-efficiency class B to substitute an old refrigerator of eco-efficiency class C, this constitutes an eco-innovation despite the fact that more eco-efficient refrigerators were available on the market at the time of purchase. At the same time, introducing a product or practice with a superior environmental performance compared to similar products or practices available in the market so far is not an eco-innovation if it substitutes a product or practice with lower environmental impact per activity or output. For example, if an individual replaces a compact car by a new sport-utility vehicle (SUV) with the most efficient engine technology for SUVs, this will not be an environmental innovation if the lifetime environmental impact of the new SUV is higher than that of the compact car.

A product or practice with new or improved characteristics does not remain an innovation forever. For measurement purposes, a unit is innovative if it implements a new or improved product or practice during a given time period, which is defined in the Oslo Manual as the **observation period.** The Oslo Manual recommends an observation period of between one and three years. For example, a public sector agency can be asked if it had any eco-innovations over the two-year period before the time of measurement, or a household can be asked it had any eco-innovations in the previous three years. It is not recommended to use observation periods of longer than three years because the ability of respondents to accurately remember when events occurred declines with time.

An eco-innovation does not require an explicit intention to reduce environmental impacts. **Eco-innovations also include the unintentional reduction of environmental impacts.** The essential characteristic that distinguishes an eco-innovation from other innovations is that it actually resulted in lower environmental impacts. For example, if a firm replaces an old machine by a new machine in order to increase its production capacity or flexibility, and the new machine has a higher environmental efficiency than the old one, this constitutes an eco-innovation.

The outcome perspective of eco-innovation implies that an eco-innovation cannot necessarily be identified at the point in time when a new or improved product is made available to potential users or when a new or improved practice is adopted. There are basically two methods for identifying eco-innovations:

- **The standard use** method analyses the environmental impacts of a new or improved product or practice based on a standardised use pattern over a typical life-time and compares the resulting environmental impacts with those of the previously offered comparable product or previously used comparable practice. This method can be applied at the time a product is made available on the market or a practice enters into use.

• **The revealed use method** establishes the environmental impacts of a new or improved product or practice based on actual usage over the entire time that the product or practice is in use and its environmental impacts after use. This method can only determine environmental impacts after the use of a product or practice has ceased. It also requires constant measurement over the lifetime of a product or practice. Consequently the method is only feasible for large-scale products or practices, such as comparing the carbon emissions of alternative methods of producing electricity.

The standard use method is preferred for surveys of units, although the accuracy of the results will depend on how closely actual use follows the standardised use pattern and differences in the comparability of new products and practices with previously used ones. This is particularly the case for entirely new products or practices that have no predecessor product or practice in the unit. Another source of inaccuracy is unrealistic evaluations of the environmental impacts of new or improved products and practices, for instance when assessment fails to take into account inappropriate use or neglects likely negative environmental impacts after use.

Inaccuracy can be unavoidable in surveys where respondents are asked to evaluate the environmental impacts of a product or practice. Respondents can believe that a new product is more environmentally friendly than a previously used product, for instance based on the product label, without considering how they intend to use the product. It is unlikely that many respondents can provide an accurate assessment of environmental performance over the product's entire period of use, unless they maintain accurate records, for instance on fuel consumption or emissions.

Eco-innovations can be measured either from **the point of view of the unit** that produces and offers the eco-innovation for use by others (producer perspective) or from **the point of view of the users of eco-innovations** (user perspective). From the producer perspective, an eco-innovation must be superior to the products produced and offered by the producer before. From the user perspective, superior environmental performance refers to the products and practices used so far. The same object (product or practice) may constitute an eco-innovation only from one perspective, but not from the other one.

Eco-innovations can be classified into several **types.** A main distinction is between product and practices. It is useful to further separate the latter into process technology and organisational methods, which gives four basic types of eco-innovation. Each type of eco-innovation is briefly defined below, while the eco-innovative characteristics of each type of eco-innovation and further details are given in sections 2.2 to 2.8.

• **A product eco-innovation** is a new or improved good or service that generates lower environmental impacts compared to the products previously produced or used by the unit **(see Section 2.2).**

• **A process eco-innovation** is a new or improved process that generates lower environmental impacts compared to the process technology previously used by the unit **(see Section 2.3).**

• **An organisational eco-innovation** is a new or improved organisational method that contributes to lower environmental impacts compared to organisational methods previously used by the unit. **(see Section 2.4).**

• For practical purposes, it is useful to distinguish four additional types of eco-innovations:

• **A marketing eco-innovation** is a new or improved marketing method for commercialising new or im proved products with lower environmental impacts, hence facilitating the adoption of these product eco-innovations by potential users **(see Section 2.5).**

• **A business model eco-innovation** is a new business model that reshapes the way users receive value based on lower environmental impacts of products (goods and services) and the way these products are produced and delivered. A business model eco-innovation is often an organisational innovation, combined with process technology and marketing innovations, to produce and provide one or more product eco-innovations to consumers. Business model eco-innovations usually put the superior environmental performance of a product eco-innovation at the centre of the customer value proposition **(see Section 2.6).**

- **A systemic eco-innovation** is a system that has been implemented or changed in order to reduce the environmental impacts of multiple actors in a coordinated way, hence improving the overall environmental performance of activities within the system in a more comprehensive and efficient way than individual actors would have been able to achieve **(see Section 2.7).**

- **A social eco-innovation** is a new social arrangement that is environmentally advantageous. Environmental advantages may result from a group of people using fewer natural resources, or from establishing principles of a circular economy among a group of people **(see Section 2.8).**

These examples of different types of eco-innovations are not mutually exclusive. An eco-innovation can include both a product and a process component or a business model eco-innovation can also be a social eco-innovation.

This chapter also discusses the measurement of other eco-innovations that cannot unambiguously be assigned to any of the types mentioned above, including the development, distribution or adoption of **renewable energy sources** and the **restoration of eco-systems** through innovations that improve biocapacity and the management of ecosystems through forest preservation and enhancement, soil erosion prevention, habitat and biodiversity conservation, or the restoration of degraded land.

2.2. Product eco-innovations

The eco-innovative characteristics of product eco-innovations are due to:

- **Lower environmental impacts** when using the product, including products with a higher energy-efficiency and products with lower emission levels in terms of air, water, soil or noise pollution.

- **Reduced resource content** (volume of materials, environmental footprint of materials) or use of hazardous substances.

- **Reduced resource use** during production or delivery.

- **Improved recyclability** after use.

- **Longer service life.**

The fact that an individual, an organisation or a group of individuals reports a product eco-innovation does not necessarily imply that the environmental performance of a product over its lifetime has actually improved. To establish total environmental performance, an Environmental Life Cycle Assessment (E-LCA) needs to be performed (see section 1.3.9 below). Without evidence, the presence of a specific eco-innovation characteristic only indicates that the environmental performance of one product feature has been improved. For example, re-designing a product to increase its service life could be counterbalanced by poorer environmental performance when producing or using the product. More durable materials and components could result in heavier products or products with more complex and hence more resource-intensive production processes.

A product eco-innovation can be measured from the producer's or the user's point of view. From the producer's point of view, a product eco-innovation needs to have a superior environmental performance compared to similar products produced by the producer so far. From the user's point of view, a product eco-innovation needs to have a superior environmental performance compared to similar products used by the user so far. Product similarity refers to the product's application (e.g. products to transport a good or a person, wash clothes, or provide entertainment).

For products for which a unit did not previously use or produce a similar good or service, a product eco-innovation must display superior environmental performance over alternatives that are available in the relevant market. In this case, a new or improved product is only a product eco-innovation if it provides the lowest level of environmental impact for its product category. For example, if a car manufacturer starts producing light trucks for the first time, the light truck will represent an eco-innovation only if it is environmentally superior to other light trucks offered in the market at the time of its introduction. In case an individual buys a car for the first time, the car is an eco-innovation only if it represents the highest eco-efficiency level for cars.

The positive environmental performance of service eco-innovations usually does not result from the characteristic of the service as such, but from how the service is delivered and the components used to deliver the service. For example, a service eco-innovation in hairdressing could be due to eco-friendly hair sprays and dyes, while a service eco-innovation in air transport could be due to more fuel-efficient aircraft and flight plans. It is often ambiguous if an eco-innovation is a service or a process to deliver a service. Under these conditions, survey respondents need to be able to select either a service or process eco-innovation category, or both.

2.2.1. Lower environmental impacts from using a product

A new or improved product with lower environmental impacts during through the following criteria for the amount of environmental impact per unit of product use:

- Consumption of energy or the characteristics of the energy consumed.
- Volume of air pollution or the characteristics (toxicity) of air pollution.
- Level or type of noise pollution.
- Volume or characteristics of other relevant pollution (e.g. soil pollution).
- Volume of water consumption.
- Area of land required when using a product.

The unit for measuring the amount of product use depends on the nature of product. If a product is fully consumed during use, the unit is a single item of the product or a quantity unit of the product (e.g. a piece of bread, a ton of steel). If a product is used to perform an operation, the unit is this operation (e.g. a washing cycle for a washing machine). If a product can be used continuously (e.g. driving a vehicle, heating or lighting a premise), the unit can be a unit of time or distance, combined with a unit of the service provided by the product (e.g. tonnes per km in case of products used for transportation, hours of lighting for a given luminous intensity).

The re-design of energy-consuming products to replace the use of carbon-based energy sources (oil, gas, coal) by renewable energy sources is discussed in section 2.6. as an eco-innovation in renewable energy.

2.2.2. Products containing fewer resources or hazardous substances

For new or improved products that contain fewer resources or hazardous substances, the positive environmental benefit is from lower environmental impacts associated with the physical content required for a product, i.e. the quantity and type of materials and substances that go into its manufacture. The evaluation of environmental performance should be made over a product's life cycle. For example, if a new or improved product contains less material at the expense of significantly lower durability, it may not qualify as a product eco-innovation.
New or improved products containing fewer resources or hazardous substances include products that:

- Contain less material.
- Replace materials and substances by substitutes with fewer negative environmental impacts during the use of the product.
- Replace 'hazardous substances' or materials with safer alternatives (see section 2.3.3).

A new or improved product that contains fewer environmental resources, e.g. because of a design that allows for the same product performance with a lower weight, could also reduce environmental impacts during its use, for instance it uses less energy per performance unit.

2.2.3. Products requiring fewer environmental resources during production or delivery

A product that is re-designed to reduce environmental impacts during production or delivery, but without necessarily altering the process and delivery technology, is another type of product eco-innovation. In contrast, a reduction in environmental impacts from altering the production or delivery process is an eco-innovation in process technology. In practice, both types of eco-innovation can occur simultaneously. It is nevertheless useful to consider product re-design for reducing environmental impacts during production or delivery as a product eco-innovation, since the product is the object of the innovation activity.

Product eco-innovation requiring fewer environmental resources during production or delivery include the re-design of products in order to:

- Reduce the use of hazardous auxiliary substances during production.

- Reduce the amount of waste material in production.

- Reduce the amount of energy needed during production, including energy needed for moving products during the production process (e.g. by enabling fewer production stages).

- Improve the efficiency of handling and shipping products by reducing the product's weight or volume or by re-shaping a product so that it can be more easily moved.

2.2.4. Recyclability of products

A new or improved product that improves recyclability after use reduces environmental impacts by contributing to the principles of a circular economy. Improving recyclability includes:

- Product design that facilitates disassembly into individual components and types of materials.

- Replacement of difficult or impossible to recycle materials with materials that can easily be recycled or re-used.

- Repurposing of waste material by reuse in a different product category and context, without fundamentally altering original physical form or structure.

- Avoiding the use of materials and substances in the product that complicates the recyclability of other materials and parts.

- Integrating an information system into the product that informs users and recyclers about product contents and recycling options (as with plastics).

As for other types of eco-innovations, the effect of recycling needs to be evaluated in comparison to a product's life cycle. For example, using materials that are easier to recycle could reduce the product's service life. Improving the ease to which a product can be disassembled could result in heavier products or more complex production processes that require a higher amount of energy to produce one unit of a product.

2.2.5. Service life of products

A new or improved product that has a longer service life can reduce environmental impacts by minimising the amount of resources needed per unit of product use. Increasing the service life of a product can be achieved by:

- Using more durable materials and components.
- Improving the ability to repair products, such as the ability to replace worn out parts.

- Measurement and control systems that prevent the misuse of the product in ways that damage it.
- Providing users with information on how to maximise the product's life (gentle use of products, maintenance requirements).

2.3. Eco-innovation in processes

The eco-innovative characteristics of process innovations are due to:

- **Less pollution i**n terms of air, water, soil or noise pollution when producing or delivering one unit of product.

- **Use of less energy, material, water or other physical inputs** when producing or delivering one unit of product, including the reduction or re-use of waste accumulating during the production process.

- **Replacement of hazardous substances** used in processes.

Processes include hardware (e.g. machinery, equipment, instruments, vehicles, buildings) and the software, knowledge and logistics to operate processes.

Eco-innovations in processes cover a variety of operations performed by units that engage in any kind of production activity, including the production of physical goods, services and digital (information) goods. Equipment used in households, such as heating systems or 'smart building' information and communication systems, are not processes. Instead they are products for final consumption.

Process eco-innovations include technology to produce goods or services, to deliver or move products or carry persons, to process information and communications, and to maintain the unit's operations (e.g. to heat and light the premises of a government office).

2.3.1. Pollution control and treatment

New or improved pollution control and treatment technology is a process eco-innovation if it reduces the level of pollution per unit of output below the previous level in the unit. Pollution includes air, water, soil and noise pollution.

Pollution control and treatment technology includes end-of-pipe technology that reduces pollution at the end of a process (e.g. through filters or catalytic converters) as well as integrated technology that reduce the volume of pollution in the course of a process (e.g. by improving combustion processes or by recycling waste back into the process).

Pollution control technology includes all technology to identify, monitor and control the generation of pollutants at their source in order to prevent or diminish the release of pollutants. Treatment technology includes all technology to reduce pollutants in a medium after the production process (e.g. outgoing air, wastewater, physical waste).

The reduction of pollution that results from changing carbon-based energy sources (oil, gas, coal) to renewable energy sources is discussed in section 2.6.

2.3.2. Resource efficient processes and waste prevention

New or improved processes can increase resource efficiency by reducing the amount of environmental resources that are used per unit of output or operation. A unit of output refers to goods production while the unit of operation refers to service production or other processes. Resource efficiency can be improved by processes that:

- Use less energy per unit of output or operation (increasing **energy efficiency).**

- Use less material, water or other physical inputs per unit of output or operation (increasing **material efficiency).**

- **Reduce the amount of waste** that accumulates per unit of output or operation, either by preventing the production of waste or by re-using waste in the process.

Increases in energy efficiency can be achieved by energy-saving technology in production, space heating and cooling, transport and logistics, information and communication technologies, and building technologies and other technologies needed to produce goods or services.

Increases in material efficiency includes the use of less material, water or other physical inputs during the production of one unit of output, in transport and logistics activities (e.g. using less packaging material), and in other operations of a unit (e.g. using less paper in administration).

Process technologies to prevent waste or to re-use of waste are usually part of a production technology. An example for waste reduction is the introduction of new machinery that more accurately processes material and hence reduces the number of failed batches. The re-use of waste includes closed production systems which re-enter scrap material into the production process. This also includes systems that re-use water, metals or auxiliary inputs. Waste prevention that has been achieved through a re-design of the product is a product eco-innovation. Methods to prevent or diminish waste by organisational methods are discussed in section 2.4.2.

Process technology that replaces the use of carbon-based energy sources (oil, gas, coal) by renewable energy sources is discussed in section 2.6. as an eco-innovation in renewable energy.

<u>2.3.3. Processes avoiding hazardous substances</u>

A new or improved process technology can avoid or reduce the use of hazardous substances by:

- Substituting a hazardous substance by a less hazardous one;
- Eliminating the need to use any hazardous substances.

Hazardous substances have one or more of the following properties: explosiveness, flammability, ability to oxidise (accelerate a fire), human toxicity (acute or chronic), corrosiveness (to human tissue or metal), ecotoxicity (with or without bioaccumulation), and the capacity when metabolised or mixed with air or water to develop one or more of the above properties. In some countries and regions, a subset of hazardous substances which must be avoided in certain products or processes is defined by law, e.g. the EU Directive to restrict the use of ten hazardous substances (lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls, polybrominated diphenyl ether, bis(2-ethylhexyl) phthalate, butyl benzyl phthalate, dibutyl phthalate, and diisobutyl phthalate).

Products that have been re-designed to not contain hazardous substances are product eco-innovations (see section 2.2.2).

2.4. Organisational eco-innovation

The eco-innovative characteristics of organisational innovations include:

- New or improved methods for managing a reduc tion in the environmental impacts of the unit's ope rations **(environmental management and auditing systems).**
- New or improved methods for managing the volume of waste per unit **(waste management);**
- New or improved methods for managing an increase in the energy efficiency of operations **(energy mana gement systems);**
- Other new or improved methods to manage activities in a unit in a way that reduces environmen tal impacts.

These methods represent an organisational eco-innovation if they have been introduced in a unit which has not used the respective method before. Improvements to existing methods or new uses of a method are an organisational eco-innovation if the change results in a further reduction of environmental impacts from the unit's activities. For example, the application of waste management methods used in production to transport and logistics is an organisational eco-innovation if it results in less waste per unit of operation.

2.4.1. Environmental management and auditing systems

An environmental management and auditing system is a tool for managing a unit's environmental activities in a comprehensive, systematic, planned and documented manner. Environmental management and auditing systems includes the organisational structure, planning and resources to develop, implement and maintain a policy for environmental protection.

Environmental management systems often integrate practices for training of personnel as well as monitoring, summarising and reporting of specialised environmental performance information to a unit's internal and external stakeholders. Environmental auditing includes the systematic, documented, periodic and objective evaluation of the unit's environmental performance, environmental management system and processes designed to protect the environment.

Environmental management systems have been standardised by ISO (14001) and the European Commission (Eco-Management and Audit Scheme - EMAS).

2.4.2. Waste management

Waste management is a tool for managing the collection, sorting, processing and safe disposal of waste that accumulates in a unit from waste inception to final waste disposal. Waste management approaches include the prevention, minimisation, reuse, recycling, energy recovery or disposal of waste. Waste management activities can be performed by any unit. In addition, there are enterprises specialised in providing waste management services (ISIC rev. 4 divisions 37 to 39).

A special form of waste management is the Extended Producer's Responsibility. This is an approach for integrating the environmental costs associated with products throughout their life cycle into the market price of the products. It includes the responsibility of the producer to take-back, recycle and dispose of a product after the end of the product's use. Extended Producer's Responsibility aims to increase the amount and degree of product recovery and to minimise the environmental impact of waste materials. The approach is often used for consumer durables, but rarely applied to short-lived consumer and intermediary products.

2.4.3. Energy management systems

An energy management system is a systematic approach for achieving continual improvement of a unit's energy performance, including energy efficiency, energy security and energy use. Energy management systems aim to continually reduce energy use per unit of output or operation, hence reducing the environmental impact of energy use.

Energy management systems usually include the development of a policy for more efficient use of energy, fixing targets and objectives to meet the policy, using data to better understand and make decisions concerning energy use, measuring the results, reviewing the effectiveness of the policy and continually improving energy management tools. Energy management systems have been standardised by ISO (50001).

2.4.4. Total quality management and other management practices

The environmental performance of a unit can be improved by management methods that do not primarily aim to reduce the environmental impact of operations, but to achieve other goals. Positive environmental impacts are often unintended side effects. They still qualify as organisational eco-innovations since the defining feature is the achievement of a reduction in environmental impacts per unit of output or operation.

A prominent example is total quality management, an organisation-wide effort to install and make permanent a climate in which a unit continuously improves its ability to deliver high-quality products and services to customers. Total quality management can contribute to environmental performance by:

- Avoiding errors in production activities that can cause environmental pollution;

- Using resources (energy, material, water, auxiliary inputs) more carefully and economically;

- Producing and delivering products of higher quality, thereby reducing their environmental impact due to longer service life and more failure-free operations.

2.5. Marketing eco-innovation

The eco-innovative characteristics of new or improved marketing methods are due to:

- Labelling and branding methods for eco-friendly products.
- Pricing methods for eco-friendly products.
- Advertising methods for eco-friendly products.
- Distribution channels for eco-friendly products.

Marketing eco-innovations contribute to lower environmental impacts by stimulating demand for eco-friendly products over demand for less eco-friendly ones.

The use of labels and brands for eco-friendly products is a way to communicate the environmental advantages of these products to users and trigger demand for such products. Eco-labels and green stickers are common methods that are frequently used for consumer products. Eco-labels have been standardised by ISO (14020 to 14025). Green stickers contain information about the environmental performance of products and are often regulated by law (e.g. the Energy Star programme in the U.S.). Offering a good or service for rent is an example of an alternative pricing strategy.

Changes to product distribution methods that result in lower environmental impacts (e.g. re-organisation of distribution to reduce the amount of transportation) are eco-innovations in process technology. The re-design of products to make them more eco-friendly (e.g. easier recycling, easier handling and transportation, facilitating a more environmentally-friendly production of products) is a product eco-innovation. Changes to production processes to reduce waste or the amount of packaging materials are process eco-innovations.

2.6. Renewable energy technologies

The adoption of renewable energy technologies represents a special type of eco-innovation, with the eco-innovative characteristics due to new or improved:

- Products that use renewable energy sources instead of carbon-based energy sources.

- Processes that uses renewable energy sources instead of carbon-based energy sources.

- Processes to generate electricity, heat or other types of energy from renewable sources.

- Products to store renewable energy plus infrastructure to collect and distribute renewable energy.

- Shifts in energy suppliers to those that provide energy from renewable resources.

Eco-innovation in renewable energy technology can lead to higher energy efficiency in a unit's operations or when using products, but it does not necessarily have to. For example, switching from carbon-based to renewable sources may lead to a higher energy consumption per unit of output or operation (e.g. for heating processes). The positive environmental impact of an eco-innovation in renewable energy can occur either at the location of energy generation or at the site of use. The positive environmental impacts from generation are often due to lower air pollution. Positive environmental impacts at the point of use are due to a reduction in the total amount of energy used or a higher share of renewables in total energy consumption.

2.7. Business model eco-innovation

A business model combines the core components of firm's operations and the methods that it uses to deliver value to customers and to the firm. A business model fulfils several strategic functions (Chesbrough, 2010):

- Articulates the value proposition (i.e. the value created for users).
- Identifies a market segment (users) and specify the revenue generation mechanism.
- Defines the structure of the value chain required to create and distribute the offering and complemen tary assets needed to support position in the chain.
- Details the revenue mechanisms by which the firm will be paid for the offering (value capture).
- Estimates the cost structure and profit potential.
- Describes the position of the firm within the value network linking suppliers and users.
- Formulates the strategy by which the firm will gain and hold competitive advantage.

A business model innovation is defined as the discovery of a fundamentally different business model in an existing business (Markides, 2006) or the adoption of a novel approach to commercializing assets (Gambardella and McGahan, 2010) (from Spieth and Schneider, 2016). Spieth and Schneider (2016) offer a model for measuring business model innovation based on three dimensions: value offering, value architecture and revenue model (Table 2.1). Value offering innovation refers to designing a new value offering that meets an existing but yet unfulfilled customer demand, or that stimulates an additional but not yet consciously perceived demand. Value architecture innovation refers to the exploration of new applications and combinations of a firm's base of resources and competences or within its external partner network. Revenue model innovation refers to the innovation of a firm's core earnings logic (Spieth and Schneider, 2016, p. 682). Others speak of value proposition, value creation and delivery, and value capture (Bocken et al., 2014).

Table 2.1. Business model innovation indicators

	Business model sub-dimension	Business model innovation element
Value offering	Target customers Product and service offering The firm's competitive positioning	Target customers have changed The product and service offering has changed The firm's positioning in the market has changed
Value architecture	Core competences and resources Internal value creation Partners in value creation Distribution	The firm's core competences and resources have changed Internal value creation activities have changed Role and involvement of partners into the value creation process have changed Distribution has changed
Revenue model	Revenue mechanisms Cost mechanisms	Revenue mechanisms have changed Cost mechanisms have changed

Source: Spieth and Schneider (2016, p. 686)

This scheme can be used to determine the novelty of a business model. The same scheme of 11 questions for 3 dimensions of value can be applied to eco-innovation. The key feature of an eco-innovation business model is to deliver value to customers by providing product eco-innovations and to organise the value delivery differently.

Business model innovation represents a complementary form of innovation to product or process innovations (Amit and Zott 2012; George and Bock, 2011) but such aspects can be part of it. Business model innovation foregrounds value (creation, delivery and appropriation) aspects which are typically backgrounded in studies that merely seek to measure innovation and the determinants of it. Examples of business model eco-innovation are offered in Box 2.1.

The value proposition of a business model eco-innovation provides measurable ecological and/or social value in combination with economic value (Boons and Lüdeke-Freund, 2013). New partnerships and forms of collaboration are typically needed for this. SBMI is radical from the point of view of suppliers and users: "Whereas both product and process innovation can be incremental and moderate, business model innovation is almost always radical, risky, and transformative"[12].

The attention to business models allows for a more integrated consideration of innovation components and the types of value that are created. Established measurement systems usually measure elements of business models (e.g. marketing eco-innovation, eco-innovative products) but they do not allow for a systemic reflection on the role of the business model for eco-innovation (e.g. new value propositions or strategic collaborations focused delivering economic and environmental value).

For collecting data on business models related to eco-innovation, two approaches may be pursued. A first approach focuses on the role of business models for different types of eco-innovations, e.g. whether a certain business model is more or less likely to support eco-innovation of a certain type. A second approach collects data on eco-innovation business models to track its diffusion.

Box 2.1. Examples of business model eco-innovations

Functional sales (also servicing or product as a service) is a generic model focused on providing the function and benefits of the product to the customer instead of the physical product. The service provider uses the product to deliver its intended function. This creates an incentive to improve efficiency of output and to extend the life-span of the product.

Energy service companies provide energy-efficiency-related and other value-added services and assume performance risk for their project or product. Their compensation and profits are tied to energy efficiency improvements and savings in purchased energy costs.

Chemical management services are strategic, long-term relationship in which a customer contracts with a service provider to supply and manage the customer's chemicals and related services. Under a chemical management services contract, the provider's compensation is tied primarily to the quantity and quality of services delivered, not to chemical volume.

Integrated pest management and performance based pest management models assume that a pest management services provider commits to achieving a certain standard or level of pest control, rather than being compensated for a particular treatment or application.

Design-build-finance-operate model is a contractual relationship between a customer and a private contractor used for construction projects requiring long-term investments. Most Design-build-finance-operate models are Public-Private Partnerships.

Product life extension focused on extending life of products by repairing, upgrading and reselling. This includes remanufacturing which uses a combination of reused, repaired and new parts to rebuild product to specifications of the original manufactured product.

Sharing business models based on a shared use of products by many customers. Examples include car-sharing, car-pooling, sharing of holiday houses and laundry facilities. In these sharing models, the consumer does not own a product but only uses it.

Closed-loop recycling (including downcycling and upcyling) that use raw materials from existing products (secondary materials) to make new products. Downcycling turns materials from one or more used products into a new product with lower quality while upcycling focuses on designing and developing products with higher quality.

Industrial symbiosis is based on a shared use of resources and by-products amongst industrial actors through inter-firm recycling linkages. The waste of one company becomes another's raw material. The aim of industrial symbioses is to reduce the costs and environmental impacts of participating companies.

Sources: OECD (2012), FORA (2010), Doranova et al. (2010), EMF (2014)

2.8. Green ICT

Green information and communication technology (ICT) is an umbrella term for ICT which helps to reduce energy consumption and the environmental pressures of production and consumption. It comprises energy efficient ICT, smart grid components, digital devices for measuring air pollution and energy consumption, apps that offer information about the environmental profile of products or green living tips. An example of green ICT is a speedometer which glows green if you drive in a fuel efficient style and red if you don't. ICT has a hardware and software component and is increasingly app-based. Examples of apps that are eco-innovations include the iRecycle app which gives the location of local recycling facilities, plugshare will give the locations of EV chargers, and an app for iPhones that helps people respond to unsupported claims from climate sceptics[13].

The influence of ICT on the environment is complex. ICT enables individuals and organisations to reduce their environmental impacts but also acts as a driver of negative impacts via the energy use of ICT (which is increasing), a driver of economic growth and enabler of environmentally harmful practices such as fly-drive holidays that can be booked online.
When handled poorly, ICT waste has negative impacts on environment and health.

2.9. Systemic eco-innovation

Certain eco-innovations combine with other technologies and practices to form a system architecture. An example is a renewable energy system that combines solar and wind power generation with energy storage technologies in the form of pumped water and battery electric cars in a vehicle-to-grid configuration. A battery electric car can be simply another type of car, or it could function as part of a sustainable transportation system, storing electricity when needed, and integrated into a public transportation system. Another example is precision farming, where the supply of nutrients, minerals and water is fully controlled through the use of information technology and a wide array of items such as GPS guidance, control systems, sensors, robotics, drones, autonomous vehicles, variable rate technology, GPS-based soil sampling, automated hardware, telematics, and software[14]. An example of a system of eco-innovation that uses less technology is the Pose-Marré building in Alt-Erkrath (Germany). The building is an old paper factory (a cultural heritage) that has been converted into a place for work and living that is heated through a heat exchange system (100 m deep). It provides housing for different age groups and was created with the help of KFW loans for eco-houses.

System innovation is transformative and based on a new architecture, in contrast to system adaption and product innovation. Eco-labels, extended producer responsibility and product sharing can be viewed as sub-system innovations. They may develop into transformative system innovation or components of system adaptation when combined with other innovations (Figure 2.1.). Concepts such as transformative and system innovation are open to different interpretations and are consequently difficult to measure precisely (they depend on undefined criteria of radicality and system change)[15].

Better data on system eco-innovations would assist the identification of drivers and barriers to these complex forms of eco-innovations and how to support major sustainability transitions, such as for the circular economy. Chapter 9 provides additional discussion of these issues.

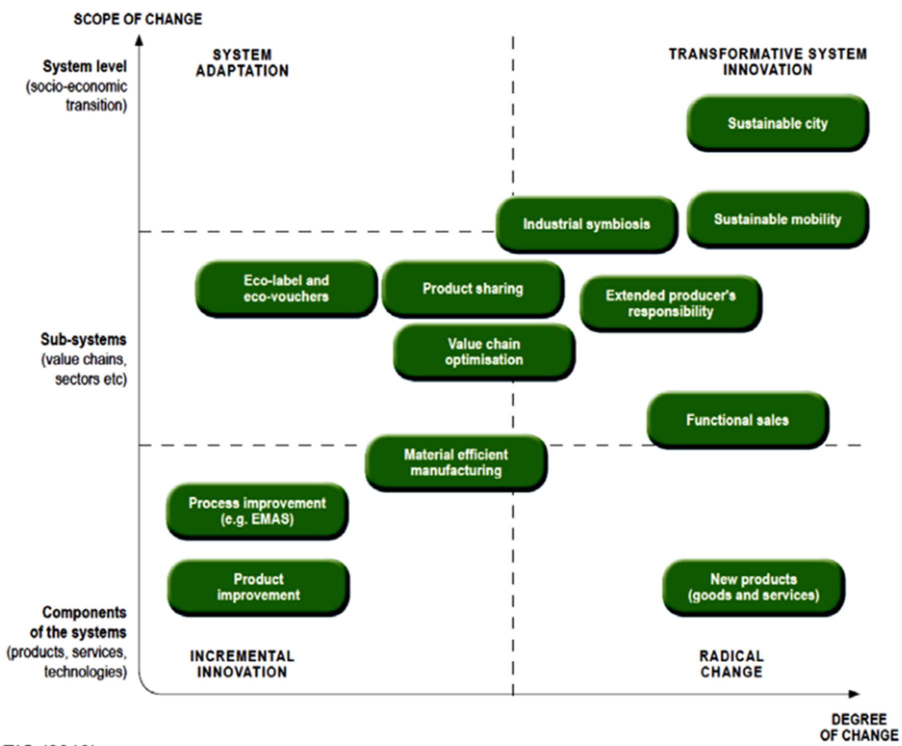
In transition processes, the interaction among different developments gives rise to outcomes, which enhance the position of certain actors and technologies—but new circumstances and counter strategies from incumbents can change the trajectory. The sociotechnical transition perspective is actor-centred while also mindful of material aspects (in the forms of financial interests, technologies, and infrastructures), hybrid systems (such as decentralized technologies integrated into centralized systems), spillovers from sectoral developments and various policy agendas, and the duality of agency and structure. Attention to niche actors and landscape factors helps researchers to understand the demise of socio-technical regimes and their gradual transformation

(Geels, 2005). Data collection for eco-innovations produced as a result of transitions needs to identify the actors, the technologies driving the system, and the counter strategies of incumbents.

2.10. Social eco-innovation

Social innovation is defined alternatively as a change in social relations (Haxeltine et al., 2016) and “a novel solution to a social problem that is more effective, efficient, sustainable or just than existing solutions and for which the value created accrues primarily to society as a whole rather than private individuals” (Phills et al., 2008, p.39). A definition combining the two elements is offered by Murray et al. (2010, p. 3): “we define social innovations as new ideas (products, services and models) that simultaneously meet social needs and create new social relationships or collaborations. In other words, they are innovations that are both good for society and enhance society’s capacity to act”. Social innovators are involved in the creation of social value often with the help of cross-sector partnerships and new roles that alter organisational boundaries. A social eco-innovation is a social innovation whose environmental impact is lower than for a relevant alternative. Possible examples of social eco-innovation are: (renewable) energy cooperatives, co-housing projects, and community gardens for growing organic food. In general, the social relation is not just a means to a goal, but is valued in its own right for building and strengthening bonds of friendship and shared identity among the concerned individuals, which contributes also to building strong, cohesive, trusting and caring communities (Weaver et al., 2017) and more responsible corpora-

Figure 2.1. A classification scheme of eco-innovation with examples



Source: EIO (2013)

tions. Social innovation can be measured by counting members of social innovation networks (slow food, eco-villages, transition towns, etc.) and by asking producers of goods and services questions about their orientation to social value creation and involvement in shared value creation activities with green benefits. A problem with the first approach is that most network organisations do not label themselves as social innovators. For studying corporate forms of social innovation the definition of Phills et al. (2008) offers a useful basis for measuring social innovation. It will be interesting to compare the attention given to social value creation in environmentally progressive firms and non-progressive firms. The attention given to social innovation corresponds with the recognition of the importance of immaterial needs in alternative measures for well-being (discussed in section 7.5). Business model innovation often involves social innovation and organisational innovation. Social eco-innovation is hardly used in business as a concept, although corporate social innovation and shared value creation are popular phrases[16].

2.11. Eco-system restoration

Eco-system restoration is an activity that can be an eco-innovation when it results in an eco-system that is improved with respect to its health, integrity or sustainability compared to the situation before the restoration activity started. Eco-system restoration refers to the renewal and restoration of degraded, damaged or destroyed ecosystems and habitats. Eco-system restoration activities include improving biocapacity and managing ecosystems through forest preservation and enhancement, avoiding deforestation, soil erosion prevention, habitat and biodiversity conservation, restoration of degraded and abandoned land, afforestation, soil remediation, re-introduction of mangroves for flood protection, reintroduction and other support for native species, daylighting streams, and habitat and range improvement for targeted species. Eco-system restoration is often managed and performed by public authorities, local initiatives or land-owners.

3

ECO-INNOVATION DRIVERS AND BARRIERS

Anthony Arundel, René Kemp and Will McDowall

This chapter discusses drivers (enabling factors) and barriers (hindering factors) for different types of eco-innovation and identifies different issues for measurement in the business, government and household sectors.

3.1. Introduction

Innovation is based on identified opportunities. The development of innovations can require multiple steps and capabilities, including financial resources, coordination, testing of ideas, and specialised equipment. This requires a process (van de Ven, 1986) that can involve multiple people and organisations, including people who are critical or sceptics.

Opportunities for innovation often have a technological basis, but the exploitation of such opportunities crucially depends on people and organisations carrying an innovation process forward. Many innovations do not start out as a strategic activity, but as a peripheral activity of a small team of developers (Kemp et al., 1998).

For developing and implementing eco-innovations, organisations can draw on external sources from which they acquire specific knowledge or technology, or they can rely heavily on internal know-how. Decisions to eco-innovate generally depend on a judgment about internal capabilities, a green ethos, or as a response to external stimuli, in particular to regulatory drivers. Eventually, this combination of factors leads to managerial expectations about potential positive gains compared to costs and risks, sometimes triggering eco-innovation processes.

The adoption of innovations developed outside an organisation is a more straightforward matter than developing innovations in-house, especially for organisations that are experienced with making changes to their processes. However, innovations are sometimes protected by intellectual property rights. In fact, the ease with which an innovation can be protected from imitation can affect innovation decisions in the business sector, but there is little evidence that a fear of imitation blocks innovation. For businesses, imitation is primarily relevant for the choice of strategy for protection, such as the decision to protect an innovation through secrecy, IP registration, lead user advantages, or marketing to obtain a dominant market position.

Individual consumers are generally price sensitive, but their frames of evaluation differ from those of organisations and are socially mediated. Consumers may be attracted by the greenness of a good or service, the cost savings associated with it and by specific performance features (aesthetics and functionalities). The non-adoption of a good or service that helps a household save money is often viewed as an example of irrational behaviour, but this is because other relevant issues are left out of the equation. For example, individuals can be reluctant to invest in housing insulation because of plans to move house, perceptions of hassle (related to decision making and discomfort during a renovation), or simply because other expenditures (such as buying a new car) are more appealing.

Behavioural change is crucial for system change, but it is also one of the most difficult changes to induce because it constitutes a break with what people are used to and consider normal. For instance, deeply embedded cultural practices such as eating meat, taking long-distance holidays and regularly buying new clothes are very resistant to change. They are culturally accepted and reproduced, despite criticism from subcultures.

Innovations are generally seen as superior to what exists. But at the beginning of their life cycle, innovations can be crudely developed in terms of user needs and be relatively expensive. The diffusion of new complex products (such as battery electric cars) will depend on improvements in performance, the availability of product variations tailored to user design preferences, cost efficiencies in production that reduce prices, and the availability of complementary infrastructure such as charging stations.

3.2. Enablers and hindering factors for eco-innovation

The innovation literature commonly discusses innovation development and adoption in terms of drivers and barriers. The literature on drivers distinguishes between internal drivers within a firm, government agency, or household; and external drivers (del Rio et al., 2017). Horbach (2008) adds technological opportunities (science push), but this can be treated as a specific class of external drivers.

Internal drivers include environmental awareness, responsibility (green ethos), knowledge, resources, skills, and capabilities, which can influence all sectors. Environmental management systems such as ISO 14001 can act as an internal driver by providing an ongoing framework for eco-innovation in the business and government sectors.

External drivers that potentially affect all sectors include regulations, pollution taxes, demand from users (market opportunities), access to financing schemes, subsidies for the adoption of environmentally preferable products or processes, availability of 'enabling infrastructures' (e.g. charging stations for electric vehicles) and institutional and community pressure. An external driver that is largely limited to firms and public research institutes is direct and indirect government subsidies for investment in eco-innovation. Important issues with measuring the concepts of innovation drivers and barriers include:

The concept of an innovation driver requires a causal relationship, such that a focus organisation intentionally reacts to one or more drivers by developing or adopting an innovation. For example, organisational size is not a driver, but simply a variable that has a correlation (usually positive) with eco-innovation. Proving causality is always far more difficult than proving association.

Similarly, the concept of an innovation barrier requires that a focus organisation takes one or more actions in response to one or more real or potential barriers. Otherwise, a specific barrier, although it may be relevant to other firms, is not a barrier for the focus organisation.

There are both proximate drivers that are close to decision making, and distal drivers. Education, general environmental awareness, a good governance system and a culture of entrepreneurship are distal drivers. The distal drivers work partly through proximate drivers and partly via other mechanisms. Past research has mostly examined the proximate drivers of eco-innovation adoption, neglecting the influence of distal factors (Hojnik and Ruzzier, 2016).

Furthermore, drivers and barriers can be context-specific. Similar combinations of concurrent forces may lead to different outcomes depending on different organizational cultures, mind-sets and contextual settings that characterize the temporal and spatial geographies where the companies operate.

Drivers are often the mirror opposite of barriers. For example, the availability of finance at a reasonable cost can encourage firms and households to invest in innovation, while the lack of low-cost finance can discourage investment. The same relationship applies to externalities such as carbon dioxide emissions, although mediated by policy. Unpriced carbon emissions can have no effect on eco-innovation (they are neither a driver nor barrier), but an adequate price on emissions can act as a driver positive stimulus of eco-innovation.

Policy actions such as subsidies, regulations, or environmental taxes can act as drivers, but under many conditions they may not be sufficient, by themselves, to change behaviour. Likewise, the existence of an environmental management system within a firm is unlikely to be the reason for engaging in a process change.

A single driver or barrier is unlikely to be sufficient to influence behaviour. Drivers are better viewed as facilitating factors. For example, a combination of policy regulation, market opportunities, and environmental awareness by managers is considerably more likely to influence a decision to invest in an eco-innovation than each of these drivers in isolation. And, in many cases, a firm, government or individual can refuse to respond to facilitating factors through innovation- at the extreme by exiting a market. Similarly, a firm that faces a cluster of barriers is more likely to defer innovation than if it only faced a single barrier. As a result, it is more accurate to refer to facilitating and hindering factors than to drivers and barriers, but as the latter are widely used, this chapter uses both sets of terms interchangeably.

Facilitating and hindering factors play a role in both the development of eco-innovations and the diffusion of eco-innovations via their adoption by firms, governments and households. It is often the case that the effects of these factors on adoption are a greater challenge than their effects on the development of eco-innovations. This is because regulation is often strongly resented by the firms and households alike and because subsidy policies for adoption are very expensive, unless the subsidies come from taxing dirty products (which is a budget neutral way of promoting an eco-innovation).

3.3. Measurement of facilitating and hindering factors for eco-innovation

Drivers and barriers can be measured on a subjective or objective basis. The existence of a price on carbon dioxide emissions that affects businesses, governments and households is an objective measure. It would only be a facilitating factor if it leads people to do something that they would not have done in the absence of the carbon price. Increasing the level of a carbon tax could make it more effective as a driver of eco-innovation. Likewise, a short payback period for an investment can stimulate adoption, but people use different criteria for an acceptable payback period. For some people, a payback period of 10 years is too long, for others it is not. An objective measure, such as a payback period of 10 years, can thus act as a hindering or facilitating factor, or neither.

Innovation decisions are ultimately determined by subjective assessments about whether something constitutes an economic opportunity that is worthwhile to undertake or not. Innovation projects involve many decisions, with past decisions setting the stage for new ones. Such projects are also affected by the strategies of competitors and the fate of new products in the market place. Longitudinal studies of innovation show that "entrepreneurs and managers cannot control innovation success, only its odds by developing and practicing skills for traversing the obstacles encountered in divergent and convergent cycles of the journey" (van de Ven, 2017). Objective measures, such as the price of a carbon tax or payback period interact with subjective measures such as risk perception, confidence and opportunity. Consequently, facilitating and hindering factors should also be measured using subjective variables and scales. To give an example, regulation can be measured in an subjective way as "perceived regulatory pressure" (as experienced by the company) and in an objective way by using emission limit values as the basis for a calculation. Both types of measures have value.

Objective measures can be derived through data collection on regulations, regulation enforcement, pollution tax levels, ISO 14001 registrations, etc. Surveys are required to obtain subjective measures of the importance of these items on facilitating or hindering innovation. Expert opinion and dedicated research can be used for analysing the evolution of green technology innovation systems (Bergek et al., 2008; Suurs and Hekkert, 2009), especially the formative phase of building a system for new technologies[17].

Many potential hindering factors can be turned into facilitators with policy intervention. For instance, a lack of skilled labour can be turned into an adequate supply of skilled labour through policies for training, a lack of consumer demand can be turned into sufficient demand through policies that provide subsidies for purchasing eco-products such as electric vehicles and a lack of complementary infrastructure can be overcome through policy subsidies to create infrastructure.

For system innovation, however, hindering factors are usually not the opposite of facilitators. Electric mobility requires charging stations, an increase in product models and for consumers to think about total lifetime costs. Barriers to product repair and re-use include a lack of access to and high costs of spare parts, lack of appropriate repair information or independent repair operators, and product design that deters re-use. Some of these hindering factors can be part of a deliberate strategy by companies to encourage consumers to purchase new products over repair.

Many eco-innovations involve two or three SNA sectors. Wherever feasible, the measurement of eco-innovation drivers and barriers should include data and indicators that are relevant to and comparable across the business, government, NPISH, and household sectors. An example is facilitating factors for activities such as recycling, which occurs in all sectors. Regulations, incentives and consumer (household pressure) can facilitate eco-innovation in recycling in the business and government sectors, with spillovers into the household sector, as when a municipality introduces new recycling systems for the collection of household waste and provides householders with an online means of suggesting improvements. Another example that involves the government and household sectors is smart city innovations to protect the green canopy, where user-developed apps remind citizens that live adjacent to trees on public boulevards to water the trees during periods of drought.

With the increasing use of co-creation to develop eco-innovations in both the business and government sectors, the role of the household sector as a facilitator of eco-innovation is likely to increase in importance, suggesting a need to collect data on the role of households as both a passive facilitator of eco-innovation via demand and their role as an active facilitator as a participant in eco-innovation. Examples of citizen-based initiatives that can become part of the NPISH sector are citizen energy cooperatives for renewable energy, repair cafes, and co-housing. There has also been a large growth in sharing platforms. Businesses and governments are involved in these initiatives to different degrees. Many sharing platforms are privately owned and commercially run, while local authorities are often involved in district heating cooperatives.

When the opposite of a barrier is a driver, it is not recommended to collect data on both of them. The issue is which is more useful to collect. Policy makers and analysts have a long-standing interest in collecting data on hindering factors because these are viewed as problems that can be solved through government intervention. This explains the common use of survey questions for businesses on factors such as a lack of skilled workers, the cost of electricity, and the effect of red tape. The problem is that analyses of data on barriers to innovation in multiple countries, including Canada and Europe, have consistently observed counter-intuitive results: the more innovative the firm, the greater the importance given to barriers. This also applies to comparisons between innovative and non-innovative firms, with innovative firms rating barriers of greater importance than non-innovative firms. D'Este et al. (2012) describe this phenomenon as the 'revealed barriers' effect. The explanation is that the more innovative the firm, the greater the awareness of possible barriers as a result of direct experience. Yet while this is a good explanation, it does not help the policy interpretation of data on barriers, which would imply that policy should ignore barriers with high importance rankings on the grounds that they are positively correlated with excellent innovation performance. Furthermore, responses to questions on barriers can represent ex-post "justifications" that neither capture actual barriers nor the opposite role of barriers as innovation facilitators, or the responses can be due to 'received wisdom' where respondents provide answers that do not necessarily reflect the experience of their firm, but reflect widespread assumptions such as regulations are a hindrance.

Data collection needs to obtain additional data that can assist with interpreting information on facilitating and hindering factors. For the business sector, these include data on a firm's location, age, industry, size, other innovation activities, and the regulatory regime that it faces. Eco-innovation can vary by all of these factors. For example, regulation activities and environmental subsidies are more important for firms in Eastern European countries than in West European countries with higher per capita GDP. In addition, firms in Eastern European countries rely more on competitors and external R&D as information sources (Horbach, 2016). The effects of a policy are likely to differ across firms. In the Netherlands, the R&D tax credit was a deciding factor for projects taking place in 19% of the companies with less than 10 employees. For companies with more than 200 employees, the decisiveness was considerably lower: only 4% of the companies would not have done the project without the WBSO (Brouwer et al., 2002).

Data collection could also cover the sources that policy makers use to obtain information on facilitating and hindering factors. For example, the Reuse and Recycling EU Social Enterprises network (RREUSE), a European umbrella organisation for social enterprises involved in re-use, repair and recycling activities, provides constructive suggestions for policies to encourage these activities. Data on the use by policy-makers of different information sources for drivers and barriers can be used to improve communication and transparency.

3.4. Types of data for collection

Facilitators and hindering factors for eco-innovation can be classified into four main categories: market (section 3.4.1), policy/regulatory (section 3.4.2.) social section (3.4.3), and technology-specific (section 3.4.4) factors.

Ideally, data collection should cover:

- Possible facilitating and hindering factors.
- Factors of high influence for different populations of prospective adopters or developers of eco-innovations.
- Data on facilitating and hindering factors that are required to evaluate the effectiveness of policies to stimulate eco-innovation development and adoption or to reduce negative side effects.

Data on policy use and outcomes are necessary for policy evaluation research on the reasons for the suboptimal use of an instrument, whether this is related to unanticipated developments, the crudeness of the instrument (taking insufficient care of situational differences) and if observed imperfections stem from the influence of the target sector (or industry) on the design or enforcement of a policy.

3.4.1. Market facilitators and hindering factors

Market prices generally do not reflect external costs (for example, the health care costs from air pollution or climate change adaptation costs,) but there are two exceptions. First, insurance rates will change in response to external costs. For instance, insurance rates are likely to increase for housing on a coastal floodplain at risk from both increased rainfall and rising sea levels as a result of climate change. Second, a decline in the average stock market values for a specific industry compared to the average could indicate that investors expect higher costs or declining markets (for instance for environmentally unfriendly products), leading investors to shift to other investment opportunities. However, an increase in insurance costs does not directly drive a change in the behaviour of organisations that cause the problem, unless the organisations causing the problem can be identified and successfully sued for damages. Otherwise, an increase in insurance premiums, such as for flood protection, which are borne by the households, governments and firms affected by increased risks.

Market prices can be made to reflect external costs through special taxes and regulation. According to economic theory, this is the appropriate strategy. Changes in market prices due to regulation, or the monetary cost of enforcing regulations, are appropriate items for measurement.

Investment in research (or lack of research) facilitates (or hinders) eco-innovation by providing solutions to environmental problems and mechanisms to access research results (collaboration, licensing, technology support services, etc.). Research can be funded by government or businesses and conducted by universities, research institutes, or private firms. Knowledge spillovers can create additional opportunities for innovation by other firms and organisations.

Data on R&D spending by businesses are collected in national government surveys. These can identify R&D expenditures of interest to eco-innovation. For example, the United States R&D survey collects data on R&D expenditures for ‘environmental protection'. The IEA collects data on energy R&D by type of activity (for instance for energy efficiency). Government research is often classified by Fields of Research and Development (FORD), which provides detailed information on the purpose of research. For instance, it is possible to identify research on carbon capture and sequestration. However, FORD data at a sufficient level of detail may not be collected or made publicly available.

Finance (or a lack of finance) is an essential facilitator (or hindering factor) for investments in eco-innovation. In 2016, the OECD established a Centre on Green Finance and Investment that should provide quality data on eco-innovation financing in the future. Investment data can be sourced from Bloomberg New Energy Finance (BNEF), which provides subscription-based research and data on renewable energy, carbon markets, energy efficiency, biofuels, carbon capture and storage, nuclear energy, water and power, green bonds and a range of sustainability-oriented debt and equity data.

Supply and quality of skilled labour (or a lack of skilled labour) contributes to the innovation capabilities within a business, government agency or household. The supply of skilled labour can refer to new graduates and be estimated from data on the highest level of educational qualifications or the type of degree held. The quality of skilled labour within organisations can be estimated using the same criteria. Surveys can be used to analyse the role of skills as an enabler and constrainer of eco-innovation (for eco-innovation generally and in specific eco-innovation processes).

Market demand (or lack thereof) for environmentally superior processes, goods and services: Collecting relevant data requires identifying environmentally beneficial goods or services and tracking their sales over time in comparison to other goods or services. For example, the rate of change in the sales share of fully electric, plug in hybrid, hybrid, petrol, and diesel automobiles can be tracked over time. There are many other product types that can be tracked, such as the market share of double (or triple) glazed windows, purchases for insulation and other retrofit materials for buildings, changes in the transport modes in a city (foot, bicycle, public transit, private automobile) etc. In addition, absolute sales levels are also required for products and services to estimate market scale effects.

Over the product life cycle, demand will change from first purchases to replacement purchases. The groups of adopters will also change. First adopters of goods tend to be technology-minded and independent decision-makers (Rogers, 2003). Market demand is not exogenously given, but can be actively encouraged through sales promotion via price, product, place and advertising by manufacturers or service organisations. Direct contact with customers, user centric design, and co-creation helps suppliers to obtain suggestions for product improvement and discover better outlets for sales and advertising. Data collection for facilitating factors should measure the presence of or investment in organisational capabilities to influence markets (marketing activities for eco-innovations) and to respond to user requirements (use of methods to obtain feedback from customers, co-creation, etc.). Eco-labelling Environmental labelling is defined as 'the voluntary granting of labels by a private or public body in order to inform consumers and thereby promote consumer products which are determined to be environmentally more friendly than other functionally and competitively similar products' (OECD, 1991, pp. 12).

Eco-labelling can drive eco-innovation by increasing demand for environmentally-sustainable goods and services. Eco-labelling reduces asymmetric information by informing consumers on the environmental impacts of products and services over their entire life-cycle. Different scheme of eco-labelling are available. In Europe a third party voluntary certification, i.e. EU Ecolabel, was established in 1992 to promote high environmental standards of products and services (Regulation 1980/2000).

Indicators for eco-labels can be constructed from data on the number of licenses by country, region and industry. Data on products and services awarded with eco-labelling licenses are retrievable at the country, region and firm levels. Second, the indicator can capture the socio-technical dimension of the eco-innovation. Eco-labelling is also awarded to products and services that comply with ethical and social aspects in their production, such as health and the safety of consumers. The disadvantage of eco-label indicators is the voluntary nature of eco-labelling. It can therefore underestimate the eco-innovation activities of firms that do not apply for certification. The number of European licenses stood at 1067 in 2010, indicating that the label captures the eco-innovative behaviour of only a few actors.

Transition costs include the cost of switching from sunk capital investments in existing technology and systems to environmentally superior technology and systems. High transition costs, particularly in the early phases of systemic change, are likely to act as a significant barrier to eco-innovation, but their effects are likely to diminish after time and with an increase in complementary investments. Experimentation is required to determine if surveys can collect nominal or ordinal level data on the effect of transition costs on investment decisions. Managers are only likely to be able to estimate the effect of transition costs for specific product lines, suggesting the use of the object approach to measurement (see Chapter 8).

3.4.2. Policy/regulatory drivers or barriers

Regulations can support (or hinder) investment in eco-innovation in all SNA sectors, including the adoption of eco-innovations for goods, services and processes. Regulations include product standards such as housing insulation and energy efficiency standards, vehicle emission standards, recycling requirements, and voluntary rating systems for consumer appliances. A lack of these types of regulations and standards or a lack of enforcement can hinder eco-innovation.

For improving policy, it is important to measure the existence of and influence of regulations on the behaviour of firms, governments and households. Data on the existence of regulations and the penalties for non-compliance can be obtained from regulations published by the relevant government authority. It can be much more difficult to obtain data on enforcement.

Voluntary standards that support (or hinder) investment in eco-innovation can be part of government regulation, such as vehicle emission standards, or voluntary, industry standards, such as the GSM standards for mobile telephony.

Voluntary standards can be environmentally beneficial by creating large markets that support eco-innovation through scale effects. A lack of standards, as for the batteries for electric bicycles, can fracture markets and increase production and consumer costs, as well as reducing consumer flexibility.

Data on voluntary standards may be available from industry groups, but this also requires expert knowledge on where voluntary standards can create larger markets without reducing competition and the types of standards that create opportunities for eco-innovation.

Financial incentives, including for R&D, include direct incentives such as grants and indirect incentives such as tax credits or subsidized graduate students. These incentives can encourage firms to invest in eco-innovation research or infrastructure; and firms, government agencies and households to purchase eco-innovations. Common incentives include grants and subsidies for R&D, investment in eco-innovation infrastructure or power generation, and subsidies for the purchase of eco-innovation products such as bicycles or electrical vehicles. Data on financial incentives should be collected for the type ofprogramme, the target of the programme, and the amount of expenditure on the programme.

Some types of financial incentives can hinder a transition to green technologies, such as subsidies for fossil fuel research, distribution and purchase. Where possible, it is very important to collect data on subsidies for goods and services with negative environmental benefits in addition to finance for eco-innovation.

It is particularly challenging to collect data on indirect financial incentives for R&D, provided through tax credits. But such incentives can be important: in many countries R&D tax credits represent a significant share of overall public support for business R&D (typically over 30% in OECD countries)[18]. Unfortunately, tax authorities rarely provide statistics in sufficient detail to enable analysis of the extent to which indirect measures support or hinder eco-innovation, unless researchers apply for access to micro-data. However, because they are typically technology neutral, R&D tax credits may often be of greatest benefit to incumbent technological systems, and can be a significant source of support to R&D for technologies that have poor environmental performance, such as fossil fuels.

Pollution taxes and emissions trading schemes (ETS) are a type of negative financial incentive (pollution taxes) or an arm's length incentive that is not funded by the government, such as ETS. Relevant data are available from PACE surveys for pollution taxes and from publications on national ETS systems. Data should be collected on the presence of specific types of pollution taxes and ETS schemes and the cost of the taxes/ETS per unit of emissions.

Policies to encourage transitions include subsidies to supply necessary infrastructure or government involvement in coordinating transitions. Collecting data on transition policies will require experts who can identify the infrastructure and coordination needs and the actions of different actors (government, firms) in creating environments that favour transitions (see Chapter 4).

3.4.3. Social drivers or barriers

Political support by citizens for (or against) long-term goals that require eco-innovation is a major factor because it can have a strong influence on policy and the continuity of policy - for instance whether or not a regulation or pollution tax will remain with changes in government. Continuity can play an important factor in business investment decisions. Data on political support can be obtained from opinion polls such as the PEW polls of public opinion in a large number of countries.

Eco-literacy concerns the level of knowledge about the environment among the adult population. Eco-literary is not astraightforward issue. Cultural and peer-group dynamics are more influential than science literacy and the communication of scientific evidence (Kahan et al., 2012). This finding shows the limitation of one-way communication from scientists to audiences including policymakers, business people, and the general public. To deal with the problem, Malone et al, (2018) advocate stakeholder involvement in the discussion of environmental problems because "mutual exchanges among stakeholders (policymakers and others involved in carbon-relevant decisions) bring to light people's values, concerns, and sticking points and allow dialogue needed to establish feasible options and implement programs". In addition, stakeholder involvement helps to identify co-benefits of reducing emissions, which help to gain widespread acceptance. Examples of co-benefits are health benefits from reduced air pollution and new jobs in renewable energy industries (Malone et al., 2018).

Indicators for the involvement of stakeholders in environmental policy (decisions) are covered in Chapter 4. In addition, household surveys could collect data on four types of ecological knowledge (Berkes et al., 2000) that can be used to measure literacy:

- Knowledge about the names of living (e.g., plants, animals) and physical (e.g., soils, water, weather) components of ecosystems.
- Knowledge about the functions and uses of each component.
- Knowledge about the land and resource management systems and the social institutions that govern them.
- Knowledge about the worldviews and cosmologies that guide the ethics of people in the system (Pil grim et al., 2007).

Opinion makers such as NGOs, political parties, media etc. can support (or counter) long-term environmental goals and influence popular support with knock-on effects on eco-innovation. Relevant data include the number and level of corporate and individual donations for pro and anti-environmental NGOs, the number and share of media articles that are pro or anti specific policies with environmental effects (for instance to reduce fossil fuel use), and data on the policy platforms of political parties, which is important for assessing policy continuity with changes in government.

Uptake of 'soft' measures, such as Corporate Social Responsibility (CSR), that encourage environmentally responsible behaviour on the part of businesses and government agencies. Relevant data can be gleaned from the annual reports of firms or government agencies.

3.4.4. Technology specific drivers and barriers

Some facilitating and hindering factors are linked to specific technologies. However, the measurement of technology specific factors needs to be approached cautiously so as not to encourage single technology solutions, but allow for a range of solutions to be used. In some cases this may not be possible, as in the case of electrical vehicles where a driver for adoption would be a developed charging station infrastructure for electric vehicles. In other cases a technology specific identification of factors can be avoided. For example, a facilitator for greater use of renewables such as wind or solar energy generation is a method of storing electricity, but there are several technical options, including pumped storage and battery storage. Consequently, in this case measurement should not specify the type of storage.

For measuring technology-specific factors for emerging technology innovation systems such as biogas, energy-efficient houses, biofuels and electric mobility, innovation researchers have developed a diagnostic tool (Bergek et al., 2008, Hekkert et al., 2007). The tool consists of an assessment of seven functional activities for system development around a technology[19].

In a subsequent step, mechanisms are identified that either induce or hinder development towards the desired functional pattern (Bergek, et al., 2014). Data on mechanisms that cause "system failures" is a precursor to finding remedies. This is important because "neglecting interactions between systemic problems may not only lead to inaccurate problem diagnosis, but also to ineffective or even counterproductive interventions" (Kieft et al., 2017). A manual for Technological Innovation Systems (TIS) analysis for such a task is produced by Hekkert et al. (2011)[20].

3.5. Data sources

Section 3.4 above describes data sources for many potential drivers of eco-innovation, such as insurance rates, the supply of skilled labour, pollution taxes, and popular opinion. Some of these are likely to be linked to specific eco-innovation technologies, such as the effect of insurance rates on climate change abatement technologies or pollution taxes on specific types of pollution. However, we don't know how or if a specific facilitating factor, such as an increase in insurance rates, influences firm or household investment decisions in eco-innovation. Similarly, policy indicators do not tell us if policies to encourage eco-innovation are enforced, adjusted in response to evidence, or effective.

These limitations with data on facilitators of firm behaviour and policy require data on the subjective appraisal of the managers of organisations or households on what influences their investments in developing or adopting eco-innovation and rigorous evaluations of policy effectiveness. Options for data collection include surveying firms, government agencies and households on the facilitating and hindering factors to their eco-innovation activities, or the use of expert appraisals of policy effectiveness (which also includes enforcement).

3.5.1. Surveys

Surveys can be used to obtain subjective data on the importance of various factors in influencing decisions to invest in or adopt eco-innovations. Relevant questions for the business sector can ask about the importance of the following items as facilitators:

- Government subsidies for R&D on eco-innovation
- Government subsidies for the adoption of environmentally friendly technologies
- Market demand for environmentally friendly goods or services
- Pollution taxes
- Emission trading schemes
- Product regulations including recycling requirements
- Product standards
- Availability of finance for eco-innovation or adoption of environmentally-friendly technologies.
- Availability of skilled labour for eco-innovation development or use.
- Expected cost savings.

The following facilitating factors are relevant to the government sector:

- Political demand from citizens for cleaner air, water, green areas (parks, etc.).
- Media attention to environmental issues
- Political pressure from eco-innovation suppliers
- Staffing levels and funding for agencies and minis tries dealing with environmental matters
- Type and source of ideas for system innovation opportunities
- Expert knowledge within government agencies about policy instruments and policy evaluation methods
- Platforms for interaction that allow for useful exchange amongst researchers, public and private actors (Rodrik, 2014: Kemp and Never, 2017).
  The following facilitating factors are relevant to the household sector:

- Municipal or other government regulations about products, waste separation, etc.
- Green labelling of good or services
- Expected cost savings
- Use of subsidies or tax rebates for purchasing environmentally-friendly products or services
- Comfort benefits in the case of energy renovation (to be weighed against the discomfort (nuisance) of renovation work)
- Aesthetics of products (with perceptions of ugliness acting as a barrier).

The relative importance of policy measures was a topic for data collection in the eco-innovation module of the Community Innovation Survey in 2008, using the following questions:

During 2006 to 2008, did your enterprise introduce an environmental innovation in response to:

- Existing environmental regulations or taxes on pollution (yes/no)
- Environmental regulations or taxes that you expected to be introduced in the future (yes/no)
- Availability of government grants, subsidies or other financial incentives for environmental innovation (yes/no)
- Current or expected market demand from your customers for environmental innovations (yes/no)
- Voluntary codes or agreements for environmental good practice within your sector (yes/no).

These questions are of great relevance to policy and research. A limitation is that these questions are asked for all eco-innovations. One way around this problem is to use the object approach and ask for a description of “the most significant eco-innovation”, followed by questions on the drivers for this innovation (see Chapter 8), or ask questions for different eco-innovation types (for instance: product eco-innovation, process eco-innovation, etc.

3.5.2. Expert appraisals

Expert appraisals can provide useful information for areas where an unbiased response from surveys is either unlikely or where other data require careful evaluation. Experts can be particularly helpful in evaluating the effectiveness of specific policies as facilitators, for identifying barriers to system innovation, and for suggesting useful policies to deal with the barriers. The quality of expert appraisals depends on the capabilities of these agents and the rigor of the process.

The OECD approach to evaluating national innovation policy is a good example of an expert appraisal, producing robust knowledge that facilitates policy learning[21]. Participation of a wide range of country experts in producing socially robust knowledge in contexts of uncertainty and diversity makes the investigation more salient and credible by focusing the inquiry on the relevant issues through the involvement of knowledgeable experts from non-governmental organizations (NGOs), environmental and energy organizations, industry associations, international organisations as well as local, regional and national public administrations, in addition to academics (Nowotny, 2013; Borrás, 2012).

Another useful approach is the Bertelsmann Stiftung indicator system for sustainable governance indicators (SGI) (Stiftung Verlag Bertelsmann, 2017), in which experts provide descriptions and indicators for variables that are not easily measured such as environmental policy stringency. The SGI uses a combination of qualitative assessments by country experts and quantitative data drawn from official sources. The process is described in full elsewhere[22], but follows six steps: the creation of an expert report for a specific country, an evaluation of the report by a second expert, mediation between the two experts if there is any disagreement, calibration of reports from different countries, approval by an Advisory Board, and final edition and publication by sgi-network.org.

Annex Chapter 3 gives an example of the SGI method for the stringency of environmental policy. Elements of the approach have been used for a 12-criteria appraisal system for eco-innovation and sustainability transitions (Miedzinski et al., 2017). The goal is to create a network of experts and practitioners that use the SGI method to (peer) review, compare and contrast relevant data, producing ing reports that can capture the nuances related to eco-innovation and benchmark country performance.

4

POLICIES FOR ECO-INNOVATION AND GREEN ECONOMY

Michal Miedzinski, René Kemp and Serdar Türkeli

This chapter covers three dimensions of measurement and analysis relevant for policies for eco-innovation and the green economy: mapping the policy landscape, analysing policy effects, and appraising policy mixes. Proposals for measurement and evaluation are given.

4.1. The framework for analysing and measuring policies in support of eco-innovation

Public policy is a key driver of eco-innovation and therefore an important area of research and measurement. There are three main reasons for developing indicators of relevance to public policy. First, they can be used to assess the effects of public interventions on eco-innovation and their contribution to wider socio-economic and environmental impacts. Second, they can be used to identify policy features that most effectively and efficiently improve environmental outcomes. Third, they can be used to adjust policies to support a transition from one sociotechnical system to another, such as the change from transportation based on fossil fuels to transportation based on zero-carbon energy. In a dynamic world of evolving technologies and changing prices, policies are likely to become unnecessary or in need of change. As noted by Rodrik (2014: 472), the policy process needs "a set of mechanisms that recognizes errors and revises policies accordingly".

Policies for eco-innovation and the green economy consist of all policies relevant to the development and diffusion of eco-innovation and the phasing out of environmentally disruptive technologies, products and practices. The two most relevant policy domains are innovation policy and environmental policy (Kemp and Pontoglio, 2011, Horbach, 2016), but relevant policies also include competition law, intellectual property law, market liberalisation programmes, education policies, sectoral strategies, territorial cohesion strategies, public procurement, etc. With so many policies relevant to eco-innovation, it is important to investigate whether and in what way each policy acts as an enabler or hindering factor for eco-innovation. As policies are designed for different reasons and because the effects of a policy instrument will differ across sectors and companies, a given policy could have no influence on some actors, or even hinder eco-innovation. Therefore, an important aim for measurement is to support policy learning, so that policies can be altered to reduce negative effects and enhance positive effects.

In order to better inform policy design and support policy learning, measurement needs to identify the specific features and characteristics of policy instruments and policy mixes, the characteristics of policy processes and governance, and the institutional capacity and competences needed to design, implement and evaluate effective eco-innovation policies.

This chapter covers three dimensions of measurement and analysis relevant for policies for eco-innovation and the green economy:

- Mapping the policy landscape: Instruments, investments, processes and actors (Section 4.2);
- Analysing policy effects: Analysing the effects and tracing the impact pathways, while taking into account the innovation ecosystem in which policy interventions are designed and implemented (Section 4.3);
- Evaluating policy mixes: Focus on specific features of policy mixes in order to evaluate policy performance (Section 4.4).

Section 4.4 summarises the key messages and challenges.

4.2. Mapping the policy landscape and governance of eco-innovation

4.2.1. Key dimensions of policy mixes

While R&D policy can help facilitate the creation of environmentally friendly technologies, it provides little incentive to adopt these technologies (Newell, 2010, p. 263). Adoption, important for follow-on improvements, calls for demand-side measures, resulting in a mix of supply and demand policies. In order to analyse the effectiveness and understand the mechanisms and characteristics of a mix of policies, several dimensions need to be monitored and analysed. The evaluation of a policy mix (a combination of multiple policies) is based on a systems approach to policy making that views public policy as an emergent, complex system of interventions, actors and processes that co-evolve over a long period of time (Kern and Howlett, 2009).

Rogge and Reichardt (2016) note that most policy research has used a narrow definition of a policy mix as 'interacting instruments aimed at achieving objectives in dynamic settings' (2016:1623). They argue that analysis of the effect of policy on sustainability transitions requires a broader scope, with attention given to complexity, policy processes and the role of long-term strategies and targets.

In order to reflect the comprehensive nature of policy mixes, policy mapping should encompass the strategic policy framework, the mix of policy instruments, policy processes, and institutional capacity. The following sections describe these dimensions with a focus on their measurable elements.

<u>4.2.2. Strategic policy framework</u>

The strategic policy framework relates to the visions, goals and targets that provide the strategic framework for the policy mix to develop a component of the green economy, such as electric mobility, the bio-economy or the circular economy. Policy visions and goals are often determined through consultation with different stakeholders and societal actors and the use of tools such as policy road mapping, an established methodology for forward-looking policy design (Ahlqvist et al., 2012).

Policy goals and expectations of persistent policy action can be just as important as the actual policies. According to an evaluation of German offshore wind policy, the long-term targets for wind power and the consistency of the instrument mix were crucial to RD&D investment (Reichardt and Rogge, 2016). Adoption decisions depended more on the actual policies (including the consistency thereof). A high level of credibility can partly offset the negative effects of inconsistencies in the policy mix.

With regard to energy and climate change, the IEA (2017) distinguishes between the following types of policy targets:

- Climate change policy targets: The primary sectoral categories are Buildings, Appliances, Transport, Industry and Energy production (including renewable energy). Carbon Capture and Storage (CCS) is also included and relates to initiatives in industry or power.
- Energy efficiency policy targets for buildings, residential appliances, commercial equipment, lighting, transport, and energy utilities (IEA's 25 Energy Efficiency Policy Recommendations)
- Resource efficiency and circular economy policy targets: Targets for raw materials, critical raw materials, waste management, recycling, remanufacturing or re-use.
- Renewable energy policy targets: Targets for energy generation or share of energy from renewable sources, divided into the type of renewable (hydropower, solar, wind, geothermal etc.).
- Multi-sectoral policy targets: Targets for several sectors, for example a programme to reduce house hold energy consumption could target buildings, appliances and renewable energy production.

Indicators for strategic policy frameworks are mostly descriptive and include:

- Explicit mention (yes or no) of innovation in the long-term vision for sustainable development in a country's strategic documents for the target area for policy support.
- Relevant policy goals and targets for eco-innovation or the green economy in research and innovation policy and in other relevant fields (e.g. construction, transport, food).
- The type of policy document with eco-innovation or green economy objectives and targets (e.g. regulatory acts, strategic policy documents, government programmes, white papers and communications).
- The legal status of policy documents (binding, optional).

- If objectives explicitly call for eco-innovation or not (resource efficiency improvements due to eco-innovation, emission reduction due to energy efficiency, etc.).
- Descriptive data on policy targets (e.g. indicators used, time horizon, stringency of goals and targets, if they are mandatory or voluntary).
- Level of ambition of goals and targets in comparison to international goals and targets, previous goals and targets, or to science-based scenarios.
- Use of a formal definition of eco-innovation (yes or no) and the criteria used to define eco-innovation.
- Use of scientific evidence to support targets and goals (e.g. citations of scientific studies or models).

4.2.3. Policy instruments and instrument mix

Policy instruments are used to achieve government goals. Eco-innovation can benefit directly or indirectly from policy instruments across various policy fields. Table 4.1 provides a taxonomy of policy instruments to support eco-innovation and describes basic indicators that can be collected for each policy. Additional customized indicators can be constructed on the content of specific policies for technology guidance, collaborative platforms and infrastructure, and the governance and regulatory framework.

Information about financial support can be obtained from policy documents (government budget and spending overviews) and existing databases. For international comparisons, financial and data can be standardized by national GDP or population. The presence or non-presence of many instruments can be ascertained from internet-based searches and from experts. Data for many policies can be difficult to standardize for international comparisons because of differences in design, but alternative methods can be used, such as comparisons based on the presence or absence of general policy types or the use of the STIR model described in section 4.5.

Data on funding can be used to compare the degree of support given to renewables with the support given to fossil fuel technologies. The data can also be used to identify hotspots of eco-innovation support and cold-spots with little or no support. For assessing the need for policy, another approach is needed: one that starts from identified barriers or challenges to a certain type of innovation or technology areas and examines whether there exist policies which deal with those barriers. Analysis into why barriers exist is useful for identifying flaws in policy processes (in terms of governance and the sources of knowledge used) and for uncovering deeper explanations for barriers such as resistance from users or incumbents or from infrastructural lock-ins.

Table 4.1. Policy instruments for eco-innovation or the green economy

Instrument: Direct financial support for eco-innovation / Green Economy

Category	Indicators
Institutional funding for public research organisations (universities & PRIs)	Level of funding for eco-innovation/green economy research; funding share on eco-innovation / green economy out of research total funding; change in funding share over time.
Project grants for public research organisations (universities & PRIs)	Level of funding for eco-innovation/green economy research; funding share on eco-innovation / green economy out of total funding; change in funding share over time.
Grants for business R&D and innovation	Level of funding for grants to businesses for R&D and innovation for eco- innovation/green economy research; funding share on eco- innovation/green economy out of total funding; change in funding share over time.
Centres of excellence grants	Number of centres fully or partially dedicated to eco-innovation research; Level of funding etc. Note that many centres of excellence will be a sub- et of public research organisations.
Procurement programmes for R&D on eco-innovation	Level of funding for Green Public Procurement (relevant for adoption) and innovation; pre-commercial procurement (relevant for R&D, design, experimentation and demonstration); procurement with specific criteria encouraging eco-innovation.
Fellowships and postgraduate loans and scholarships	Number and funding for fellowships and postgraduate loans and scholarships explicitly focused on eco-innovation relevant topics; change in funding share over time.
Loans and credits for innovation in firms	Level of funding for loans and credits for eco-innovation in firms, share of funding for innovation in firms; change in funding share over time.
Public finance	Level of funding for publicly financed loans and credits for eco-innovation (e.g. public investment or development loans and financial mechanisms, e.g. guarantees, that are channelled to 'green' projects or eco-innovation research); share of total publicly financed loans, change in share over time.
Feed-in Tariffs	Level of payments to the outcomes generated by eco-innovations, often applied to renewable energy technologies; rate of payment per unit produced.
Equity financing	Level of public funds for venture capital and other forms of equity financing spent on eco-innovative, level of funding over time.
Innovation vouchers	Level of funding for innovation vouchers[23] for eco-innovation projects.

Instrument: Indirect financial support

Category	Indicators
Corporate tax relief for R&D and innovation	Rate, level and share of tax relief for R&D and innovation that is for eco-innovation. Can be difficult to measure because tax credits for R&D are typically technology-neutral.
Tax relief for households for R&D or adoption of eco-innovation	Rate and level of tax relief to households for the promotion of eco-innovation goods and services.
Debt guarantees and risk sharing schemes	Debt guarantees and risk sharing schemes with preferential conditions for investments with lower environmental impacts.
Taxation of environmentally-harmful technologies	Levy or purchase tax on harmful technologies.

Instrument: Technology guidance and business advisory services

Category	Indicators
Technology transfer and business advisory services business.	Number of centres and level of funding for national/ regional technology transfer and business advisory services that are fully or partly focused on eco-innovation and business advisory services for eco-innovative
Business incubation advice	Number of centres and level of funding for business incubation advice that is fully or partly focused on eco-innovation

Instrument: Collaborative platforms and infrastructure

Category	Indicators
Clusters and other networking and collaborative platforms	Number and level of funding for programmes to support clusters and other networks and collaborative platforms specifically focused on eco-innovation (e.g. clean tech clusters)
Dedicated support to new research infrastructure	Level of funding for new research infrastructure of relevance to eco-innovation research and demonstration (e.g. new materials testing facilities, emission testing facilities, toxicity testing labs)
Information services and databases	Number and level of funding for information services and databases focused on eco-innovation and/or addressed to eco-innovative companies and other relevant stakeholders

Instrument: Governance and regulatory framework

Category	Indicators
National strategies, agendas and plans	Number of national strategies, agendas and plans that are fully or partly focused on eco-innovation. See also section on strategic policy framework.
Creation or reform of governance structures or public bodies	Number of created or reformed of governance structures or public bodies with specific mandates and tasks related to eco-innovation (e.g. new department in ministry focused on eco-innovation or new regional agency focused on environmental technology). See also section on Institutional capacity.
Policy intelligence e.g. evaluations, forecasts)	Number of thematic evaluations and foresights focused on eco-nnovation. See also section on Institutional capacity.
Formal consultation of stakeholders or experts	Number of formal consultations of stakeholders or experts with an explicit focus on eco-innovation. See also section on Institutional capacity.
Horizontal STI coordination bodies	Number of STI coordination bodies that explicitly recognition the role of eco-innovation in horizontal STI (e.g. adding topics related to eco-innovation to agendas of STI councils); share of all STI bodies that recognize role of eco-innovation. See also section on Institutional capacity.
Product and process standards and certification	Number and share of total; examples include energy performance standards for appliances, equipment, and buildings.
Labour mobility regulation and incentives	Number of labour mobility regulations and incentives designed to encourage mobility of staff with competences relevant for eco-innovation (e.g. eco-design, environmental impact assessments)
Intellectual property regulation and incentives	Funding for intellectual property regulation and incentives with a specific focus on eco-innovation (e.g. by promoting open access to relevant IP or by supporting young eco-innovative firms).
Public awareness campaigns and other outreach activities	Funding for instruments to increase eco-innovation knowledge, awareness and training among stakeholders or the general public (information campaigns, targeted training programmes, labelling schemes that provide the purchaser with information on a product's energy usage or emissions performance (IEA, 2017).
Science and innovation challenges, prizes and awards	Number and funding for S&T challenges, prizes and awards focused on eco-innovation (e.g. prizes fully devoted to eco-innovation; specific prizes on eco-innovation within larger prize schemes)

Source: Policy taxonomy adapted from EC-OECD STI Policy Survey (2017).

4.2.4. Policy processes

Six policy processes are relevant to the policy mix for eco-innovation: agenda setting, policy design, policy implementation, policy monitoring and evaluation, policy coordination, and stakeholder participation.

The choice of indicators for each policy process depends on the context of data gathering exercises. Due to the high costs of data collection for policy processes, it may be necessary to give priority to indicators with the highest relevance for evaluation and monitoring. The next section lists relevant data of relevance to each of the six processes.

Agenda setting

Visioning activities

- Discussion of different types eco-innovations for achieving the vision
- Status of the visioning process (formal or informal)
- Methods and type of evidence used in the visioning process
- Transparency (the vision is or is not published as an official document and made publicly available)
- Openness of the vision process (methods and channels of consultation e.g. conferences, workshops, interviews)
  - Number and types of questions on innovation in consultations
  - Number and roles of ministries and agencies involved
  - Number and level of government officials involved
  - Number and types of external stakeholders involved
  - Transparency of the process (e.g. availability of documentation).
- Frequency of the visioning process (Is the process to be repeated or revisited? at what intervals?)
- Coherence of the visioning process (Does the visioning process take into account other relevant strategic processes?)

Prioritisation and target setting process

- Methods and evidence used in the prioritisation and target setting process
- Transparency of the process (e.g. availability of documentation)
- Coherence of the prioritisation process (Does the process take into account other relevant strategic processes?)
- Frequency of the prioritisation process (Is the process to be repeated or revisited? At what intervals?)
- Openness of the prioritisation and target setting process (methods and channels of consultation: conferences, workshops, interviews)
  - Inclusive or exclusive process (views of non-governmental actors considered)
  - Types and number of stakeholders involved
  - Types and number of inputs received
  - The use of scientific evidence in the process
- Consultations seeking validation of priorities and targets:
  - Openness of the process (open for participation or by invitation only)
  - Types and number of stakeholders involved
  - Types and number of inputs received
  - The use of scientific evidence in the process

Policy design

- Selection of policy instruments
  - Methods and evidence used in the policy design process (e.g. how advantages and disadvantages of various instruments are assessed)
  - Coherence of the policy design process (Does the process take into account other relevant policies?)
  - Use of evidence (use of evidence from ex-post evaluations of previous policies?)
  - Use of risk minimization methods (e.g. via ex-ante policy evaluations, impact assessments, simulations, etc.)
  - Transparency of the process (documentation available)
- Design of specific instruments
  - Methods and evidence used in the policy design process for specific instruments

- Use of evidence in the process (e.g. from policy evaluations)
- Considers risky nature of eco-innovation (e.g. inclusion of experimentation and de monstration measures)
- Coherence of the policy design process
- Transparency of the process (documentation available)

• Design of policy portfolios
  - Existence of processes to design policy portfolios and instrument mixes
  - Methods and evidence used in the policy design process
  - The use of evidence (e.g. the use of evidence from policy evaluations)
  - Coherence of in the policy design process
  - Transparency of the policy design process (documentation available)

• Budgeting
  - Budgets and forms of financial support (e.g. grants, subsidies, credits and loans, guarantees, tax reliefs)
  - Transparency of the budgeting process

Policy implementation

• Implementation system
  - Mapping of bodies responsible for implementation of instruments (competence mapping, multilevel governance perspective)
  - Monitoring and reporting (Design of monitoring and reporting systems, data collection)
  - Adaptability and flexibility (possibility to adapt policy implementation to specific local contexts or situations, participation of local and regional administrations in implementation, etc.)
  - Implementation resources (institutional capacity, availability of sufficient staff, technical resources, financial resources)
  - Coordination mechanisms (see also section on Institutional capacity)
  - Mechanisms to ensure consistency and coherence of instrument mix (information excchanges between ministries, working groups, correction mechanisms etc.)
  - Mechanisms to ensure participation and concertation (use of public-private-people partnerships, established contacts with existing policy networks, advocacy coalitions around challenges, etc.)

Policy monitoring and evaluation processes

• Policy monitoring and evaluation data
  - Number of indicators created and quality of monitoring data for eco-innovations
  - Number of indicators created and to measure impacts of eco-innovation on environmental outcomes.
  - Types and quality of scientific evidence and expertise used
  - Stakeholder participation in developing evidence base of policies for eco-innovation.

• Evaluation
  - Evaluations of the effects of instruments on the production of eco-innovations
  - Evaluation of supported eco-innovations on environmental outcomes

• Policy learning processes
  - Presence of learning from co-design, experimentation and demonstration measures
  - Number of dedicated working groups involved in policy learning (status, number of participants, frequency of meetings)
  - Evidence of the use of evaluation in policy design (e.g. citations, processes)

Policy coordination processes

• Coordination mechanisms between legislative and executive powers (formal and informal meetings to ensure consistency and coherence)
• Coordination mechanisms across government ministries (formal and informal meetings to ensure consistency and coherence)
• Coordination mechanisms with stakeholders (for mal and informal meetings to ensure consistency and coherence)
• Coordination mechanisms between national and sub-national authorities of regions and cities (for mal and informal meetings to ensure consistency and coherence)

• Coordination mechanisms between sub-national authorities of regions and cities (formal and infor mal meetings to ensure consistency and coherence).

Stakeholder participation

• Openness of policy process
  - Inclusive or exclusive process design (e.g. open invitations to take part in consultations published online and/or in print media, active engagement of various types of stakeholders, existence of mechanisms allowing for wide participation, level of openness at different phases of policy process from agenda setting to policy evaluation)
  - Nature of stakeholder engagement at different stages of policy (idea sourcing, data provision, expert opinion to co-design and co-implementation of instruments; physical and virtual participation)
  - Openness to criticism and learning (processes allow the expression of critical views on government positions by stakeholders, government processes allowed to take account of critical views by stakeholders)
• Mapping types, roles and engagement of actors in different phases of policy:
  - Types and numbers of actors involved in the policy process at different stages (numbers by type of actors, interests represented (businesses, NGOs, regions, etc.); level of engagement of disadvantaged groups and citizens).
  - Types and quality of inputs by stakeholders in policy process (e.g. number of position papers and other types of inputs submitted, authorship of positions, scientific quality of positions submitted, channels used to communicate positions etc.).
• Prevention of regulatory capture
  - Actions taken to prevent undue influence on process by incumbents or commercial interests

4.2.5. Institutional capacity

Effective policies for eco-innovation depend on well-developed institutional capacities to make good policy choices and correct policy imperfections. These include capacities in strategy, inter-ministerial coordination, policy intelligence, consultation and communication, implementation and learning and adaptation. Examples of types of data to collect are given below for each type of capacity.

Strategic capacity

Data on the existence of strategic planning and the extent to which eco-innovation policy is a part of strategic planning can be collected for the number of entities (units, commissions etc.) involved in eco-innovation and the number of personnel devoted to eco-innovation or related topics such as environmental sustainability:

o Number of planning units of relevance at the centre of government (number, educational attainment of personnel, years of experience of allocated personnel)
o Number of devoted personal advisory cabinets for ministers
o Number of devoted personal advisory cabinets for president/prime minister
o Number of devoted extra-governmental bodies
o Number of non-governmental academic experts involved in the decision-making process
o Number of expert commissions
o Number of cooperation projects between govern ment and academia
o The frequency of meetings between strategic plan ning staff and the head of government
o The frequency of meetings between government and non-governmental academic experts
o The extent to which long-term eco-innovation challenges are addressed.

The measurement of the above variables may not be easily do-able and the measures capture policy inputs, not the quality of the output. The quality element of strategic capacity can be assessed through diagnostic questions, where a diagnostic approach towards strategic capacity would seek answers to questions such as: Are relevant actors involved in strategic discussions about the need for policy and the desirability of a policy programme in light of market uncertainties, the relative advantages and costs of alternatives?

Inter-ministerial coordination capacity
Possible measures of inter-ministerial coordination capacity for eco-innovation include:

- Existence of inter-ministerial coordination, and the extent to which eco-innovation policy benefits from this inter-ministerial coordination by measuring:
  - The existence a relevant government office (including number, educational attainment, years of experience of its allocated personnel)
  - Ministry demand for evaluations of eco-innovation policy
  - Use of eco-innovation policy considerations in developing strategy
  - Number of ministries interacting with government office in the preparation of eco-policy proposals
  - The extent to which cabinet committees and ministerial committees are able to coordinate eco-innovation policy proposals prior to cabinet meetings.
  - The extent to which ministry officials and civil servants coordinate the drafting of eco-innovation policy proposals with other ministries before eco-innovation policy proposals reach political coordination bodies (such as ministerial commit tees or the cabinet).
  - Number and frequency of informal coordina tion mechanisms to support formal mechanisms of inter-ministerial coordination (e.g., coalition committees, informal meetings within government or with party groups, informal meetings across levels of government) .
  - The extent to which ministry officials and civil servants coordinate the drafting of eco-innovation policy proposals with other ministries before eco-innovation policy proposals reach political coordination bodies (such as ministerial commit tees or the cabinet).
  - Number and frequency of informal coordina tion mechanisms to support formal mechanisms of inter-ministerial coordination (e.g., coalition committees, informal meetings within government or with party groups, informal meetings across levels of government) .
  - The extent to which government achieves cohe rent eco-innovation policy communication (e.g. coordinating communication across ministries).

The assumption that more is better may not be true. For assessing the quality of inter-ministerial coordination diagnostic questions are useful. A diagnostic approach towards inter-ministerial coordination would seek answers to questions such as:
Is there sufficient inter-ministerial coordination? Are all relevant ministries included in an even way? Is coordination appraised by a high-level committee (involving independent experts)? Positive answers to those questions would lead to a high score in a policy scoreboard. Numerical values can be assigned to qualitative measures such as poor, quite good, very good.

Policy intelligence capacity
Policy intelligence capacity can be measured through the use of regulatory impact assessments and the extent to which eco-innovation policy knowledge management benefits from these impact assessments. Data collection can address the following activities:

- Assessments of the effects of eco-innovations on the public budget
- Assessments of the compliance costs for businesses, public administration and citizens of eco-innovation policies
- Use of ex-ante simulations of eco-innovation impacts in policy development
- Assessments of ex-post evaluations of eco-innovation policies
- Level of in-house expertise in effective and efficient policy design (presence or number of personnel with graduate degrees in policy design / evaluation, experience in designing effective and efficient policies.

Useful diagnostic questions are: are policy proposals subjected to ex-ante appraisal, are policies evaluated ex-post and is there sufficient in-house knowledge for assessing claims from corporate interests (about the effects of certain policies) and for designing policies that combine effectiveness with efficiency?

Societal consultation and communication capacity
Rodrik (2014, p 485) assigns a positive role to the embeddedness of policy in business, consisting of 'strategic collaboration and coordination between the private sector and the government with the aim of learning where the most significant bottlenecks are and how best to pursue the opportunities that this interaction reveals'. Platforms for interaction allow for useful exchanges amongst researchers, public and private actors about innovation possibilities and can identify useful policies and obtain buy-in from relevant actors. However, suggestions obtained from platforms must be critically assessed to determine if i) the policy and research suggestions are not influenced by regulatory capture, ii) the policies, mixes and research suggestions insert an element of discipline and predictability in policy, and iii) the public interest is safeguarded by accountability and legitimacy in the design and implementation phases (Rodrik, 2014).

Relevant diagnostic questions include:

- Does the government consults with societal actors trade unions, employers' associations, leading business associations, opinion leaders, religious communities, and social and environmental interest groups in preparing its eco-innovation policy?
- Is there evidence that consultations are considered at different stages of policy processes (e.g. existence of easily accessible account of consultations)?
- Are the embedded relations healthy, based on discipline and is the public interest sufficiently safe guarded?

The answers to these diagnostic questions can be transferred into scores for a policy scoreboard. Especially the question of healthy embedded relations is critical for creating policies that serve the public interest and not just those of business organisations with large pockets of money.

Implementation capacity
Data collection for implementation capacity, or the ability to effectively and efficiently implement policy instruments, can cover the following topics:

- Use of incentives to ensure that ministers implement the government's eco-innovation policy
- Use of monitoring of policy implementation by executive agencies and local authorities
- Level of training on implementation by personnel responsible for it
- Level of flexibility in implementation given to different agencies or local/regional governments

Possible answer categories are: high, moderately high, not so high and low.

Learning and adaptation capacity
The capacity to learn from previous policies and to adapt policies to new knowledge and circumstances depends on two pillars: *evidence-based evaluations* that allow policy lessons to be drawn, and an ability to make societal actors accept policy changes. The latter depends on the distribution of costs and benefits, but also on open statements that the policies will be reviewed and adjusted. Industry does not mind policy change per se. What they seek to resist are abrupt policy changes (such as the termination of a subsidy programme for a budgetary reason or because of a new government). A commitment to a sequential approach helps to make use of contingencies and lessons, while maintaining a sense of direction. This can take the form of an announced path for increasing carbon taxes, a gradual tightening of regulations and standards, or the testing of policy actions in pilot projects before wider use (Kemp and Never, 2017).

An example of policy learning is the Top Runner programme for improving the energy efficiency of products in Japan. The scheme covers a variety of products, including passenger cars, room air conditioners and electric rice cookers. Based on detailed market and engineering information, standards are set for energy efficiency by Evaluation Standard Subcommittees and authorized by the Ministry of Economy, Trade and Industry (METI). METI also considers proposals for revision and adaptations when the target year is reached[24]. The measurement of policy learning is discussed in the next section.

4.3. Measuring policy effects

4.3.1. Types and dimensions of policy effects

Analyses of the effects of policy on eco-innovation must consider different areas, scales and timeframes. In addition, a systems perspective needs to account for the context in which an intervention is implemented, often analysed as existing and emerging drivers and barriers to eco-innovation.

Eco-innovation can have both economic and environmental impacts. Economic impacts at the level of the firm include changes in productivity and sales from new-to-market products etc., while sectoral economic impacts can include productivity (value-added) and employment. Environmental impacts can be measured using Environmental Life Cycle Analysis (E-LCA) (see 1.3.9). Consequential LCA examines changes in environmental pressures and the environmental profile of a good or service, whereas attributional LCA only examines the latter.

Given that the rationale of public support to eco-innovation is driven by both environmental and economic challenges, it is crucial that indicators capture both the economic and environmental impacts of policy. There is also a need to extend eco-innovation indicators to consider social impacts of eco-innovation through the use of social impact assessment methods[25].

The effects of public intervention can be studied at different scales: the micro-scale (products, services, organisations, households), meso-scale (sectors, value chains) and macro-scale (countries, regions). The influence at the micro-level can be studied through counterfactual analysis that estimates the additional amount of R&D conducted that is due to the subsidy. Meso-level effects can be studied via sector surveys, where the sample size should be large enough to identify heterogeneous effects. For analysing the effects of eco-innovation diffusion at the macro-level, environmental rebound effects from cost savings need to be accounted for. Table 4.2 provides examples of indicators of the environmental pressures of eco-innovation at different scales.

Analyses of the causal links between policy intervention and its effects must take into account the evolution of effects over time. In this respect, evaluation and impact assessment studies commonly differentiate between outputs, outcomes and wider impacts (OECD, 2010):

- Output: The products, capital goods and services or behaviours that result from a policy intervention.
- Outcome: The short-term and medium-term effects of the outputs.
- Wider impacts: Intended and unintended primary and secondary long-term effects from one or more policy instruments.

4.3.2. Policy causality

The key question that any analysis of policy impacts has to answer is to what extent and in what way observed changes in eco-innovation performance stem from policy interventions (individual policies and policy mixes). In general, the level of confidence with which the observed or anticipated changes can be attributed to policy intervention is highest for the immediate outputs and outcomes of individual instruments. Sophisticated methods are required to analyse the long-term impacts of one or more policy instruments.

Several methodological methods are available for assessing the innovation effects of environmental policy and innovation policy instruments (Kemp and Pontoglio, 2011). Each method is prone to limitations. Ideally, a mixed-method methodology can be used to examine the impacts of policy on eco-innovation. An example is to undertake interviews with industry and technology suppliers about the drivers of technology development and adoption before doing econometric analysis (Kemp and Pontoglio, 2011). This will reduce the risk of econometric misspecification and the risk of accepting econometric results at face value. Since the effects depend on the design of the instrument and contextual circumstances, data must be collected on both the policy design and the context.

Table 4.2. Indicators of environmental pressures for eco-innovation

	Micro level		Meso level	Macro level
	Productions of goods / Services	**Consumption by households**	**Industries / Value chains**	**Countries / Regions**
Materials[1] (mass units: kg or tonnes)	Material Input per Service unit (MIPS)	Material use per household	Material use by industry Domestic/ Raw/	Total MaterialConsumption (DMC/RMC/TMC); Physical Trade Balance
Water[2] (volume: units: litres and m^3)	Use per unit of output of good or service. Product water footprint.	Use per household by type of water	Use by industry by type of water	National water abstraction. Water Exploitation Index (with drawal relative to supply). National water footprint (incl. embodied water)
Land[3] (area units: m^2 or hectares)	Land requirement per unit of good or service. Product land footprint	Land use per households by type of land (brownfield vs. greenfield)	Land use by type of land (brownfield versus greenfield)	Land area covered by urban areas. Land conversion from one type of land to another. National land footprint (incl. embodied land)
Carbon and Air[4] (mass units: kg or tonnes)	Embodied GHG emissions per unit of good or service. Embodied emissions of key pollutants (small particles, SOx, NOx, VOCs, ozone) per unit of good or service	GHG emissions per household. Emissions of other key air pollutants per household	GHG emissions per unit of output and overall by industry. Emissions of key pollutants per unit of output and overall by industry	National emissions data for GHGs and associated pollutants. National carbon footprint (incl. embodied GHG emissions)

Notes: 1. Where possible, estimates should be based on a LCA of materials use. 2. Where possible, estimates should be based on a LCA of water requirements. Water use changes by time of year may be important. Type of water refers to the use of green (water in soil and available to lants), blue (water in aquifers, rivers and lakes) and grey (used) water. Changes in emissions of harmful pollutants towater may be relevant in some cases. 3. Land use change may be more environmentally damaging in some locations than others. Some indicators of impact in terms of biodiversity and ecosystem services may be required. 4.Where possible, estimates should be based on LCA of GHG emissions and associated local pollutants. Source: Miedzinski et al. (2013)

In general, policy evaluation (especially programme evaluation) requires high quality data on the policy itself, the users and non-users of the policy, and contextual factors. Narrative-based evaluations and qualitative interviews are useful for understanding why certain instruments or processes work or don't work under real world conditions (in terms of desirable actions of businesses or households), but they are not useful for measuring effects[26].

Analyses of the effects of individual policies are typically guided by evaluation criteria and questions targeting specific aspects of these criteria. The typical policy evaluation criteria include relevance, effectiveness and efficiency. Evaluations of policy mixes require an evaluation of interaction effects: whether policies work synergistically, conditionally (on other policies) or antagonistically (Givoni et al., 2013).

4.4. Key messages and measurement challenges for analysing policy for eco-innovation

The need for a systemic view on policy effects on eco-innovation

Data collection for use in analyses of policy impacts on eco-innovation is important for identifying policy weaknesses and for learning about the long-term cumulative effects of various policy instruments. Special attention should be given to the effects of policy mixes for stimulating systemic types of change. Research on the effects of instrument mixes, rather than individual instruments, allows for better ex-ante assessments of the risks of rebound effects and can reveal policy inconsistencies (i.e., policies working against each other). A useful model for evaluating policy mixes and policy agendas is the Sustainability Transition and Innovation Reviews (STIR) framework (see Box 4.1), which offers a method for comparative assessment of, and reflection on, the capacity of policy systems to deliver sustainability transitions. The framework starts from the assumption that any attempt to provide a comparative assessment of country performance should be responsive and open to the divergent contexts and institutional capacities of the countries in question. It is based on a set of diagnostic issues, which are examined with the help of statistical information and expert appraisal.

The STIR framework has a summative and formative evaluation element through the combination of scores and expert-based explanations behind the scores, helping government officials and politicians to undertake action because of gaps in performance due to observed weaknesses. The aim of STIR is to contribute to a policy learning process through a comprehensive policy appraisal framework that aids policy thinking and helps policymakers to undertake concrete steps to improve current policies by appraising the 12 criteria listed in Box 4.1: Agenda centrality, Relevance, Directionality, Environmental policy stringency, Alignment, Legitimisation, Demonstration, Specialisation, Coherence, Distributional impacts, Effectiveness and Policy evaluation and learning.

Box 4.1. The Sustainability Transition and Innovation Reviews (STIR)

STIR is a new policy appraisal framework focused on the role of public policy in supporting innovations to enable transition towards sustainability. The framework relies on literature reviews and the structured solicitation of expert views. STIR supports policy reflection on problem framing, policy design and capacity building for policies to support sustainable innovation.

The process has three main purposes:
- Policy evaluation – STIR is a systemic policy evaluation tool based on a mix of self-assessment and exert appraisal focused on individual countries.
- Public debate and policy learning – STIR can contribute to a policy learning process. It provides a com prehensive policy appraisal framework for national debates and policy reflection on concrete steps to improve current policies.
- International collaboration – STIR aims to stimulate international debate and collaboration on the current and future role of public policy in enabling systemic changes in economies and societies towards sustainability.

STIR maps, analyses and appraises public policy to support innovation for sustainability, taking into account the main phases of policy cycle, including agenda setting, policy design, strategy and decision-making, policy implementation, and policy evaluation. The reviews feature a comprehensive set of 12 appraisal criteria designed to capture the key attributes of public policies supporting innovation for sustainable development. The scores obtained through policy appraisal can be presented as a policy scoreboard.

The appraisal questions cover the following criteria:
- Agenda centrality – the position of innovation for sustainability in the policy debate and policy agenda.
- Relevance – the extent to which policy vision and objectives are consistent and adequate for sustainability challenges.
- Directionality – the extent to which policy is oriented towards sustainability.
- Environmental policy stringency – the extent to which policy protects environment.
- Alignment – the extent to which policy mobilizes change agents for the vision and to engage in transformative eco-innovation.
- Legitimisation – the extent to which choices on the direction of transition pathways have a democratic and social mandate.
- Experimentation and demonstration – the extent to which policy creates strategic arenas for experimen tation and demonstration of transformative system innovation.
- Specialisation – the extent to which policy encourages innovation specialization in the most relevant areas for sustainability impact.
- Coherence – the extent to which the policy mix is coordinated and coherent.
- Distributional impacts – the extent to which policy redistributes costs and benefits of transition between societal groups and regions.
- Effectiveness – the extent to which policy is effective in achieving impact.
- Policy evaluation and learning – the extent to which policy is based on evidence and supported by a learning environment.

STIR is a new initiative developed in the framework of the Innovation for Sustainable Development (Inno4SD) project **(http://www.inno4sd.net/)**

For assessing technology-specific blocking mechanisms, the technology innovation system may be used (Bergek et al., 2008, Hekkert et al., 2007).

Evaluation system as a policy learning system
Policy evaluation systems need to be designed for policy learning. This requires formal monitoring and evaluation studies, deliberative reflection, and the use of research results in the design of further policies. Developing an evidence base for transformative policies is not only about the technical capacity to collect and analyse data, but also about appreciating different methods for analysing data, embracing risk and uncertainty, and building a shared understanding among key stakeholders (Miedzinski, 2015). In the context of future challenges, the process needs to focus on shared understanding of the implications of what is known and what remains uncertain about societal challenges and their impacts. This calls for an integrated approach to monitoring and evaluation of policies that incorporates both a system of data collection and dedicated policy arenas to discuss the evidence.

Key challenges
Despite studies and research projects implemented in recent years, measuring the policy effects on eco-innovation still poses methodological challenges. Data collection is required to meet several key challenges:

- Improving conceptual and methodological approaches linking eco-innovation to other key indicators, most notably to those measuring the UN's Sustainable Development Goals.
- Improving and developing new methods, models and indicators to anticipate and measure trade-offs between economic and environmental effects of public intervention.
- Improving data aggregation methods on meso- and macro scale impacts, taking into account the risk of rebound and other undesired effects.

- Clarifying different analytical scales and scope of eco-innovation analysis, notably in relation to the meso-level analysis (e.g. value chains, functional areas).

5

INPUTS TO ECO-INNOVATION AND GREEN ECONOMY

Christian Rammer, Nicolò Barbieri and Massimiliano Mazzanti

This chapter discusses the measurement of inputs to eco-innovation. Next to traditional indicators (R&D, patents and publications) the chapter discusses new eco-focussed indicators (eco-design, labels, knowledge networks, eco-literacy and the use of trade and FDI data).

5.1. Traditional indicators

Indicators of inputs to eco-innovation can be measured at the level of industries, regions and countries. Three groups of indicators are discussed:

- **Traditional eco-innovation indicators** have been available for some time and include R&D (see the OECD's Frascati Manual), innovation (see the OECD/Eurostat's Oslo Manual), patents and scientific publications. Indicators for eco-innovation are obtained by identifying the eco-innovation component of these indicators. For example, R&D is limited to R&D for developing new environmental technologies or patents are limited to patents of relevance to environmental technology.

- **New eco-innovation indicators** develop new measurement concepts that are deliberately designed to capture eco-innovation. These concepts are better-suited than the traditional indicators to measuring eco-innovation in all its dimensions, but they require separate data collection efforts.

- **Indicator systems** have been developed to provide comprehensive measurement of eco-innovation activities, capturing different dimensions and actor groups. These systems usually employ traditional and new eco-innovation indicators and sometimes aggregate them to create composite indicators or indexes. The Eco-Innovation Score board of the Eco-Innovation Observatory, the ASEM) Eco-Innovation Index (ASEI), and the Global Cleantech InnovationIndex (GCII) are prominent examples of this approach (details of which can be found in Annex 1).

5.1.1. R&D for eco-innovation

R&D activities are relevant to the scientific and technological dimensions of innovation. R&D comprises "creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications" (OECD, 2015; p: 30). R&D expenditures are usually provided as 'intramural' or 'extramural' activities depending on whether they are performed inside or outside the boundaries of a unit. Data on intramural expenditures tracks R&D performed within the focal unit, irrespective of the source of funds, whereas the extramural expenditures covers what the focal unit pays to obtain the results of R&D activities performed by other units (OECD, 2015).

R&D expenditures measure current costs and capital expenditures such as instruments, equipment, etc. An important part of current costs concerns labour costs, including wages, salaries and benefits for human resources devoted to R&D activities. Statistics on R&D investments and R&D personnel are usually provided by sector and are used to gauge trends in R&D activities by the government, business, and NPISHs sectors. R&D by universities and publicly funded PRIs (public research institutes) are often separated out from the government sector. Since R&D expenditure measures the generation of new knowledge, it represents an imperfect measure of one step (creation of new knowledge) in an innovation process that may or may not lead to an innovation. Furthermore, a large percentage of innovation activities do not use R&D (Cainelli et al., 2015; Rammer et al. 2009), particularly in the services industries or for organisational innovation (Arundel and Kemp, 2009).

Almost all R&D is performed by the government and business sectors. R&D expenditures can have several socio-economic objectives. When they are aimed at reducing the environmental pressure of economic activities, R&D expenditures can be employed as an input to eco-innovation. In this case, creative activities increase the stock of knowledge that can be used to create new products, services and processes to reduce environmental impacts over their life-cycle.

Two eco-innovation input indicators can be derived for R&D: expenditures and R&D personnel, although data availability limits the use of the latter.

The only consistent data across OECD countries is for government budget appropriations for R&D (GBARD) in “control and care for the environment”. These refer to budget provisions instead of to actual expenditure. Eurostat provides GPBARD data for European Union countries for different environmental objectives (see Figure A5.1). Government budget expenditures on R&D for eco-innovation are spent by universities, publicly funded research institutes, and by some government ministries. The International Energy Agency (IEA) provides statistics on government expenditures on R&D for multiple countries for different environmental purposes, including energy efficiency, renewable energy, hydrogen and fuel cells, etc.

There is poorer coverage of business expenditures on R&D for eco-innovation. Most data sources do not differentiate between business R&D expenditures for eco-innovation and for other purposes. There are only a few limited sources of business R&D expenditures on eco-innovation for individual firms. One source is the OECD project Environmental Policy and Firm-Level Management, which provides data on R&D expenditures for environmental conservation, but only for the year 2003. The project defined environmental R&D in the business sector in two ways: the share of R&D that is environmentally motivated and the share that is environmentally relevant in reducing environmental impacts either in the company or elsewhere (at the point of use) (Johnstone, 2007). Another option is to use total R&D expenditures for environmental industries such as the renewable energy industry or the water and sewage industry. This requires the unrealistic assumption that the entire amount of R&D expenditures in the industry is for eco-innovation (Barbieri et al., 2016).

There are several other limitations to measuring R&D as an input to eco-innovation. First, R&D expenditures cannot be easily disaggregated across regions, sectors and enterprises due to the difficulties in ascribing R&D activities to multi-plant companies, especially when R&D collaboration occurs between several firms (De Marchi, 2012). Second, data on the number of R&D personnel active in environmental-related R&D are not publicly available. Third, by focusing on formal R&D, these indicators substantially underestimate the role of small and medium enterprises in which knowledge creation typically takes the form of informal R&D (Kleinknecht et al., 2002).

In addition, the classification system employed to link R&D to socio-economic objectives influences the amount of R&D expenditures for eco-innovation. Figure A5.2 gives government R&D appropriations for the EU-28 by NABS2007 (i.e. Nomenclature for the Analysis and comparison of Scientific programmes and Budget). This classification method is more parsimonious than the previous one (Figure A5.1) and does not differentiate between environmental objectives. Possible future changes in classification systems could affect data on R&D expenditures for eco-innovation.

Even with the limitations of R&D data for eco-innovation, tracking total public and private expenditures on eco-innovation R&D is useful as a measure of the priority given by both governments and businesses to environmental issues. However, for micro-level research on eco-innovation, data availability is a serious limitation, particularly in the business sector. This could require specialised surveys or improvements to the data collected in national R&D surveys. Furthermore, to build useful and comprehensive eco-innovation indicators, surveys on green R&D should break down the term ‘environment’ into different categories such as reductions in resource use, pollution prevention, etc., in order to effectively capture the knowledge efforts in each environmental field (Arundel and Kemp, 2009).

5.1.2. Patents for eco-innovation

Patents provide exclusive intellectual property rights to patent holders for a defined period of time (usually 20 years). In return, patent applicants must disclose the technicalities of inventions. In addition, patents are examined for novelty and other characteristics, which ensure the originality of the invention.

Patents provide extensive structured and unstructured data that supports their use as an input indicator for eco-innovation (Tseng et al., 2007). The structured data covers the name and geographical location of the applicant/assignee and inventors, filing dates, technology classification codes, citations to earlier patents and non-patent literature, and the length of the examination process. These data can be readily extracted from patent databases. Unstructured data covers the textual description of the invention and its claims. This information can be extracted using text-mining techniques.

Two main approaches are employed to identify green patents. The first uses the information provided by the technology classification codes. Several classification systems are available, but the most widely used are the International Patent Classification (IPC), the Cooperative Patent Classification (CPC), the European Classification system (ECLA) and the United States Patent Classification (USPC). All classification systems use a list of hierarchical codes whose technological specificity grows with the number of digits. Green patents can be identified by using keywords to search for green technologies in the descriptions of the technological codes. The OECD and the World Intellectual Property Organisation (WIPO) provide lists of CPC and IPC codes for climate change adaptation and mitigation technologies. A widely used list of environmental technological codes is the ENV-TECH (OECD) that detects green patents in the following macro technological fields: environmental management, water-related adoption technologies, climate change mitigation technologies related to energy generation, transmission or distribution, capture, storage, sequestration or disposal of GHG; and climate change mitigation technologies related to transportation, buildings, wastewater treatment or waste management and production or processing of goods. Figure A5.3 shows the trends in patenting activities for different categories of environmental technologies in the EU-28.

The second approach is based on keyword searches (e.g. photovoltaic panels, water management, etc.) within the title and abstract of patent documents (de Vries and Withagen, 2005). Both approaches are often combined to reduce errors from including irrelevant patents or excluding relevant patents. Ignoring this source of error can create an upward or downwards bias in a patent indicator for eco-innovation.

The widespread use of patents as a proxy for inventions of relevance to eco-innovation is mainly due to data availability, increasing computational performance for analysing large databases, and the availability of analytical methods for data extraction. A major advantage is that patent data are available at the micro level and can be aggregated to the sector, industry, region or country level. The European Patent Office maintains a concordance table between patent and industrial classification codes, which can be used to estimate the number of green patents in specific industries. The information on applicants allows for patents to be aggregated by sector and sub-sector (governments, higher education, businesses and NPISH sectors. Figure A5.4 shows the geographical distribution of green patents at NUTS2 level over the period 1980-2012 using PATSTAT 2016. Patents contain data that can be used to address the issue of large differences in patent quality. Data on the number of patent citations, the breadth of the technological content, the number of renewals, and the number of countries for which a patent application is made can be used as measures of patent quality, either in terms of novelty (citations and technological breadth) or commercial value (number of renewals and countries of application).

Patents are public information. Several web platforms provide free access to the patent documents (e.g. Google Patents, Espacenet, etc.), while raw data are available at reasonable cost from subscriptions (i.e. to PATSTAT). The OECD and Eurostat provide aggregated indicators for environmental patents.

Patents have two major limitations as input measures for eco-innovation. First, although frequently described as proxies for innovation, this is incorrect.

Patents measure inventions, whereas an innovation, by definition, must be made available on the market or used within the organisation. Many patents are never used in an innovation. Strategic patents to block competitors, but never used in an application, will be included in patent counts and overestimate inputs to eco-innovation.

Second, not all eco-innovations, including both technical processes and organisational innovations, are patented (Arundel and Kemp, 2009). Innovators can choose alternative methods to protect their innovation from imitation (e.g. secrecy), or the cost of a patent application can exceed the benefits to a firm. Furthermore, patents only capture the generation of new knowledge that can be used for innovation, but not the diffusion of innovations. This is relevant for eco-innovation since many process-related eco-innovations are not developed by the innovator, but by a specialised technology producer (e.g. a mechanical engineering firm) and purchased by the innovator from a supplier. The patent (if any) associated with this eco-innovation will be owned by the specialised technology producer and not by firms that adopted the technology. In addition, patent-based indicators are biased towards the manufacturing sector because most services and service processes cannot be patented.

5.1.3. Publications for eco-innovation

Scientific publications can be used as an indicator for research results of relevance to eco-innovation. Relevant indicators are obtained from bibliometric analysis and capture one output of scientific research. As for patent data, bibliometric indicators can be produced for different fields of environmental research and citations can be used to identify high-impact publications. Unstructured textual information in the title, abstract, and acknowledgements can be used to identify publications related to the environment, energy efficiency, resource efficiency, energy productivity, material productivity, eco-innovation, etc. Barbieri et al. (2016) used the scientific literature on eco-innovation to identify the main topics of research and knowledge trajectories. Scientific publications can capture knowledge diversification across a variety of research fields (Kwon et al., 2016; Türkeli et al., 2018a, Türkeli and Kemp, 2018b) and data on the affiliation of authors can measure collaboration between science and industry. Citations are of value for assessing knowledge flows across countries and regions.

The main databases used to create bibliometrics are Web of Science and Scopus. The majority of the studies employ keyword searches to identify environmental-related publications. Examples of eco-innovation indicators include the number of environmental-related scientific publications and the number per capita, co-authorship of scientific articles, and co-occurrence of research areas within publications. Figure A5.5 shows the trends in published scientific articles on eco-innovation between 1976 and 2016.

An advantage of bibliometric indicators as inputs to eco-innovation is the capability to measure the social and institutional dimensions of eco-innovation dimensions. Relevant publications on eco-innovation are found in diverse research fields, including social science, law and basic sciences. This can reduce a bias towards the manufacturing sector. The main disadvantages are similar to those for patents. Automated keyword searches can include papers that are not relevant to eco-innovation and fail to identify relevant papers.

5.1.4. Eco-innovation input indicators from innovation statistics

Innovation statistics following the Oslo Manual are collected in many European and other countries. For some countries, data are available for one input indicator for eco-innovation:

- The number (share) of firms by industry with innovation activities to reduce environmental impacts (objectives of innovation).

The advantages of innovation statistics based on the Oslo Manual is that they are available for representative samples of firms, often in both the manufacturing and services industries, and they directly cover the production and diffusion of eco- innovations. Unfortunately, only one input indicator is currently produced for eco-innovation, but other indicators are available for drivers **(see Chapter 3)** and for outputs **(see Chapter 6).**

Innovation surveys such as the CIS could be used to collect data on non-R&D inputs into eco-innovation. The following expenditure categories can be used (see also OECD 2018):

- Acquisition of capital goods (machinery, equipment, vehicles, buildings, software, intellectual property rights) used for process technology eco-innovation or for setting up production facilities to produce product eco-innovations

- Cost of own personnel (excluding R&D personnel) engaged in eco-innovation activities

- Cost of material and other supplies (excluding material and other supplies for in-house R&D) that were used for eco-innovation activities

- Purchase of external services (excluding contracted-out R&D) required for eco-innovation activities

5.2. New eco-innovation indicators

5.2.1. Eco-design tools

Firms and organisations can reduce the environmental impact of their products and processes by adopting 'eco-efficiency' design, such as 'Design for Environment' or 'Eco-design'. These methods can reduce material consumption and improve reuse and disposal. Although eco-design is defined as 'the systematic integration of environmental considerations into product and process design' (NCR Canada, 2003), its application has significant economic effects for firms and organisations. Eco-design can improve market appeal and reduce production and delivery costs for goods and services (Knight and Jenkins, 2009). In addition, eco-design can use Life Cycle Assessment (LCA) tools to assess the environmental burden of products (Bovea and Pérez-Belis, 2012).

To date, the use of eco-design has mainly been studied through case studies, but questions on eco-design could be included in surveys and used to create indicators for the number and share of firms that use eco-design as a tool for eco-innovation. Additional questions could capture data on the effects of eco-design on material use, environmental impacts in the production, distribution and consumption phase, product life spans, and reuse and recycling (see Chapter 6). A problem that must be addressed before including eco-design in surveys is the lack of a shared and comprehensive definition of eco-design and the variety of methods that can be included under this rubric. However, these issues can be addressed by asking questions on the use of specific eco-design activities and eco-design goals.

There are several advantages to collecting data on the use of eco-design. First, eco-design is relevant to goods, services, process and organisational innovations, in part because it covers non-technological design and incorporates social and ethical factors. Second, it directly targets innovations. Third, it embraces different aspects of environmental sustainability, such as the impacts of product production and use on material, energy, water, etc.

5.2.2. Eco-knowledge networks and collaboration

Knowledge networks and collaborations can create new environmental-related knowledge for future exploitation. This type of input indicator heavily relies on network and cluster analysis and on the idea that individuals, firms and institutions are embedded in webs of exchanges and collaborations. Depending on the interaction under analysis, this indicator sheds light on the dynamic knowledge process that stands at the heart of the development and diffusion of eco-innovation.

Once networks are identified using different data sources, the objective is to study the shape or structure of the network. The strength of such an approach relies on the possibility to investigate graph-theoretic properties of the network. Some of these properties are: connectedness of nodes, network density, cohesion, centrality, betweenness, etc. Different indicators can be built in order to capture a variety of dimensions. For example, citation networks can be created using scientific publications as nodes and citations between them as ties between network vertices (Epicoco et al., 2014; Barbieri et al., 2016). Moreover, network and cluster analysis can be employed to assess the shape of networks whose nodes are represented by patent documents and the citations between patents as the links between these nodes (Cecere et al., 2014a, 2014b).

The advantage of using eco-knowledge networks and collaborations resides mainly in the accessibility of the information these tools provide, thanks to the graphical representation of the input data. In addition, qualitative research can be carried out in order to provide policy implications.

Additional data can be collected on collaboration for eco-innovation, either through surveys or from corporate annual reports of firms, government agencies, and university knowledge transfer offices. The data can be used to construct indicators for the number and share of firms and organisations active in collaboration on eco-innovation. Surveys will provide the most reliable data, but other data sources can indicate where there are clusters of collaborative activity on eco-innovation.

5.2.3. Eco-innovation related trade

International trade in eco-innovations is one of the main transfer channels for green knowledge embodied in goods and services. The main international lists associated with international green trade, such as OECD-164, FoEG-153, APEC-54 and EGA-165, focus on environmental goods and services on the basis of their end use. Therefore, they capture the adoption of environmental goods and services through imports, competitive pressure on domestic firms to innovate, and a source of knowledge via reverse engineering or imitation.

Vendors of environmental technology can opt for third party verification of their claims for the performance of their environmental technologies. Environmental Technology Verification (ETV) is a new tool to help innovative environmental technologies reach the market. The “Statement of Verification” delivered at the end of the ETV process can be used as evidence that the claims made about the innovation are both credible and scientifically sound[27]. The performance is not assessed against the performance of alternatives and does not consider rebound effects.

Eco-innovation goods and services (EGSS) imports by industry or governments is an activity indicator of eco-innovation from the point of use, and exports of eco-innovative goods and services can be categorised as socio-economic outcomes with environmental benefits. The Eco-Innovation Scoreboard uses an annually updated indicator for “Exports of products from eco-industries” (percentage of total exports) based on Eurostat data and a “selected list of 25 trade codes referring to “environmental goods and services”” as a component of socio-economic outcomes (Giljum et al., 2014). No indicator system has yet provided information on “imports of products from eco-industries elsewhere by industries, governments or households”. Data on the “net trade balance of eco-industries” (measured as the total value of exported goods and services minus the total value of imported products) are also available.

The knowledge spillovers from green trade are a topic in need of deeper research, for instance to compare knowledge spillovers from imported goods and services, with the spillovers from domestically produced eco-innovations and those based on a combination of foreign and domestic knowledge.
Trade indicators for eco-innovation inputs include:

- Imports of products from eco-industries elsewhere (% of total imports) by industry, government, households
- Imports of environmental goods and services (EGSS) by industry, government, households

5.2.4. Eco-innovation related foreign direct investments

Foreign direct investment (FDI) is a transfer channel for eco-innovation knowledge and technologies. Green FDI can be considered as FDI that advances progress towards reaching environmental and climate goals, including environmental protection and resilience (UNEP, 2017). Eco-innovation-related FDI can transfer clean technologies that are relatively less polluting (e.g. end-of-pipe abatement) and more input-efficient compared to domestic production. Eco-innovation related FDI can also support technology leapfrogging, whereby FDI transfers state-of-the-art production and pollution-control technologies to FDI recipient countries. Finally, it can create knowledge spillovers to domestic firms by encouraging the adoption of best practices in environmental management by affiliates, domestic competitors and suppliers (Golub et al., 2011).

Research to define and measure green FDI is at a relatively early stage. At the international and national levels, the most common approach is to include FDI in environmental goods and services (EGS) as a component of the green FDI definition. While comprehensive data collection for EGS is not widespread, the 2012 System of Environmental-Economic Accounting: Central Framework (CF) is expected to enable progress in this field (UNEP, 2017). (Please refer to Annex 5 for different definitions and measures).

5.3 Comprehensive indicator systems for eco-innovation

The Eco-Innovation Scoreboard (Eco-IS) measures eco-innovation performance across EU Member States. The 16 indicators are grouped into five areas: eco-innovation inputs, eco-innovation activities, eco-innovation outputs, resource efficiency and socio-economic outcomes. The innovation inputs consist of commonly-used indicators for R&D investments and human capital investments in R&D in general. Innovation sources other than those based on R&D are not included. This means that the indicator is biased towards favouring countries with a high share of manufacturing in GDP that rely more on R&D investments than the service sectors. The indicators for innovation activities concern firms only and include survey results on their energy, material efficiency, and management of environmental impacts and responsibilities. The 'innovation outputs' are measured through green patents, academic publications and media coverage.

The ASEM Eco-Innovation Index (ASEI) measures the status and level of eco-innovation of ASEM member countries. The scope of the 2015 ASEI is considerably broader than the Eco-IS by including the 28 Member States of the EU, Norway, Switzerland and 21 Asian countries (ASEM, n.d.). The ASEI website uses the definition of the European Commission from 2012, which states that 'progress towards the goal of sustainable development' should be the aim or result of eco-innovations. This is reflected in the broad choice of indicators categorized into four sub headings: Eco-innovation capacity, eco-innovation activity, eco-innovation supporting environment, and eco-innovation performance. The scale of the index varies from 0 (minimum) to 100 (maximum).

In contrast to the Eco-IS, the ASEI includes policy-relevant indicators for the implementation of environmental regulations (indicator 2.2 in Table 2) and public expenditures on green R&D (indicator 2.1). An indicator for private sector R&D is not provided, but there is an indicator for awareness level of company's sustainable management (number of United Nations Global Compact participant firms, ASEI 2015, pg. 158). Important new categories are: eco-innovation support environment and capacity. While the focus of the Eco-IS is stricter on eco-innovation, the ASEI also includes more general aspects such as the economic competitiveness and general innovation capacity of a country. It also has a special focus towards SMEs.

A comparison of Asian countries with those in Europe shows that Europe scores higher in Eco-innovation Capacity and Activities, and significantly higher in the Supporting Environment. Asia displays a good eco-innovation capacity score but scores relatively low in terms of policy support for eco-innovation (Jo et al., 2015).

The Global Cleantech Innovation Index (GCII) is developed by the Cleantech group. The GCII consists of five sub-categories: general innovation drivers, cleantech-focussed innovation drivers, evidence of emerging cleantech innovation, evidence of commercialized cleantech innovation. The report defines clean technology innovation as “doing more with less (e.g. fewer materials, less energy expenditure, reduced water availability), while making money doing so”. The indicators focus mostly on the activities of companies and businesses. The second and latest GCII from 2014 covers 40 countries (including the G20). Of the 40 countries covered by the GCII, 9 countries are not included in the Eco-IS or the ASEI (namely Argentina, Canada, Brazil, Israel, Mexico, Saudi Arabia, South Africa, Turkey and USA).

6

OUTPUT AND OUTCOME INDICATORS FOR ECO-INNOVATION

René Kemp, Anthony Arundel and Serdar Türkeli

This chapter discusses the measurement of eco-innovation through output and outcome measures. An output indicator for eco-innovation measures the development or adoption of product or process innovations with environmental characteristics. In contrast, an outcome indicator measures the economic, environmental or social effects of eco-innovations on the firm, government agency or household itself (internal effects) or on an economy or society (external effects). Some types of data, such as for sales, can be used to construct an output or outcome indicator, depending on the purpose of the indicator.

6.1. Output indicators for eco-innovation

An output indicator for eco-innovation measures the development or adoption of product or process innovations with environmental characteristics. Examples include the percentage of firms or government agencies that have introduced a process eco-innovation, either developed in-house or adopted from external sources, the percentage that offered a product eco-innovation to potential users, and sales of product eco-innovations. Another example is count data for the number of eco-innovations developed by a firm. The market share of an eco-innovation product is an output measure.

High quality output data for eco-innovation are required to test theories of the factors that enable eco-innovation, trends over time in eco-innovation activities, the effect of policy actions on the diffusion of eco-innovation products, and for testing economic theories of relevance to eco-innovation. An example of the latter is the use of data on the cost and characteristics of eco-innovative products to test Hicks' induced innovation hypothesis on price-induced innovation. Other potential uses are to support practical methods to encourage eco-innovation. For example, the creation of 'materials passports' would promote not only better recovery of materials, but also allow researchers to track innovation by product categories. In the Netherlands, the materials register Madaster has been created for real estate buildings[28].

The term 'output indicator' is often used incorrectly. As an example, the innovation output Indicator of the Innovation Union scoreboard is not an output indicator, but a composite indicator that includes, in addition to one output indicator, an intermediate indicator for innovation (patents) and an activity indicator (employment in knowledge intensive sectors).

Patents are commonly called an output indicator, but they are more accurately viewed as an input indicator for knowledge (the patented invention) with potential commercial applications (see Chapter 5.1.2). Activities to develop eco-innovations are not output measures and consequently related indicators, such as the share of firms that conduct innovation activities to develop specific types of eco-innovations, are not output indicators. Innovation activities can be abandoned, ongoing, or for other reasons fail to produce a product or process eco-innovation. Investments in different activities to create eco-innovations are inputs to eco-innovation (see Chapter 5.1.4).

6.1.1 Output indicators for eco-innovation products

Output indicators for eco-innovation include direct measures of innovation diffusion, such as count data for the number of goods and services eco-innovations produced over a defined time period, and changes to product characteristics. Relevant data can be obtained from announcements in trade journals[29] and product information databases. An example is the green car database established by Yahoo. Product databases can be used to trace the evolution of product characteristics over time.

For specific products, a database of eco-innovations could be created by sampling the 'new product announcement' sections of technical and trade journals, or by examining product information provided by producers. As an example, Newell, Jaffe and Stavins (1999) used the Sears Catalogue to create a database of changes in energy efficiency for three products: room air conditioners, central air conditioners and gas water heaters. Using econometric analysis, they were able to estimate the influence of energy prices and policy on the energy efficiency of these products[30]. For analysis and international comparison, goods and services should be classified using the UN's central product classification (CPC)[31].

The advantages of sampling product announcements to collect output data on eco-innovations include[32]]:

- They measure actual innovations introduced in the marketplace.
- The indicator is timely: announcements times are close to the date of commercialization.
- The data are relatively cheap to collect and do not require direct contact with innovative firms, replacing the need for time-consuming questionnaires.
- Product descriptions can be used to determine to performance characteristics of the information and to infer other qualities, such as whether or not it is a radical innovation.

There are several limitations to the use of product databases. First, many product databases do not consistently include environmental information. Second, firms rarely report in-house process innovations in technical or trade journals, for instance if they use secrecy to prevent the leakage of commercially valuable information to competitors. Third, product classification systems can differ by country, as for cars[33], which could reduce comparability between different product databases assembled by researchers.

Data on sales from eco-innovative products is a useful output indicator because it measures adoption rates. Optimally, this information should be obtained by sector for specific product lines. Some relevant information may be available in annual reports, or data could be collected through surveys. If possible, data collection should be collected on an annual basis to produce time series data. Sufficient detail should be collected for product lines to be able to differentiate between the environmentally innovative characteristics of different products. For example, a hybrid SUV can be less green than a small car.

For studying progress to a green economy, attention should be given to the stock of the non-green products and technologies, to see if this is growing or becoming smaller. A distinction of stocks into two categories of 'green' and 'non-green' is too crude given the complexities behind evaluations of environmental impacts. Data at lower levels of aggregation are needed. For products, detailed data on relevant environmental aspects are required, next to size and price. The information on environmental effects should be based on real use (as shown by the big disparity between test results for pollution and fuel economy for diesel cars).

Innovation surveys provide an alternative method of collecting output data product innovations. Respondents can be asked if they had any product eco-innovations over the observation period and they can be asked for information on the characteristics of their eco-innovations.

6.1.2 Output indicators for eco-innovation processes

Logistic, production, and delivery innovations that reduce resource requirements per unit of output are potential eco-innovations. Output indicators include the share of firms by industry with a process eco-innovation and the share of goods or services produced using these eco-innovation processes.

As many eco-innovation processes may not be made public, the best method for obtaining output data for eco-innovations is through an innovation survey.

6.2. Outcome indicators for eco-innovation

Outcome indicators measure the economic or environmental effects of eco-innovations. There are three main types of outcome indicators for eco-innovation:

- Indicators for the internal effects of eco-innovations on the firm itself. These are primarily due to process eco-innovations, but can also include the effects on the firm from sales of product eco-innovations.
- Indicators for the external effects of product innovations through their intended use by consumers such as individuals, governments, other firms, etc.

- Indicators of absolute environmental effects, such as changes in global CO_2 emissions due to eco-in novations or a change in regional NO_x emissions due to eco-innovations. Absolute effects can be due to both the internal effects from using process eco-innovations within the firm and the external effects from using product eco-innovations by con sumers.

6.2.1 Outcomes of process eco-innovation use within the firm

The effects of eco-innovation on the firm itself can be measured through subjective survey questions that ask if any of a firm, agency or household's innovations had a number of observed effects. Since beneficial effects can be provided by innovations that were not intentionally designed as eco-innovations, all types of innovations should be included. The following examples are drawn from the 2014 CIS:

- Reduced material use per unit of output
- Reduced water use per unit of output
- Reduced energy use or CO_2 'footprint' (reduce total CO_2 production)
- Reduced soil, noise, water or air pollution
- Replaced a share of materials with less polluting or hazardous substitutes
- Replaced a share of fossil energy with renewable energy sources
- Recycled waste, water, or materials for own use or sale

Some of the questions refer to a unit of output while others refer to absolute declines, such as 'reduced energy use or CO_2 footprint'. Other outcome questions are undefined, such as 'reduced soil, water or air pollution' or 'replace a share of materials with less polluting or hazardous substitutes'. If space is available, as in a survey dedicated to eco-innovation, questions on reduced material use or replacements of material or energy can include categorical response categories to capture the percentage share of reduction or replacement, such as 0%, over 0% to up to 5%, 5% to up to 10%, etc.

The above survey questions on outcomes can also ask about all innovations and intentional eco-innovations only.

For the business sector, it is of interest to include questions that ask about the effect of eco-innovations on the competitiveness or viability of the firm. This includes collecting data on total sales from product eco-innovations and from other types of products (for use in calculating the share of total sales from product eco-innovations) and the effect of eco-innovation on profit margins (relative profit margin for eco-innovations versus other types of innovations (if any) or all other types of products). If possible, data should also be collected on the eco-innovation share of product sales or relative profit margins over time.

An extension of subjective questions is to calculate eco-efficiency, or the environmental impact per unit of a product value (WBCSD, 2000). Eco-efficiency is best known as a concept for the business sector (ESCAP, 2009) but it is also applicable for outcomes such as energy or water use for the three other sectors of government, NPISHs, and households.

Eco-efficiency can be measured either for resource efficiency or for pollution (or waste) intensity. Eco-efficiency indicators for individual firms, government organisations or households are internal outcome indicators. Eco-efficiency indicators for specific products, for an industry or sector, or for a geographical area (region, country, etc.) are external outcome indicators. Calculation requires data for outputs (sales, value-added, etc.) and emissions at the level of measurement (i.e. for the firm or from national environmental accounting for the country level). An example of an eco-efficiency indicator is the amount of CO2 emission per million Euros of production or GDP. Relevant data for calculating eco-efficiency indicators include:

- Quantity of product produced or sold, net sales or value added as output indicators
- Energy consumption, from renewable sources and non-renewables
- Water consumption

- Greenhouse gas (GHG) emissions, including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_20), hydro-and perfluorocarbons (HFCs, PFCs)
- Other air pollutants: nitrogen oxides, sulphur dioxide etc.
- Total waste, broken down into toxic and non-toxic waste
- Product durability which can defer replacement
- Service intensity

6.2.2 External outcome indicators

As noted above, eco-efficiency measures at the level of an industry or geographical region are external outcome indicators. An advantage of external eco-innovation outcome indicators is that some types of rebound effects are accounted for. For instance, an increase in the energy efficiency of lighting could lead to greater emissions from other industries, but all such emissions are captured in a national level eco-efficiency indicator (although rebound emissions from foreign travel will be missed). However, it can be difficult to identify the contribution of innovation to a change in an eco-efficiency indicator, such as the amount of GHG emissions per million currency units of GDP. The cause of a change in eco-efficiency could be due to innovation, a consumer shift to bigger or smaller products (bigger TV sets, more powerful, heavier cars or smaller city cars) or something else. Changes in eco-efficiency at the national level can also be due to national changes in industry structure (energy intensive or polluting industries relocating abroad) or due to shifts in trade.

Decomposition analysis can be used to decompose emissions into contributing sources. An example is Nie et al. (2016) who decompose total CO_2 emissions into six multiplicative components: the CO_2 emission coefficient of energy, the quantity of energy required per unit output or activity (energy intensity), the inputs needed to produce intermediate outputs (Leontief effect), the shares of final demand for each industry, the shares of consumption, investments, and exports in final demand, and final demand. Studies of this kind can produce indicators for the relative role of each determinant. Decomposition analysis can also be used to decompose energy use for space heating/cooling, cooking, lighting and electric appliances (Nie and Kemp, 2014).

Other external outcome indicators measure economic outcomes. Many of these indicators do not distinguish between eco-innovations and older environmental production methods. Nevertheless, these indicators are valuable for measuring the economic viability of eco-innovation over the long term. Examples include:

- Share of new investment in environmentally-friendly production methods (i.e. investment in renewable electrical energy as a share of total investment in electrical energy production)
- Share of GDP from the environmental goods and services sector (EGSS)
- Sector shares of production using environmentally-friendly methods, such as share of electricity generated through renewables, eco-concrete as a share of all concrete used, etc.
- Exports of products from eco-industries as a percentage of total exports (this indicator is included in the Eco-Innovation Scoreboard).
- Trade balance in environmental goods and services sector (EGSS) (see Annex 6)
- Change in the stock market capitalization of DGSS firms compared to other firms

An important avenue for research is to examine correlations between different types of innovation measures. Innovation indicator research based on direct indicators could assist in explaining changes in eco-efficiency, whilst accepting that there is no simple causal relation between innovation and eco-efficiency, as changes in eco-efficiency reflect sectoral changes and non-innovative price-based substitution. Eco-efficiency research can also be used to determine what magnitude of change is needed for achieving an absolute decoupling. To halve the environmental impact of an economy that is twice the size of the current economy would need technologies and practices whose impact is a factor of 4 lower.

6.2.3 Absolute external outcome measures

Eco-efficiency indicators are relative measures. The eco-efficiency of CO_2 emissions could consequently increase while total emissions also increase, for instance if aggregate economic growth is faster than the improvement in CO_2 eco-efficiency. Many environmental problems require emissions to fall below a known threshold, such as CO_2 and NO_x emissions or heavy metal and nitrogenous pollution of soils. These require absolute declines in addition to improvements in eco-efficiency. One approach is to examine changes in ecological footprints (see Moll and Gee, 1999; Machiba, 2008). Another is to identify and track changes over time in absolute outcome indicators such as total emissions at either a regional, national or global level. Many air pollutants such as NOx emissions need to be tracked at a local level (urban and rural areas), soil pollutants such as nitrogenous fertilizers need to tracked at the local or regional level, while ozone-destroying emissions and GHG emissions need to tracked at both the national level (to determine responsibility) and the global level.

The selection of which absolute outcome data to collect is specific to each environmental problem. Ideally, absolute outcome data should be collected both at the level of production, for instance individual manufacturing plants, government departments, infrastructural assets (airports, ports), farms, etc.; and through sampling of the affected medium (air, soil, water, etc.). The former is required to assess responsibility, levy environmental taxes, etc. The lat-ter is required to measure progress towards environmental goals. The following list provides topics for data collection for seven environmental systems[34]. Further details on absolute outcome measures are provided in Chapter 7.

- Clean Water and Sanitation
  - Access to improved water
  - Access to improved sanitation
  - Freshwater withdrawal
  - Imported groundwater depletion

- Affordable and Clean Energy
  - Access to electricity
  - Access to non-solid fuels
  - CO_2 from fuels & electricity
  - Renewable energy in final consumption

- Sustainable Cities and Communities
  - PM2.5 in urban areas
  - Improved water source, piped
  - Rent burden
- Responsible Consumption and Production
  - E-waste
  - Wastewater treated
  - Production-based SO2 emissions
  - Net imported SO2 emissions
  - Nitrogen production footprint
  - Net imported emissions of reactive nitrogen
  - Non-recycled municipal solid waste
  - Municipal solid waste

- Climate Action
  - CO_2 emissions from energy
  - Imported CO_2 emissions, tech-adjusted
  - Climate change vulnerability
  - Effective Carbon Rate

- Life below Water
  - Marine sites, mean protected area
  - Biodiversity
  - Clean waters
  - Fisheries
  - Fish stocks overexploited or collapsed

- Life on Land
  - Terrestrial sites, mean protected area
  - Freshwater sites, mean protected area
  - Red List Index of species survival
  - Annual change in forest area
  - Imported biodiversity impacts

6.2.4 Socio-economic outcomes

Socio-economic outcomes of eco-innovation include both the benefits and disadvantages of eco-innovation activities. This can include jobs created or eliminated, changes in competitiveness, as well as the turnover, revenues, profits and expenses of firms (EIO, 2017).

7

GREEN ECONOMY AND GROWTH

Andrea M. Bassi, Carlos Tapia, René Kemp, Serdar Türkeli, Donald Chapman and Fernando J. Díaz López

Eco-innovation is important for the UN-SDG agenda, the green economy agenda of UN Environment, the green growth agendas of OECD, as well as on the national development agendas and growth strategies of many countries worldwide. In this chapter, we list environmental outcome indicators that are important to monitor for a green economy. We discuss intensity and productivity indicators, absolute measures for the living environment and socio-economic well-being indicators in terms of known limitations and their importance for use.

The concept of a "green economy" was introduced over 20 years ago in the book Blueprint for a Green Economy (Pearce et al., 1989). The United Nations Environment Programme (UNEP) defines the green economy as "an economy where growth in income and employment is driven by investments that reduce carbon emissions and pollution, enhance energy and resource efficiency, and prevent the loss of biodiversity and ecosystem services". At the same time as reducing environmental risks, the green economy is expected to lead to "improved human well-being and social equity" (UNEP, 2011). Growth in income and employment in the green economy is driven by investments that:

- Reduce carbon emissions and pollution.
- Enhance energy and resource efficiency.
- Prevent the loss of biodiversity and ecosystem services.

Similarly, the OECD defines green growth as "fostering economic growth and development, while ensuring that natural assets continue to provide the resources and environmental services on which our well-being relies" (OECD, 2011).

These definitions highlight the mandates of the UN Environment Programme and the OECD. The former prioritizes environmental preservation for poverty reduction, while the latter emphasizes economic growth through efficiency improvements. Green growth is not only about achieving reductions in the total level of environmentally harmful emissions, but about unlocking new growth potential through a transition to a less resource intensive economy. Several similar definitions exist (e.g. circular economy, blue economy, resilient economy), each emphasizing specific facets of a more sustainable and resilient economy. Over the years it has become clear that neither the green economy nor green growth are the final objectives. Sustainability is the ultimate objective for social, economic and environmental development. As a result, the green economy has increasingly been used as an approach, and green growth as a target.

At the country level, the concept of a green economy is used to guide policy formulation and assessment that more effectively leads to sustainable development. This requires integrating social, economic and environmental factors into a coherent policy that improves the performance of the country as a whole, instead of specific sectors. A green economy supports national development by 1) improving efficiency (e.g. in buildings and in the manufacturing sector) and by 2) reducing the impact of human activity on the environment (e.g. by lowering water and air pollution, reducing and recycling waste). By doing so, it supports reaching both country goals and the UN's sustainable development goals (SDGs).

Eco-innovation is essential to the green economy approach for achieving green growth. Eco-innovation can support the greening of existing sectors as well as trigger new growth in emerging 'cleantech' sectors. Eco-innovation is also crucial to the replacement of outdated technology (and capital investments) with new and more efficient forms.

7.1. Environmental outcome indicators for the Green Economy

Environmental outcome indicators capture the negative impacts of anthropic actions on the natural environment and human health. There are two main categories of these indicators:

- 'End-point' indicators that measure the ultimate consequences of unsustainable practices, (e.g. soil erosion, biodiversity loss or premature deaths due to pollutants).

- 'Mid-point' indicators that measure the concentrations and flows of pollutants that are released into the environment and negatively impact the environment or human health

The choice of indicators to be collected depends on the prevailing production technologies in each time and region. Factors to consider include 1) the existing scientific consensus on the harmfulness of different technologies (e.g. the known toxicity of the substances that are emitted); 2) the actual volumes or quantities of pollutants released into the environment in an area (e.g. the order of magnitude of local emission rates in relation to global averages), 3) the specific sensitivity of the local environment to pollutants (intrinsic qualities such as fragility, diversity, etc.), and 4) the reliability and technical complexity of obtaining relevant data, in respect to resources available.

7.1.1 Environmental Outcome indicators

7.1.1.1. Atmospheric pollutants

Air quality indicators capture the emission rates of compounds that are released into the atmosphere in quantities that significantly alter its chemical composition (ozone (O_3), nitrogen oxides (NOx) etc.) and toxic compounds that are not naturally found in the biosphere and which decompose slowly (hexachlorobenzene (HCB), dichlorodiphenyltrichloroethane (DDT), etc.).

The latter are normally listed as toxic and hazardous substances in official inventories[35]. Emissions from natural sources are not normally considered. Table 7.1 provides an overview of main groups of chemical substances that can harm human health or ecosystems. The table also summarizes their key genesis and toxicology standards.

Table 7.1. Overview of air outcome indicators

Substance	Artificial sources	Impacts	Toxicity based on WHO guidelines[36]
Nitrogen dioxide (NO_2) and Sulphur dioxide (SO_2)	Combustion engines; thermal power generation	Soil and water acidification	NO_2: 40 µg/m³ annual mean 200 µg/m3 1-hour mean SO_2: 20 µg/m³ 24-hour mean 500 µg/m³ 10-minute mean
Other forms of Nitrogen (nitrate, nitrite, organic nitrogen and ammonia)	Intensive livestock and farming, food industry, treating sewage, garbage processing	Water eutrophication	None
Ozone (O_3)	Reactions between precursors (NOX, VOC and CO.	Mucous irritation and respiratory systems of animals and plant tissues	100 µg/m3 8-hour mean
Carbon Monoxide (CO)	Combustion engines, thermal power generation	Low concentration, Long-term effects: greater risk of heart attack. High concentration (indoors): clumsiness, coordination problems, asphyxia	10 mg/m3 8-hour mean 30 mg/m3 1-hour mean
Particulate matter (PM)	Coal, wood or diesel combustion; Reactions between precursors (NOX, SO_2, NH_3, etc.)	Human health: cardiovascular and respiratory diseases	Annual means: $PM_{2.5}$: 10 µg/m3 PM_{10}: 20 µg/m3 24-hour means: $PM_{2.5}$: 25 µg/m3 PM_{10}: 50 µg/m3
Volatile organic compounds (VOC)	Paints and coatings, fossil fuels, asphalts, cleaning products, tobacco, cosmetics and other chemical substances.	Relevant for indoor air quality. Short term effects include tissue irritation, headaches, dizziness and nausea/vomiting. Long-term effects include lung cancer and aplastic anaemia.	None
Polycyclic aromatic hydrocarbons (PAH)	Incomplete combustion of organic matter (wood or biofuels)	Environmental health: toxic for aquatic life. Human health: different forms of cancer	No WHO guidance EU thresholds[37]: Benzene: 5 µg/m³ year average (EU) 3 µg/m³ year average (JAP)[38] Benzo(a)pyrene): 1 ng/m³ year average (EU)
Persistent organic pollutants (POPs)	First-generation chemicals including pesticides, solvents, pharmaceuticals, and industrial chemicals	Human health: POPs are bioaccumulative. They may cause developmental defects, chronic diseases and premature death	No WHO guidance. POPs are highly restricted by the Stockholm Convention on Persistent Organic Pollutants (2001)
Heavy metals (HM)	Metal industry processes and products, including batteries and accumulators, fuel cell electrodes, ammunition, metal products, etc.	Environmental health: high acute toxicity to animals and aquatic life. Bioaccumulative. Human health: cancer, degenerative diseases, damage on central nervous system.	Lead (Pb) 0.5 µg/m³ year average Arsenic (As) 6 ng/ m³ year average (EU)[37] Cadmium (Cd) 5 ng/ m³ year average (EU)[37] Nickel (Ni) 20 ng/ m³ year average (EU)[37]

Source: Author's elaboration based on Australia's National Pollutant Inventory (sources and impacts)[39]

Table 7.2 provides a selected list of air quality outcome indicators in accordance with the Framework for the Development of Environment Statistics - FDES 2013 (United Nations Statistics Division, 2016) and the official list of SDG Indicators[40]. The methodological guidance for these indicators is provided by the WHO (2006).

Table 7.2. Overview of selected air outcome indicators available from international databases

Indicator	Global trend	Coverage	Data provider
Annual mean concentration of particulate matter of less than 2.5 microns of diameter ($PM_{2.5}$) [ug/m^3] in urban areas	Uncertain/diverse across geographies	Good	WHO[41]
Annual mean concentration of particulate matter of less than 10 microns of diameter (PM_{10}) [ug/m^3] in urban areas	Uncertain/diverse across geographies	Good	WHO[41]
Annual emissions of CO - (National Reports, UNFCCC), Excluding Land Use, Land-Use Change and Forestry	Improving (decreasing emissions)	Poor	United Nations Framework Convention on Climate Change (UNFCCC) via the UNEP Environmental Data Explorer[40]
Annual mean concentration level of tropospheric ozone (O_3)	Unknown	NA	NA
Annual emissions of SO_2 (National Reports, UNFCCC), Excluding Land Use, Land-Use Change and Forestry	Improving (decreasing emissions)	Poor	United Nations Framework Convention on Climate Change (UNFCCC) via the UNEP Environmental Data Explorer[42]
Annual emissions of NOx (National Reports, UNFCCC), Excluding Land Use, Land-Use Change and Forestry Decreasing	Improving (decreasing emissions)	Poor	United Nations Framework Convention on Climate Change (UNFCCC) via the UNEP Environmental Data Explorer[42]

Source: Authors' elaboration

7.1.1.2. Absolute measures for CO_2 and GHG emissions

The growing recognition of climate change has led to the collection of data to measure CO_2 and Greenhouse Gas (GHG) emissions. GHG emissions include gases with a known significant contribution to global warming. GHGs include carbon dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O) and "F-gases" (Table 7.3).

Table 7.3. Overview of greenhouse gases, their principal sources and sinks and global warming potential

Greenhouse Gas	Principal Anthropogenic Sources (and natural sinks)	Global Warming Potential[1]
Carbon Dioxide (CO_2)	Fossil fuel use, land use change (oceans, terrestrial biosphere)	1
Methane (CH_4)	Fossil fuel mining/distribution, livestock, rice agriculture, landfills	21
Nitrous Oxide (N_2O)	Agriculture and associated land use change	310
"F-gases" Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), Sulphur Hexafluoride (SF_6)	Industrial processes	140 - 23,900

Source: IPCC (2007) AR4 WGI & WGIII; 1: Relative to carbon dioxide.

Several manuals are available on the estimation and compilation of national GHG inventories. The United Nation's Framework Convention on Climate Change (UNFCCC) is the main recipient of national estimates of GHG emissions, which must be provided by countries that are signatories to various UN protocols for climate change. GHG data are generated using measurements and simulation models. Data on GHG sources and sinks are provided for energy use (e.g. industries, transport); industrial processes and product use; agriculture, forestry and land use; and waste sectors. Detailed data on GHG emissions by country over time are available from the UNFCCC (http://di.unfccc.int/time_series).

7.1.1.3. Absolute measures for the living environment

Measures for water

Alongside air pollution, water contamination is one of the primary areas of environmental concern and public attention. Water use indicators can measure water use, water supply stress (from water withdrawals) and water quality.

Total water withdrawal by sector is the most widely used indicator for water use patterns at the national level. It generally includes any form of renewable (surface freshwater), non-renewable (over-extracted groundwater or fossil groundwater) as well as 'artificially-generated' (desalinated or recovered) water.

Water quality indicators measure the concentration of toxic or harmful substances in water bodies. Widely used measures include the concentration of chlorophyll, oxygen consumption substances, nitrates and nitrites, and phosphorus and other nutrients. These are frequently reported as standard indicators, including Biochemical oxygen demand (BOD), Chemical oxygen demand (COD), Dissolved oxygen (DO) and total hardness (TH). Other physical and chemical qualities of water that are frequently measured include pH, alkalinity, electric conductivity, temperature and turbidity.

An emerging issue is marine litter and plastic concentration in the ocean. Plastics photo degrade into smaller pieces that are ingested by organisms, particularly in the marine environment. Plastic pollution is analysed through direct sampling of marine litter or through bio-indicators, typically the concentration of plastic particles in the stomachs of fish and seabirds. For example, the OSPAR Commission[43] has developed indicators to measure the amount of plastic litter in the North East Atlantic, but unfortunately standardized data are not yet available worldwide.

Indicators can also measure the response to deterioration in water use indicators. Restorative actions for water management are generally documented by means of water treatment and recovery indicators. These are generally available from comparable international datasets with good spatial and temporal coverage, such as FAO's AQUASTAT[44].

Table 7.4 below provides a selected list of water outcome indicators. These indicators are in accordance with the Framework for the Development of Environment Statistics - FDES 2013 (United Nations Statistics Division, 2016) and the official list of SDG Indicators[40].

Table 7.4. Overview of selected water outcome indicators available from international databases

Indicator	Global trend	Coverage	Data provider
Total and sectoral water withdrawal	Worsening (increasing withdrawal in all regions)	Good (for some years only)	FAO, AQUASTAT[44]
Biochemical oxygen demand (BOD)	Uncertain/diverse across geographies	Good	Global Environment Monitoring System (GEMStat)[45]
Municipal Wastewater production	Worsening (increasing release at global level; collection and treatment are also increasing)	Good (for some years only)	FAO, AQUASTAT[44]
Direct use of treated municipal wastewater	Improving (increasing use of recycled water)	Poor	FAO, AQUASTAT[44]

Source: Authors' elaboration

Measures for soil

Soil indicators are not as widely available as air and water indicators. The FAO manages an international dataset on soil characteristics that is oriented towards agricultural productivity (FAO, 2017), but unfortunately the dataset pays very little attention to environmental aspects. As a consequence, soil outcome indicators are usually addressed through proxies that focus on aspects related to land cover and land management practices, essentially land removal rates and similar figures, as well as on the consumption of pesticides and fertilizers as proxies of potential soil pollution.

Table 7.5 provides a selected list of soil outcome indicators. These indicators are in accordance with the Framework for the Development of Environment Statistics - FDES 2013 (United Nations Statistics Division, 2016) and the official list of SDG Indicators[40]. Although one SDG indicator specifically focuses on soil degradation (Indicator 15.3.1 on the proportion of land that is degraded over total land area), the indicator is not yet available from the UN Statistical Division repository[46].

Table 7.5. Overview of soil outcome indicators

Indicator	Global trend	Coverage	Data provider
Area affected by soil erosion	Unknown	Very good, but data for 1990 only	FAO Global Assessment of Human-induced Soil Degradation (GLASOD)[47]
Area affected by physical or chemical soil deterioration	Unknown	Very good, but data for 1990 only	FAO Global Assessment of Human-induced Soil Degradation (GLASOD)[47]
Consumption of fertilizers (tonnes of nutrients)	Worsening (increased consumption)	Good	FAOSTAT, Food and Agriculture Organization of the United Nations[48]
Pesticides Use (tonnes of active ingredients)	Uncertain/diverse across geographies	Low	FAOSTAT, Food and Agriculture Organization of the United Nations[48]

Source: Authors' elaboration

Measures for biodiversity

Midpoint indicators are rarely collected for biodiversity because of the difficulty in ascribing biodiversity loss to a single cause or combination of environmental stressors. Instead, end-point indicators are used, such as the number of endangered species. Alternatively, data on theoretical biodiversity stocks (biodiversity indices) or proxies (total protected area) are used in international scoreboards developed by environmental organizations such as the European Environment Agency (EEA) and the US Environmental Protection Agency (EPA).

Table 7.6 below provides a selected list of biodiversity outcome indicators. These indicators are in accordance with the Framework for the Development of Environment Statistics - FDES 2013 (United Nations Statistics Division, 2016) and the official list of SDG Indicators[40].

Table 7.6. Overview of biodiversity outcome indicators

Indicator	Global trend	Coverage	Data provider
Land removal from natural use for urban and artificial uses	Worsening (increased land removal at global level)	Very good	The indicator is not directly available but can be calculated easily using land cover data from FAOSTAT, Food and Agriculture Organization of the United Nations[48]
Number of vulnerable, threatened, endangered or critically endangered species	Worsening (increased number of vulnerable, threatened, endangered or critically endangered species)	Very good	IUCN/SSC[49]
Status of marine fish stocks (Fish stocks exploitation)	Worsening for most species (increased exploitation)	Very good	FAO Reports on fisheries and aquaculture resources[50]
Protected Areas (Terrestrial and/or Marine)	Improving in all regions (increased area protected)	Very good	United Nations Environment Programme/World Conservation Monitoring Center (UNEP-WCMC)[51]

Source: Authors' elaboration

7.2. Resource productivity indicators for the Green Economy

The concept of “stocks and flows” is critical for understanding the green economy. The change in built capital and natural resource stocks, with the former trending up and the latter trending down, will have lasting impacts. For built capital, resource consumption is locked in throughout its lifetime (for example the energy consumption of a light bulb or a vehicle). For natural resources, the absolute reduction of natural assets could undermine the regenerative capacity of natural systems and the provision of ecosystem services. For instance, a decline in forested land will reduce carbon uptake for many years to come. The green economy needs to improve environmental sustainability at a rate that exceeds the rate of environmental degradation and ensure that thresholds for long-term environmental damage are not crossed. Otherwise, irredeemable damage to the environment, ecosystem services, human health, and socio-economic systems will occur. This requires progress towards an absolute decoupling between economic growth and environmental outcomes.

Resource intensity and productivity indicators measure the extent to which resources are used to carry out social and economic activities. The former represents how much of a given resource is used to produce a unit of a given good or service, while the latter measures the amount of economic output (e.g. GDP) per unit of resource input (materials, water, energy, etc.). An increase in resource productivity is a necessary although insufficient pre-condition for absolute decoupling.

Indicators of resource intensity and productivity can be estimated for production and consumption on a per capita basis. Alternatively, other denominators can be used, such as water consumption per hectare in agriculture. Production-based indicators can be complemented with consumption-based (demand) indicators. Production-based measures capture the total amount of energy consumed during production processes relative to produced GDP, while demand-based energy productivity is the real disposable income generated per unit of energy consumed during all of the various stages of production of the goods and services consumed in domestic final demand, irrespective of where the stages of production occurred. A comparison of these two indicators permits an assessment of the extent to which a country produces or imports more (or less) resource intensive production processes.

Table 7.7. Resource efficiency indicators for climate change and water stress (UNEP, 2014c)

Topic	Indicator (different perspectives)			
	Production	**Consumption**	**Intensity**	**Productivity**
Climate change (particularly relevant for fossil energy use)	GHG emissions due to national production	Carbon Footprint as global warming potential	GHGs emissions per GDP (tons/€)	GDP per GHG emissions (€/tons)
Water stress	Water use for national production	Water Footprint for domestic consumption	Water use per GDP (m^3/€)	GDP per water use (m^3/€)

Higher productivity is a consequence of more efficient production systems and technologies. Therefore, productivity and efficiency are terms that are frequently used indiscriminately. However, the productivity (economic output to environmental input) of national economies can depend on sectoral factors, such as the share of manufacturing or financial services in the economy. Similarly, it is important to stress that resource productivity indicators do not capture the environmental impact of resource extraction, use and end-of-life management, neither do they fully describe the circularity of economic systems through regenerative practices such as eco-design, product repair, remanufacturing, recycling, etc. Therefore, resource productivity indicators should be used in combination with environmental outcome indicators and other indicators to achieve more realistic evaluations of decoupling processes.

7.2.1. Material productivity

Material productivity refers to the amount of economic value generated by the consumption of a unit of material input. The economic value that an entire economy produces is generally captured through its GDP. The material consumption of an economy can be analysed through different indicators, as shown in Figure 7.1.

The most widespread indicator to capture this dimension is Domestic Material Consumption (DMC). This indicator measures the total quantity of materials used within an economic system, excluding indirect flows. DMC is generally available from most National Statistical Offices, which compute it relying on the System of Environmental-Economic Accounting (SEEA). However, the DMC indicator excludes all material consumption from imports of manufactured and semi-manufactured products.

A more comprehensive indicator is Raw Material Consumption (RMC). Contrary to DMC, RMC includes materials embodied in imported products and can therefore monitor the upstream effects of local production and consumption patterns. As such, RMC is a better measure of the total material footprint of an economy. The downside is that RMC is not actually measured, but estimated by using trade models and assumptions on the total raw material extraction caused by processed goods traded internationally[52]. In a way, RMC is more comprehensive but less accurate than DMC. And RMC is much more difficult to compute than DMC.

Considering that both DMC and RMC have been included in the list of indicators supporting the SDGs, it is expected that both their availability and accuracy at the national level will increase in the near future.

7.2.2. Water productivity

The description of material productivity also applies to water productivity. Water productivity can be measured in terms of local direct water consumption, following the guidance of the UN SEEA-water methodology In addition, data on water withdrawal rates (available from NSOs and international repositories) can be combined with GDP data to calculate water productivity. The official list of SDG indicators includes an indicator called “change in water-use efficiency over time” (6.4.1). Still, it seems that neither the indicator nor the metadata will be shortly available.

A preferable indicator is to calculate the total (direct and indirect) water footprint of an entire economy, but the necessary data on the water content of imports are not available from international harmonized repositories.

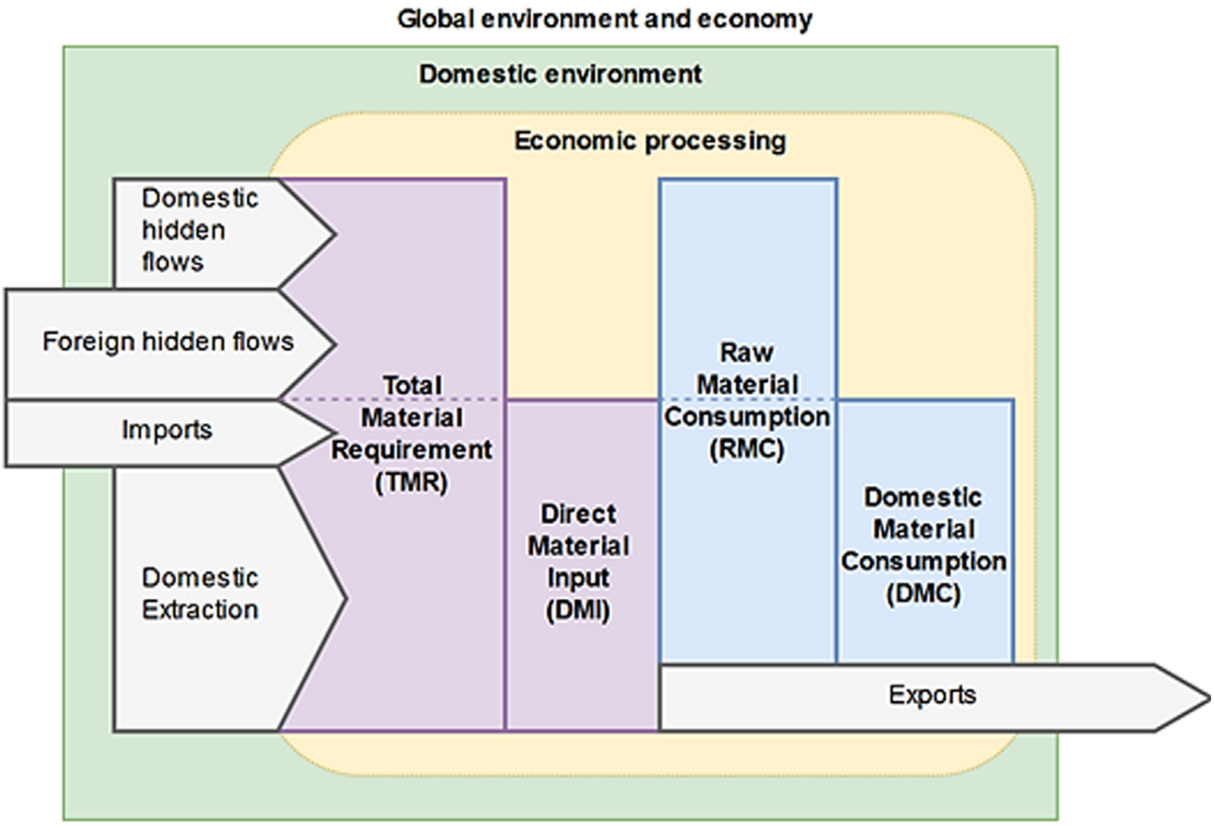
7.2.3. Waste productivity

In principle, the waste productivity of a given economy can be analysed using the same approach as described for material and water inputs. However, reliable waste data are not currently available at the international level. Even in the most developed regions, waste data, either in terms of quantity, composition or hazardousness, is highly unreliable. The same goes for data on waste imports and exports. Furthermore, an established methodology to compute a Waste Footprint based on MRIO models is not currently available. Although the official list of SDGs includes an indicator on hazardous waste generated and treated per capita and by type of treatment (14.4.2)[53] , it seems that the indicator will not be available any time soon. In the years to come, substantial resources will have to be invested at the global level on the collection of reliable waste data and related indicators.

7.2.4. Energy and air emissions productivity

As for material, water and waste productivity, energy productivity is measured by dividing total economic output by energy consumption, sometimes differentiated by energy source. The Total Primary Energy Supply (TPES) is often used to estimate energy productivity and to account for losses in the production and transformation process of energy. Data are generally available for energy consumption, production and emissions. The former is collected by national governments and harmonized by international organizations (e.g. the International Energy Agency). Data on emissions are collected

Figure 7.1. Selected Material Flow Accounting indicators



through inventories that each country prepares for national communications to the UNFCCC. The quality of these inventories varies, especially to the extent that disaggregated or aggregated energy balances are used. While emissions from energy are generally well covered, GHG and other emissions from land use are normally less accurate due to the lack of up to date data and maps.

Table 7.8 below provides a selected list of productivity indicators for different environmental and economic dimensions. These indicators are in accordance with the Framework for the Development of Environment Statistics - FDES 2013 (United Nations Statistics Division, 2016) and the official list of SDG Indicators[40].

Table 7.8. Productivity indicators

Dimension	Indicator	Global trend	Coverage	Data provider
Material productivity	GDP per mass unit of Domestic Material Consumption (DMC)	Improving in developed economies; Worsening in emerging industrial economies; Worsening at global level	Good	United Nations Statistics Division[54]
Material productivity	GDP per mass of Raw Material Consumption (RMC)	Stable in all regions	Good	United Nations Statistics Division[54]
Water productivity	GDP per volume of total water withdrawal	Unknown, only one data point available	Good	FAO, AQUASTAT (water withdrawal) and WORLD BANK (GDP)[55]
Water productivity	GDP per volume of total water footprint	Unknown, only one data point available	Good	International Water Footprint Network (Mekonnen and Hoekstra, 2011)
Waste productivity	GDP per mass of total waste generated	Unknown	NA	NA
Energy productivity	GDP per unit of primary energy consumption (e.g. GDP in $ per kg of oil equivalents)	Improving in developed economies; Worsening in emerging industrial economies; Improving at global level	Good	International Energy Agency[56], private companies (e.g. BP)[57], national energy ministries; and WORLD BANK (GDP)[58]
Emissions productivity	GDP per mass of air emissions (e.g. CO2)	Improving in developed economies; Worsening in emerging industrial economies; Improving at global level	Good	International Energy Agency[56], private companies (e.g. BP)[57], national energy ministries; and WORLD BANK (GDP)[58]

7.3. Data collection on environmental pressures, outcomes and productivity

Various organisations around the world are involved in data collection on environmental pressures, outcomes and productivity.

In Europe, the European Environmental Agency produces an annual environmental indicators report, using data from statistical offices, which are used to produce indicators for integrated assessment and collective interpretation. The EEA approach is depicted in Figure 7.2.

Based in Seoul, The Global Green Growth Institute (GGGI) is developing the Green Growth Potential Assessment (GGPA) and the Green Growth Performance Measurement (GGPM), which offer country-specific indicators and a simulation tool to help governments obtain a picture of the potential benefits of green policies and investments. For 130 countries across all world regions, composite indicators are produced for resource efficiency, resilience to risks, social inclusion, natural capital stock protection, economic opportunities and green growth. In addition to producing indicators, the GGGI produces specialised reports on countries and themes.

For OECD countries, a green growth indicator system is developed by the OECD secretariat, using the green growth measurement framework (Figure 7.3). This framework consists of 26 indicators relevant to green growth. The indicators can be used to monitor progress in: i) environmental and resource productivity of the economy; ii) the natural asset base; iii) the environmental dimension of quality of life; and iv) economic opportunities and policy responses. Indicators that describe the socio-economic context and the characteristics of growth provide important background information. An overview of the indicators is given in the Annex for Chapter 7 (Table A.7.1) and the framework is shown in Figure 7.3.[59]

Figure 7.2. The MDIAK model of the European Environmental Agency

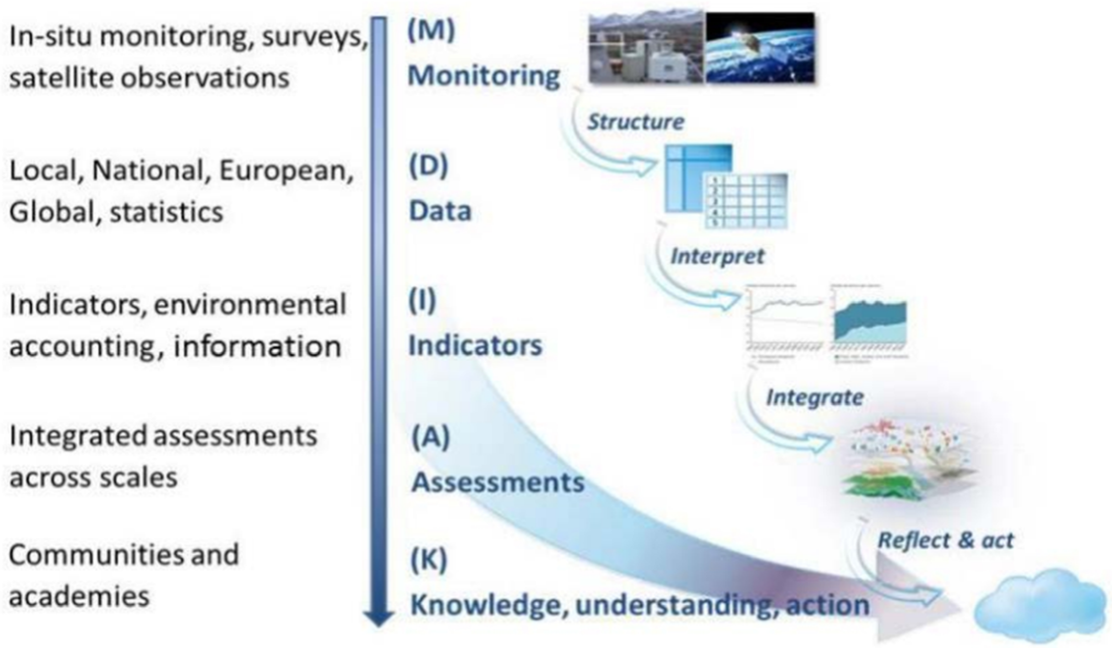
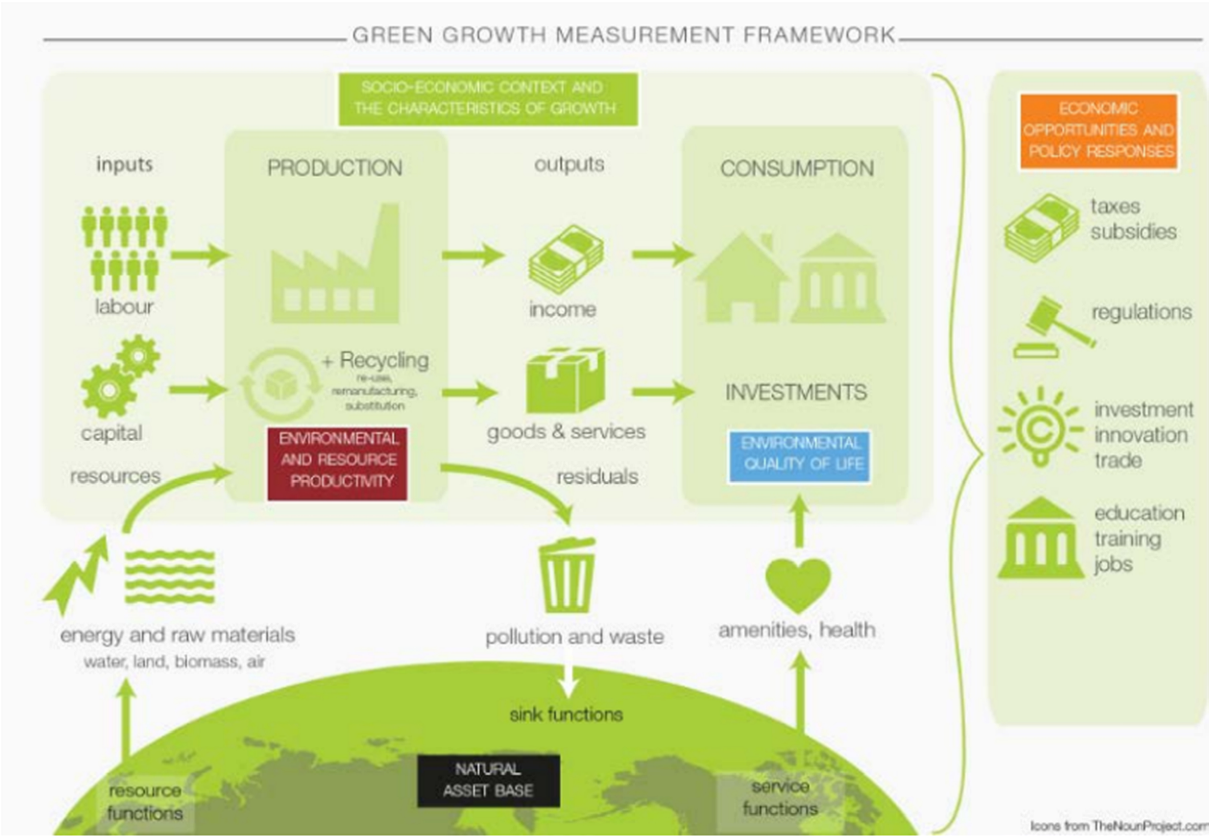


Figure 7.3. The OECD Green Growth Measurement Framework



Source: OECD (2017, p. 14)

Cooperation between indicator experts and international organisations engaged in green growth measurement and analysis occurs via the Green Growth Knowledge Platform. The initiative is led by the GGGI, the OECD, the United Nations Environment Programme (UNEP), the United Nations Industrial Development Organization (UNIDO), and the World Bank[60]. Other important sources of information on environmental pressures and outcomes include the Environmental Performance Index of Yale University and the Sustainable Governance Indicators of Bertelsmann Stiftung. Each draw on a number of data sources (listed in the Annex to Chapter 7). An open–access searchable web tool (www.measuring-progress.eu) offers a concise collection of green economy indicators, accompanied by easy-to-understand information that can help users who are not familiar with scientific terminologies to interpret results and select the indicators most suited to their analysis[61]. The web tool also provides further indicator suggestions and discusses pitfalls of interpretation.

7.4. Known limitations of environmental outcome and productivity indicators

There are several limitations to consider when using environmental outcome indicators to inform policy formulation and assessment:

• Attribution - Occasionally, proximate and rather predictable impact pathways linking individual stressors (e.g. specific technologies) to potential consequences can be established (e.g. between the emission of Sulphur dioxide (SO_2) and oxides of nitrogen (NO_x) to soil and water acidification). However, the impact pathways are often difficult to predict (e.g. between the emission of GHGs and local climate change impacts), or difficult to attribute to a single cause (biodiversity loss is often due to multiple environmental stressors). This makes it necessary to simultaneously track a number of causes of environmental degradation and makes it difficult to draw partial conclusions on the contribution of specific sub-systems of socio-technological systems.

• Allocation - From a technical standpoint some indicators, such as those linked to activities that are intrinsically mobile, such as transportation, can be difficult to allocate to a single region or country. In this case it is important to follow international standards or recommendations on allocation practices and to transparently document all assumptions and allocation rules.

• Ethics - Environmental stressors and their consequences can be temporally and geographically detached from each other. This implies that individual actors might have little power to influence the factors causing undesirable impacts, to the point that they are discouraged from collecting data and setting environmental targets. This has important and complex implications for environmental governance that transcend the selection of environmental indicators per se, but the issue should nonetheless be acknowledged if relevant environmental outcome indicators are to be produced.

The above points highlight the importance of addressing indicator collection as part of a broader process of environmental governance rooted in environmental ethics (Benson, 2001). In order to choose and set up relevant scoreboards of environmental output indicators, it is essential to engage in deep and long-lasting dialogue with the core actors involved in each of system under study, as well as establishing stable platforms to exchange appropriate measurement frameworks with peers that are responsible for similar environmental issues in other regions or countries.

As indicated by the Green Growth Knowledge Platform (GGKP, 2013) developments in productivity or intensity indicators require cautious, in-context interpretation:

• Attribution: Improvements in resource efficiency and productivity can come from eco-innovation in resource use, processes or management practices. These can directly reduce resource consumption or substitute the use of one resource for another. In an imperfect market, this can hide increasing use of scarce environmental inputs. Further, when assessing regional or national resource efficiency and productivity, improvements can be due to changes in industry structure, without any investment in eco-innovation.

• Allocation: In the case of cross-border or global environmental goods, such as climate, changes due to a shift to imports would show up as improvements in the national carbon productivity/intensity indicator, while in fact no progress with respect to emission reduction would have been achieved at a global level (i.e. no absolute, or global, improvement in the decoupling of growth and emissions).

• Country context: Productivity or intensity indicators need to be assessed in respect to each country's level of development or endowment of natural assets. As a result, benchmarking across countries is not always possible.

• Impacts on future development: In the context of sustainable development, resource and productivity indicators can rely on a simple aggregation by tonnes of material or GDP (especially in the context of developing countries), and may not reflect the different levels of scarcity nor the individual environmental effects of different materials. Further, simple ratio indicators do not provide information on relative versus absolute decoupling, or the position relative to thresholds related to significant increases in environmental risks. Data on resource stocks and embedded flows are still required to better understand the extent to which progress is made towards effective resource decoupling.

7.5. Socio-economic (SE) indicators for the Green Economy

7.5.1. Quality of life

The Report by the Commission on the Measurement of Economic Performance and Social Progress (Stiglitz et al., 2009) recommends the development of better indicators for quality of life and sustainability. As a result, NSOs in many countries have expanded data measurement on quality of life issues. In Europe, A Quality Life Expert Group (EG) was established by the Directors of Social Statistics to create a list of indicators on quality of life, identify data gaps, and make recommendations on possible future data (Eurostat, 2017).

The report presents a comprehensive framework of quality of life indicators to cover:

- Material living conditions (median income, inequality of income, severe deprivation rate)
- Productive or other main activity (employment rate, job satisfaction)
- Health (life expectancy, self-perceived health status)
- Education (tertiary education attainment)
- Leisure and social interactions (satisfaction with time use, help from others)
- Economic security and physical safety (inability to afford unexpected expenses, homicide rate, perception of crime, violence or vandalism in the living area)
- Governance and basic rights (trust in the legal system)
- Natural and living environment (urban pollution, perception of pollution or other environmental problems in the living area)
- Overall experience of life (life satisfaction).

The main data source for these indicators is EU-SILC (Statistics of Income and Living Conditions)[62]. For a green economy, the indicators for the natural environment (item 8 in the list) are a pivotal element. On this issue, the report notes that “environmental conditions are important not only for sustainability but also because of their immediate impact on the quality of people’s lives” by affecting human health and by offering amenities or degraded conditions. Direct effects occur through air and water pollution, hazardous substances and noise. Indirectly, human health and well-being are affected through climate change, transformations in the carbon and water cycles, biodiversity loss and natural disasters that affect the health of ecosystems.

The environmental health effects of pollution can be assessed in three ways: by measuring exposure to harmful emissions, by measuring lost life years because of pollution, and through subjective perceptions of pollution and other environmental problems. In the UK, the impact of public exposure to airborne particulates has been estimated to reduce average life expectancy by approximately six months and to cost public health over £16 billion a year (DEFRA, 2015). In Northern China, people live 3.1 years less than people in the South of China due to air pollution concentrations that are 46 percent higher.

A subjective indicator for the experience of environment-related nuisances is calculated as the percentage of households that answered ‘Yes’ to the question: Do you have any of the following problems related to the place where you live: pollution, grime or other environmental problems in the local area such as: smoke, dust, unpleasant smells or polluted water? The indicator lumps together different environmental nuisances that are better separated from each other and does not inquire into the seriousness of the problems experienced. In contrast, the indicator on satisfaction with recreational and green areas uses a response scale from 0 to 10, where 0 means not at all satisfied and 10 completely satisfied. In general, the use of scales is preferred over simple yes/no answers. The demand for environmental protection and amenities can be determined via opinion polls, election results for green parties, and people's support for green measures. Trust in governance and awareness about environmental problems is needed for pro-environment policies. These results can be compared to other policy issues. In Germany, respondents ranked preserving "democracy and freedom" as the most relevant indicator and "further increasing life expectancy" as the least relevant. Average per capita income was rated as the second least relevant factor (Gieselmann et al., 2013, p. 4).

The EU Quality of Life Expert Group notes the need for more and better indicators to assess environmental-related quality of life aspects. For example, emissions indicators refer mainly to the aggregate quantities of various pollutants, rather than to the share of people exposed to dangerous doses. Existing indicators need to be supplemented to cover the number per capita of premature deaths from exposure to air pollution, of people lacking of access to water services and nature, or exposed to dangerous levels of noise and pollution; and the damage inflicted by environmental disasters. Survey measures of people's perceptions and evaluations of the environmental conditions of their neighbourhood are also needed. These indicators need to be provided for people from different social groups because access to water or nature or exposure to poor conditions varies by income and other factors (Eurostat, 2017).

An example of a composite index is the Canadian Index for Well-being (CIW). It consists of 64 indicators representing eight interconnected domains of importance to quality of life and a summary indicator. The framework is based on a broad consultation with Canadians and the inputs of national and international experts (Canadian Index of Wellbeing, (2016). The domains for indicator measurement are: Community Vitality, Democratic Engagement, Education, Environment, Healthy Populations, Leisure and Culture, Living Standards, and Time Use.

The OECD (2017) indicators for better life includes two environmental indicators: exposure to air pollution (the weighted average of annual concentrations of particulate matters less than 2.5 microns in diameter (PM2.5) in the air) and water pollution (measured as people's subjective appreciation based on the question: "In the city or area where you live, are you satisfied or dissatisfied with the quality of water?").

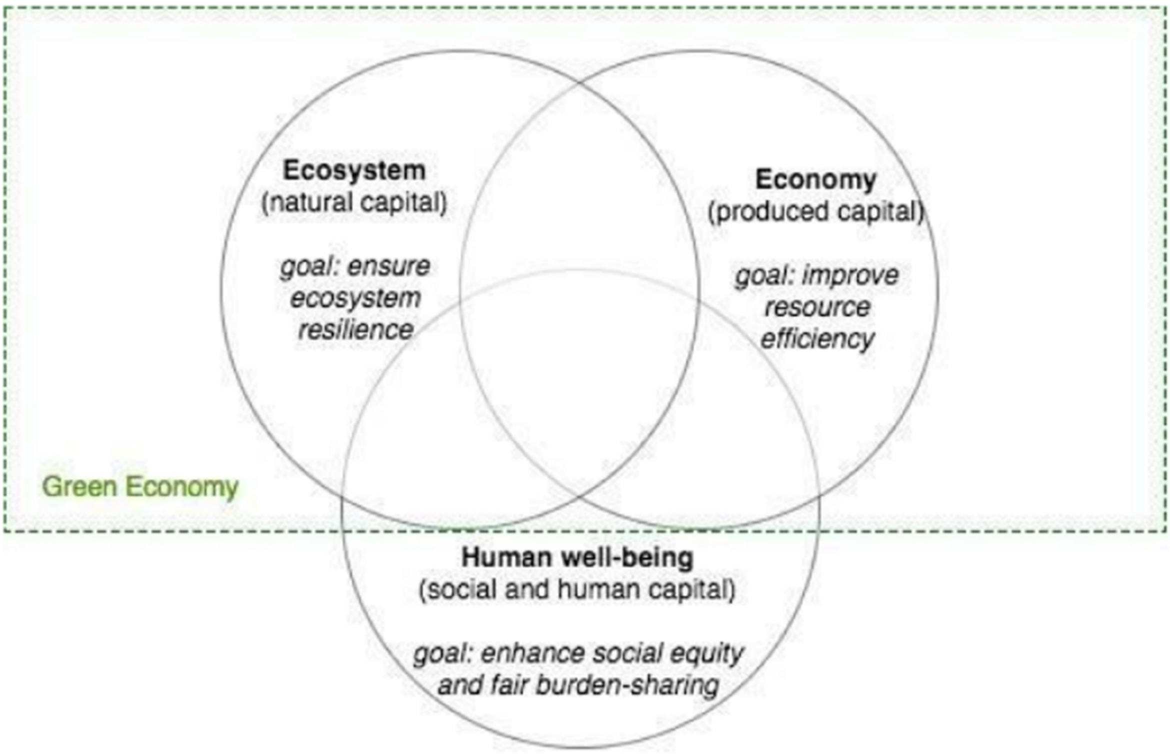
In general, indicators for well-being help to track issues and gaps in well-being. Eco-innovation is of relevance for reducing environmental pressures, but it also contributes to the sources of well-being. Eco-innovation initiatives such as sharing and repair and reuse centres can help to restore community life or provide jobs to people suffering from employability disadvantages (migrants, people with a mental or physical handicap and people with a life history of crime, substance addiction or psychiatric problems. Eco-innovation can also provide jobs in export sectors and offer a more green and pleasant natural environment for people to live in and to visit.

A neglected issue so far is the quality of life in the workplace. This is higher in companies that provide staff with greater autonomy, where work is done cooperatively and where people's competences are used. Psychological studies find that autonomy, relatedness and competence are basic psychological needs (Deci and Ryan, 2008; Keller, 2016). Economists attribute a positive value to competition for reasons of efficiency, but this overlooks the important role of cooperation in innovation and that competition and systems of meritocracy can undermine people's innate desire for being valued for what they are (Sennett, 1998). Consumption competition can also have negative effects (Schor, 2010). Instead of making people happier, consumption competition can drive people to live excessively busy and stressful lives. Psychological research finds a negative correlation between materialistic lifestyles and psychological well-being (Kasser, 2002). Indicators for workplace quality (autonomy, collaboration, etc.) and consumption competition can help to round out other indicators for well-being.

The acceptance by policy makers that there are multiple components to well-being could encourage policies to give greater emphasis to public goods. Public libraries, green parks and low traffic environments offer important benefits to all population groups. Urban gardens and repair activities in the informal economy could also restore some of the community life. More work is needed on the quality of life aspects of eco-innovation, in particular social innovation such as community energy, product sharing and companies catering to the self-determination needs of workers. System innovation could support a wide variety of quality of life aspects. More attention should be given to the negative side-effects of consumption rivalry. The building of multiple indicator systems would help to provide research-based answers to these issues.

The above aspects are taken up more in the literature on well-being than in the literature on a green economy and the SDGs. This is acknowledged by the EEA.

Figure 7.4. Green Economy concept according to the EEA



Source: Redrawn from EEA, 2016

A brief note on measuring eco-innovation for a Blue Economy

As noted in the introduction activities to promote blue economic growth for marine and maritime industries have attracted increasing attention, although to date many reports have not evaluated the need to develop eco-innovations for the Blue Economy[63]. The use of of green or non-polluting technologies is highly desirable and relevant to Blue Economy industries including energy, marine biotechnology, ocean mining, extraction and commercialisation of marine resources, ecosystem services, and coastal protection. Recently, reports by the OECD and the European Commission considered the role of innovation for the Blue Economy by presenting business cases and examples of ongoing scientific, research and innovation projects with the potential to foster economic growth and employment in marine and maritime-related activities (OECD, 2019, European Commission, 2019). However, no measurement framework for the role and characteristics of eco-innovation was proposed. In this respect, many of the proposals for data collection in this document can be adapted to cover green activities, including eco-innovation and the circular economy, for the Blue Economy. For example, as noted in the fol-lowing chapter, surveys can be used to identify the factors that drive eco-innovation and value creation in the marine and maritime industries.

8

METHODOLOGIES FOR DATA COLLECTION

Anthony Arundel, Christian Rammer,
Michal Miedzinski and Fernando J. Díaz López

This chapter discusses methodologies for collecting new data and existing data collection exercises. Special attention is given to the use of dedicated eco-innovation surveys. Surveys are uniquely suited for collecting data on the prevalence of eco-innovation in different sectors and for collecting data on drivers and barriers to eco-innovation. Methods for collecting new data through data mining via web-scraping are also discussed.

8.i. Introduction

The measurement of eco-innovation through surveys can either use the object-based method, collecting data on specific eco-innovations, or the subject-based method, collecting data on the eco-innovation activities of actors such as the economic units defined in the SNA (OECD, 2018). Surveys can use hybrid approaches that combine both methods. Data can be obtained from existing sources or through new surveys. While using existing data sources can reduce the effort in terms of time and resources required for data collection, this approach is often limited to specific sectors, industries or organisations or to specific types of eco-innovation. Collecting comprehensive and representative data on eco-innovation usually requires additional information from surveys, although data mining techniques such as web-scraping provide options for producing more timely data in the future without surveys.

All four SNA sectors, business, government, on-profit institutions serving households (NPISH), and households, play a role in eco-innovation. Consequently it is useful to collect data on eco-innovation activities in each of these sectors in order to provide full coverage of an economy.

The business, government and NPISH sectors consist of organisations that share similar features: all combine inputs to create outputs such as goods and services that are provided to households or other organisations, either through the market (business and government owned enterprises) or at no direct cost (government agencies and NPISHs). Households can also combine resources to create outputs, but most households in high-income economies do not provide goods or services for the use of others. In low and middle income economies the production activities of households are a major part of the informal economy. With the exception of their role in the informal economy, households primarily consume the goods and services of other organisations. The implication for data collection is that the business, government and NPISH sectors can share similar features, such as a focus on eco-innovation activities that affect the use of resources (process eco-innovations) and the environmental characteristics of product eco-innovations. Data collection for households needs to focus on consumption and the role of the household in eco-innovation systems, such as purchasing decisions, recycling, rebound effects, and social drivers and barriers. This does not imply that households are never involved in developing eco-innovation (see von Hippel for examples of innovation in the household sector), but their role is likely to be minor.

8.1. Data collection: sources and methods

Data on eco-innovation can be obtained from surveys, new product announcements, in trade journals or corporate websites; annual corporate reports, organisations that fund R&D for eco-innovation, patent databases, capital investment databases, bibliometrics, and the knowledge valorisation/ technology transfer offices of universities and public research institutes (data on eco-innovation projects funded by firms; licensing revenue from eco-inventions, etc.). Data sources that are posted online, such as corporate reports, can be accessed through web-scraping methods.

Well-designed surveys, either as the source of existing data or for new data collection exercises, have a distinct advantage over many other methods of data collection: they can provide representative results for all businesses, government agencies or households in an economy that meet pre-defined eligibility criteria, such as for firm or agency size. This is particularly important for the construction of indicators on the presence of eco-innovation or the drivers and barriers to eco-innovation. Other data sources are either unrepresentative or introduce biases through self-selection.

Unrepresentative data only cover a subset of firms or eco-innovations. An example is the use of new product announcements to identify eco-innovations. Firms are only likely to report major products and are unlikely to report many improvements or process eco-innovations. Other examples include data from research funding organisations on firms that obtained subsidies for research of relevance to eco-innovation, or data on R&D activities. Funding data will only capture successful applicants, leaving out firms that did not apply at all or applied but were unsuccessful. R&D data do not capture the innovation activities and investments of eco-innovative firms that do not perform R&D. Self-selection is an issue for many data sources and occurs when firms or government agencies must voluntarily take steps to publicise an innovation (as with product announcements), apply for a patent, or apply for funding.

8.1.1. Existing data sources

Data on eco-innovation activities, policies and the green economy can be obtained from existing data compilers that use a range of data sources. For each type of data, information on the original source, reliability and limitations of the data needs to be collected. Existing data can be used to identify and count eco-innovations introduced during a defined period of time, or to count the number of units having introduced eco-innovations. Relevant data for this purpose are as follows:

- Patent data about inventions in green technologies.
- Data from firms, for instance in trade journals, product announcements, or trade fair materials on the eco-efficiency of their products.
- Tests of the environmental characteristics of products by independent organisations (e.g. consumer organisations).
- Financial data about capital investments and funding to firms (e.g. investment in venture capital, private equity, mergers and acquisitions, initial public offerings)
- Sales data of products by eco-efficiency classification (e.g. CO_2 emissions for cars, energy efficiency of household appliances, etc.).
- List of organisations using eco-labels or green stickers.
- List of organisations that have implemented environmental management systems (based on ISO 14000 family or EMAS) or energy management systems (ISO 50001).
- List of green technologies that have obtained a certificate of performance or a statement of verification from an environmental technology certification or verification scheme.

8.1.1.1. Compiled sources of eco-innovation data

To provide a full picture of eco-innovation, measurement is required for multiple factors, which often can only be met through combining data from multiple sources. Examples for combining data sources on eco-innovation are as follows:

- Survey a sample of inventors with a patent of relevance to eco-innovation in order to query if the patented invention was spurred by specific regulations, environmental concerns, economic gains for the inventor, etc.
- Link patent and R&D data on eco-innovation with data on economic outcomes collected from administrative data, surveys, digital sources, etc. in order to determine the role of eco-innovation inputs on economic performance.
- Combine meso and macro information on eco-efficiency with micro data from firms on organizational and technological eco-innovation to better understand the links between micro and macro measures.
- Combine information on general innovation investments with information on eco-innovation and environmental performance.

Several data sources compile relevant data from multiple sources. Examples include the EIO index, the ASEM Eco-Innovation Index (ASEI) and the Global Cleantech Innovation Index (GCII). All are limited to eco-innovation in the business sector.

The EIO index provides indicators for eco-innovation inputs, activities, and outputs; resource efficiency, and socio-economic outcomes. The innovation inputs are restricted to R&D data (derived from surveys) and the activities from the 2008 European Community Innovation Survey module on environmental innovation. This provides data on the percentage of firms that introduced a product, process, organisational or marketing innovation that resulted in lower energy or material inputs and the share of companies with ISO 14001 certification. Data are also provided for green patents and for academic publications on eco-innovations.

The ASEM Eco-Innovation Index (ASEI) provides indicators for eco-innovation capacity, activity, performance, and supporting environment. It includes indicators from the Environmental Performance Index (EPI) system of the World Economic Forum on environmental policy and quality of life related to environmental factors. It has a focus on SMEs.

The Global Cleantech Innovation Index (GCII) covers 'cleantech innovation', defined as "doing more with less (e.g. fewer materials, less energy expenditure, reduced water availability), while making money doing so". The GCII covers cleantech-focussed innovation drivers, emerging cleantech innovation, and commercialised cleantech innovation. Novel indicators include early stage private investment (amount of venture capital invested in cleantech companies as a percentage of GDP in PPP), cleantech-friendly government policies in the field of energy (government policies supporting clean energy including tax incentives, feed-in tariffs, renewable energy mandates and others) and four indicators on commercialised cleantech innovations: revenues of cleantech companies, renewable energy consumption and renewable energy jobs, late-stage private investment and exits, and the number of successful publicly-traded cleantech companies.

8.1.1.2. Compiled data sources for the green economy

Several sources of compiled indicators are available for the green economy and green growth. The European Union funded the creation of the www.measuring-progress.eu website by the Netgreen research team, which pools over 200 indicators, notably most of the sub- indicators of the Eco-Innovation Scoreboard as well as the Global Cleantech Innovation Index (GCII). It also includes GGGI's Diagnostic Indicators, the Global Green Economy Index (GGEI) of Dual Citizen, which includes both data and perceptions, and the OECD Green Growth Indicators. Moreover, it includes the Green Transition Scoreboard (Ethical Markets Media), the Resource Efficiency Scoreboard (Eurostat), and the Environmental Performance Index, as well as other related indicators such as the MSCI Global Clean Technology Index, the Global Innovation Index (GII), the Innovation Union Scoreboard (Eco-IS), and the Global Competitiveness Index (GCI).

The European Commission supported the development of an indicator-based analytical tool (IGrowGreen) in order to assess Member States' structural reforms and progress towards 2020 targets. In 2012, the UN Environmental Program (UNEP) together with the OECD, the Global Green Growth Institute and the World Bank launched the green growth knowledge platform (GGKP) which pools several indicators and measurements of national environmental performance (Green Growth Knowledge Platform, 2016). There are also a few indicator sets under construction. UNEP, for example, is working on two measurement initiatives: the Green Economy Progress (GEP) index and an Integrated Green Economy Modelling (IGEM) tool.

All of these collections of indicators (or scoreboards) provide valuable data. Some, such as NETGREEN, are aggregators, providing links to hundreds of indicators collected by other organizations. Many of them include environmental indicators that measure pollution levels such as GHG emissions, eco-innovation indicators that cover investments to improve the efficiency with which natural resources are used such as GHG emissions per unit of economic output; and policy indicators that support eco-innovation and other activities to improve environmental or resource efficiency outcomes.

The OECD's (2009) Green Growth indicators are comparable to the Oslo Manual's model of business innovation. It includes inputs such as R&D, patents and publications; outputs such as the number of innovations, and outcomes such as sales of eco-innovations and resource efficiency. A similar approach is used in the Eco-innovation Observatory's eco-innovation scoreboard, which includes indicators for inputs (government expenditures on environmental R&D, patents and publications); outputs (the share of firms with an eco-innovation); and outcomes including resource efficiency, the intensity of GHG emissions by GDP, and the employment, sales, and exports of the eco-industry.

An issue for data collection is the level of detail required of indicators. For example, a patent for an incremental improvement in a logistics algorithm could, if applied, result in a small decrease in the road transport of goods, resulting in a very small decrease in total particulate and NOx emissions. Measuring the beneficial effects of this patent–based innovation could be of value to a better understanding of road transport, but it may be of little relevance to the development of R&D support policies to reduce particulate emissions. It may also be difficult to estimate the effect of this single innovation, given other system level and indirect factors that influence particulate emissions.

8.1.1.3. Data on eco-innovation policies

Data on policy impacts can be obtained from generic innovation surveys that include questions on the use of and influence of different types of policies (regulation, environmental taxes, etc.) or from dedicated surveys to evaluate specific policy instruments. Generic innovation surveys can be used to evaluate the effect of general policy types on eco-innovation outputs such as product or process eco-innovations, but due to a lack of detail they are unsuited for examining the effect of specific policy instruments on outputs or the effect of policy on environmental outcomes. Dedicated policy evaluation surveys on specific instruments can include questions on environmental outcomes and enabling and hindering factors (including policy instruments).

Reliable policy evaluation requires research on contextual factors that influence differences in policy effectiveness in encouraging investment in eco-innovation, eco-innovation outputs, or eco-innovation outcomes. Knowledge of contextual factors is necessary to identify variables that need to be measured to produce accurate evaluations (for instance to control for confounding factors). Qualitative contextual data can be obtained from interviews and focus groups on the why and how of eco-innovation activities by organisations and households. In most cases purposeful sampling rather than random sampling is used to select interview or focus group respondents.

Expert-based methods such as expert interviews, panels or surveys of experts are a useful tool to interpret quantitative data on policy effects and to identify variables for measurement. Independent experts can also critically examine claims about the costs of regulation, the benefits of particular eco-innovations and capabilities for change. Expert knowledge of a sector, including consumer demand, is critical to the choice and design of appropriate policy instruments

8.1.1.4. Existing surveys

Surveys of organisations or households on eco-innovation can build upon existing surveys or use a dedicated eco-innovation survey. Several existing surveys collect data of relevance to eco-innovation:

- Household surveys on the use of appliances that relate to environmental technologies (cars, washing machines), about environmentally-friendly practices at home (behavioural change towards less polluting activities), environmental choices of consumers (favouring green products and services), etc.
- Pollution Abatement Costs and Expenditures (PACE) surveys: costs for different types of environmental protection methods, often focussed on end-of-pipe technology, no information on product eco-innovation.

- Investment surveys: investment in capital (private equity, venture capital, M&A, IPO), new production equipment, transport equipment or information/ communication technology). As new investment is usually based on the latest available technology and criteria for risky decisions are often related to the existence of proprietary technology (e.g. patents), it can be associated with eco-innovation (either intended or unintended).
- Energy use surveys: measures on energy efficiency, types of energy sources used
- Waste treatment and disposal surveys: measures on changes in waste volumes and disposal methods.
- Innovation surveys: Inclusion of modules on eco-innovation, as in the 2008 and 2014 European Community Innovation Survey.

8.1.2. Methods for collecting new data through surveys

Data collected through dedicated eco-innovation surveys can be superior to data from existing surveys for two reasons. First, they can use consistent definitions of different types of eco-innovation, as proposed in this Manual. Second, they can collect data on a wide variety of eco-innovation inputs, drivers and barriers, activities, outputs and outcomes. Dedicated surveys, however, are costly.

8.1.2.1. Dedicated eco-innovation surveys

Dedicated eco-innovation surveys of businesses, government organisations, NPISHs and households can collect a broad variety of data on eco-innovation: inputs such as the use of government incentives, material resources, knowledge flows including licenses to IP; organisational capabilities, innovation activities including different types of expenditures on innovation; outputs such as eco-innovations in the form of processes, goods and services; and outcomes such as reductions in externalities such as air, water and soil pollution. In addition, surveys can collect data on the eco-innovation goals of all types of organisations, including the role of eco-innovation in corporate social responsibility, a strategic focus on product or process innovations and on specific types of eco-innovations (reduce water consumption, reduce greenhouse gas emissions, reduced environmental effects from the normal use of products by households) and marketing of the environmental characteristics of products.

Data collected from surveys can be used to create statistics and indicators of eco-innovation and for analytical research on the relationships between incentives, inputs, outputs and outcomes.
Survey methods for collecting data on innovation are covered in greater detail in Chapter 9 of the 4th revision of the Oslo Manual (OECD/Eurostat, 2018) and, for the energy sector, in Chapter 7 of the UN (2016) publication “International Recommendations for Energy Statistics (IRES).” This section only provides a basic overview to guide surveys of eco-innovation.

Sampling issues
In order to be useful for the construction of indicators, surveys need to be based on a representative sample of units within the sector or industry of interest. Surveys of eco-innovation in the business sector can sample different types of units including establishments (such as power generation or manufacturing plants) or enterprises, which is the smallest legally-defined autonomous unit that can take decisions on investments, such as on innovation. Sampling at the enterprise level has the advantage of enabling data linkage with other surveys, for instance on R&D or general innovation activities.

Contact information for businesses, NPISHs, and government organisations is available in both private and official business registers. The latter are more up-to-date and accurate, but are often only available to National Statistical Offices (NSOs). Surveys of governments can be challenging because there is no equivalent to an enterprise. For instance, a Ministry of Health will be included in a business register, but not the different divisions within the Ministry. Obtaining information on the eco-innovation activities of government agencies will often require sampling divisional or departmental heads. Divisions or departments may need to be identified from organisational charts (organograms).

Eco-innovation and externalities are shaped by an enterprise's industry. The 'term' industry within the SNA is not limited to manufacturing, but includes all economic activities such as financial services, accommodation services, mining, consumer goods manufacture, aviation transport, road transport, etc. Data on an enterprise's industry can be obtained from private and official business registers, but if not available a suitable question needs to be included in the survey questionnaire. Aggregation to the main aggregated sectors of interest for eco-innovation (commercial, industrial and transportation) requires classifying industry data by the International Standard Industrial Classification (ISIC) system at the two-digit division level. The fourth aggregated sector, residential, is similar to the household sector in the SNA.

A simple random sample of all businesses in a region or country is an inefficient method of estimating eco-innovation because of large variations in the types of eco-innovations that are required in each industry and the types of externalities that each industry produces. Stratified sampling is recommended, where the sampling fraction (the percentage of units in the population that is sampled) varies depending on data requirements. For instance, a high sampling fraction should be used for industry strata of high interest but with only a few enterprises (such as electrical power generation). A low sampling fraction can be used for industry strata with hundreds or thousands of enterprises, such as in retail, food services and accommodation. In addition to industry, strata can be defined by the size of the responding unit and its geographical location.

Non-stratified random sampling can be a practical approach for small scale surveys to explore and/or identify the number of enterprises with eco-innovation-related activities, products or services not reported or captured in existing business registries. An example is to use a small survey to identify Cleantech companies in a region or country and their basic characteristics of these companies.

The production of statistics and indicators from a stratified sample needs to use weights to adjust for differences in sampling fractions across strata. The weight equals the reciprocal of the sampling fraction in each stratum. The weight should be further adjusted by the reciprocal of the response rate in each stratum. For a census, strata can be constructed post-survey to identify non-response rates in strata defined by firm size, sector, region etc.

The production of statistics and indicators from small random sample (of fewer than 100 observations) can be used if high quality data are obtained. A common method to assess the quality of the data from a small-scale survey requires testing the availability and reliability of the collected data. This requires a good response rate, the use of adequate methods for estimating missing data and where relevant a KMO test of sampling adequacy with values above 0.6 (c.f. Tashakkori and Teddlie, 1998, McCallum, et. al. 1999, Montalvo 2002, Diaz Lopez, 2008)[64].

Survey methods

Eco-innovation surveys can be conducted online, by post, through computer assisted telephone interviews (CATI), or via computer assisted personal interviews (CAPI or face-to-face interviews). The choice of which survey method to use depends on costs, expected response rates, and the effect of the method on data quality. CATI and CAPI both require trained interviewers, which increase costs. Online surveys are the least expensive because they reduce mailing costs and question responses are entered directly into a database, but they can suffer from low response rates, particularly in surveys directed to the managers of businesses or government agencies. Response rates can be improved by following an online survey with a mail-out of a printed version of the questionnaire to non-respondents and by providing several rounds of reminder letters or emails (Millar and Dillman, 2011). Response rates are also increased by personalisation, for instance sending the cover letter and reminder letters to named respondents, changing the wording of reminders, using stamps on a posted questionnaire instead of machine franking, etc. Face-to-face surveys using printed questionnaires rely on the availability and relevance of the respondent. They require interviewers with a really sound knowledge of the topic as they are often asked to clarify the meaning of a number of questions. Their disadvantage is that they can be really time consuming and can induce errors in the transcription of the responses, but they can be a valid alternative for small scale-surveys relying on low budget.

Frequency of data collection and observation period
National general innovation surveys are usually conducted yearly, every two years, or every three years. The frequency of eco-innovation surveys will be influenced by cost and user requirements, but a three-year frequency is likely to be acceptable for subjective data.

Surveys need to use a defined observation period that limits the scope of all questions. For instance, a household survey could ask respondents about the characteristics of their major purchases in the previous two years. Similarly, business and government surveys could ask about activities to develop or implement eco-innovations in the previous two years. For comparability, it would be useful if all surveys used the same observation period.

Questions and questionnaire design and nature of items
This manual identifies the types of data that are useful to collect but it does not provide specific questions for collecting data on eco-innovation. Examples of eco-innovation question and questionnaires can be obtained from the 'eco-innovation measurement' section of the inno4sd website[65]. Potential questions need to be carefully tested through cognitive testing via face-to-face interviews (Willis, 1999) with a sample of respondents drawn from the population of interest. Cognitive testing ensures that all questions are understood as intended and that all survey respondents can provide reasonably accurate responses to the questions.

Good question and questionnaire design is essential for obtaining high quality data, high response rates, and permitting comparability across countries, regions, industries and sectors. Is recommended to avoid using ambiguous questions and questions that include more than one questionFor example, a single question should not ask if the respondent's business introduced a product eco-innovation or a service eco-innovation. Instead, separate questions should be asked to identify "product eco-innovations" and service eco-innovations.

To support analysis questions can assign a numeric value to different magnitudes or qualities of a variable, for example the use of (such as Likert scales) to measure qualitative attributes such as importance, attitudes, opinions or behaviours. Small-scale surveys of eco-innovation have successfully used 7-point Likert scales with positive results for data strength and reliability (Montalvo 2002, Diaz Lopez 2009, Diaz Lopez and Montalvo 2015a, Freire, 2016). The use of a few open-ended questions can assist in-depth research

8.1.2.2. Data collection priorities for surveys

The main priority for data collection from new surveys is to collect data for constructing indicators that are not available from other sources. A second priority is to collect data for analysis, such as on the factors that support successful eco-innovation.
The specific types of questions for inclusion in new surveys should be identified in consultation with data users, including policy analysts, academics, and businesses. Policy analysts and policy-makers often require representative indicators on the prevalence of eco-innovation, the use of government support and incentives for eco-innovation, and the drivers or barriers to eco-innovation. When available over time, this information can be used to track changes in eco-innovation activities, for instance in response to government investments or economic and social trends.

Surveys of organisations (businesses, government, NPISHs)
Surveys need to be based on sufficiently large samples to provide indicators by industry or agency type, firm or agency size, region, etc. The priorities for new surveys of organisations and households are determined by a lack of representative, alternative sources of data. These priorities include:

- The prevalence of any eco-innovation and different types of eco-innovation (products, processes, etc., **see Chapter 2**)

- Subjective measures of the importance of different types of drivers, with a focus on policy incentives, plus the importance of barriers where relevant (**see Chapter 3**).
- Use of eco-innovation inputs such as eco-design de sign principles and knowledge sources (**see Chapter 5**)
- Outcomes of eco-innovation including reduced material use, energy use, pollution, etc., sales and employment effects, etc. (**see Chapter 6**).

Surveys of households

Surveys of households should be able to provide data by household age, size, income, and presence of children. The priorities for new surveys of households include:

- Barriers and drivers to purchasing eco-innovations
- Use of incentives for purchasing eco-innovations
- Characteristics of major purchases
- Barriers to use of or support for systemic environ mental innovations
- Consumer choice surveys
- Level of eco-literacy and concern with different environmental issues

Surveys of both organisations and households need to cover all organisations or households, including those with and without eco-innovations. This is necessary to benchmark the prevalence of eco-innovation activities in a sector and to track changes over time.

8.1.3 Methods for collecting new data through data mining

"Big data", often based on data available on the internet, theoretically provides a considerably cheaper and more timely source of data on the eco-innovation activities of organizations than surveys. The main methodology is data mining by web-scraping bots that use textual analysis to identify innovation activities that are posted on the websites of businesses or public sector organizations such as municipalities or government agencies.

The use of data mining to identify innovation and eco-innovation activities is in its infancy, but significant progress is expected in the future if methods are found to solve four issues that reduce the reliability of web-scraping:

1. Self-selection due to organizations only posting information that they want to make public. For instance, public sector agencies may not post information on eco-innovation failures, while firms may not report a process eco-innovation if it is financially advantageous to keep process innovations hidden from competitors.

2. Incomplete and non-comparable data, whereby different organizations post different kinds of data or use different terms to describe their innovations. For instance, a firm could describe an eco-innovation without ever using the word 'innovation' or other words that can be used by a bot to identify novelty (Bianchi et al, 2018).

3. Poor representativeness, whereby some members of a population are more visible than others. For instance, some small firms could lack a website (Kinne and Axenbeck, 2018), or eco-innovative departments within a government ministry could lack a separate web page.

4. Lack of accurate and comprehensive terms in widespread use for eco-innovation activities. For instance, simple text phrases such as 'recycling waste' could lead to misleading results because the term might be used to refer to future plans, government regulations, or the activities of other firms or organizations.

To date, a small number of studies have used web-scraping to develop innovation or eco-innovation indicators in the business or public sector. Several of these studies have been able to validate web data or web-scraping results against high quality data obtained using other methods. The most common result is that using web data substantially underestimates the level of innovation activities. For example, Côté and Stanciauskas (2018) use manual

inspection (rather than web-scraping) of the websites of a random sample of 1,050 European firms with 10 to 249 employees and determine that 14.3% of these firms reported an innovation on their website. In contrast, a comparable estimate derived from the European Community Innovation Survey estimated that more than double, 30.9%, of the sample should have reported an innovation.
NESTA (2018) experimented with the use of big data to produce several innovation indicators, some of which can be verified against other data sources. Examples include using web scraping to estimate university spin-offs and start-ups in the UK or the number of accelerators and incubators in the UK. The experiments noted problems with estimating university spin-offs and start-ups due to the proprietary nature of some of this data (and the investment of one source in methods to block web-scraping). In respect to accelerators and incubators, web-scraping only identified approximately half of known incubators and accelerators. The most useful experiments concerned producing data for innovations for which there were no other data sources, such as the number of firms in the UK active in virtual reality technology.

Beaudry et al. (2016) use web mining to identify innovation activities instead of the simple presence or absence of innovation or an innovative organization. They identify four activities (R&D, intellectual property, collaboration, and external financing) on 133 corporate websites maintained by companies that had responded to an earlier survey on these activities. Correlations of the results between the two methods are positive and statistically significant, but the correlation coefficients are low, between 0.22 and 0.37, indicating that the web-scraping method considerably under reports these activities.

Gok et al. (2015) use web mining to identify R&D activities by 296 British firms that manufacture environmental technologies and compare their results to patent and publication data. They find that web mining identifies more R&D activity than patents or publications, but they do not validate their results against survey data.

Bianchi et al. (2018) propose the use of web-scraping to identify the use of four methods of solid waste collection by municipalities. Although this is a study of technology adoption instead of eco-innovation, the approach could be usefully applied to estimate the uptake of known, pre-defined eco-innovations by organizations. It may also be easier to measure adoption of a technology than innovations, since an adopted technology can remain in use for many years, increasing the probability that it can be identified from a website.

These experimental results show that web-scraping has so far been unable to match the accuracy of surveys on innovation, but for some uses it could provide more comprehensive data than traditional indicators such as patents or bibliometrics. Web scraping could also be useful for identifying technology adoption or providing preliminary information for emerging areas of activity that are not adequately captured in surveys. Extensive additional research and refinement of machine learning is required before web-scraping can provide a cheaper source of eco-innovation data that can provide the accuracy, depth and granularity of survey data.

An alternative method for data mining is the use of computer-aided content analysis of a large set of digital documents (e.g. academic articles or industry magazines in a PDF format). Diaz Lopez and Montalvo (2015b) propose a qualitative data mining method to systematically review eco-innovation literature in a dataset of digital documents based on standard premises for data selection and preparation, analysis and visual representation. The proposed method has been validated by the authors to identify major factors influencing innovation patterns and environmental performance over a specific period of time (years 1901-2030) in a given industry (Diaz Lopez and Montalvo 2015a).

9

SYSTEM INNOVATION AND ECO-INNOVATION MEASUREMENT

René Kemp

Green system innovation can achieve environmental and other benefits through the use of alternative systems of production and consumption. System innovations are not prone to good measurement because they are dynamic and context-specific. Progress is best tracked through diagnostic questions addressed to stakeholders.

Given the current structure of modern economies and weak demand for green products, it is unlikely that eco-innovations will achieve an absolute decoupling between resource use and economic growth. According to the European Environmental Agency (EEA):

"Europe's persistent environmental challenges are systemic, in the sense that they are tied in complex ways to prevailing economic, technological and social systems. Next to adopting green technologies and practices, societies should find new ways for meeting key human needs such as food, mobility, energy and housing. This requires fundamental changes in sectors of production and user practices, which in turn require changes in other systems, such as the fiscal and financial systems, and the knowledge systems supporting decision-making"
(EEA, 2015).

Drawing on the literature on sustainability transitions (Geels, 2005, Grin et al., 2010); the EEA's 2010 State of the Environment Report identified the need for more integrated (systems) approaches to addressing persistent environmental and health problems and for a transition to a green economy. The key features, policy approaches and assessment requirements for different levels of environmental challenges are given in Table 9.1. The systemic challenges faced today require appropriate assessment methods that go beyond the collection of basic indicators. Data needs to be collected on social, technological, environmental, economic and political aspects of systemic change, with attention to factors such as ownership, design for sustainability, governance, the management of local and global commons, the use of foresight, and stakeholder participation.

Systemic change for sustainable development can consist of changes in socio-technical systems for meeting a societal function such as mobility or nutrition and fundamental changes in work practices, ownership and economic organisation. Transitions in socio-technical systems are referred to as system innovation (Geels, 2005). Another type of change is socio-economic, involving changes in the structure of an economy (profit-based, benefit-based and hybrid forms) and the role of capitalism, the money economy and markets in shaping consumers, consumption decisions, work activities and government policies (Kemp et al., 2018).

The concepts of a green economy and a circular economy combine socio-technical and socio-economic perspectives. This chapter examines measurement issues for system innovation, using the case of a circular economy. A circular economy is an example of a green system innovation "that is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times" (EMF, 2014a; 2014b; 2016, p. 19). Resources are regenerated or recovered and business models seek to maximise the value extracted from finite stocks of technical assets and materials (EMF, 2016, p. 22). In addition to a circular economy, the transition to a green economy would require several other system innovations, including a renewables based energy system, e-mobility, and ecological precision farming.

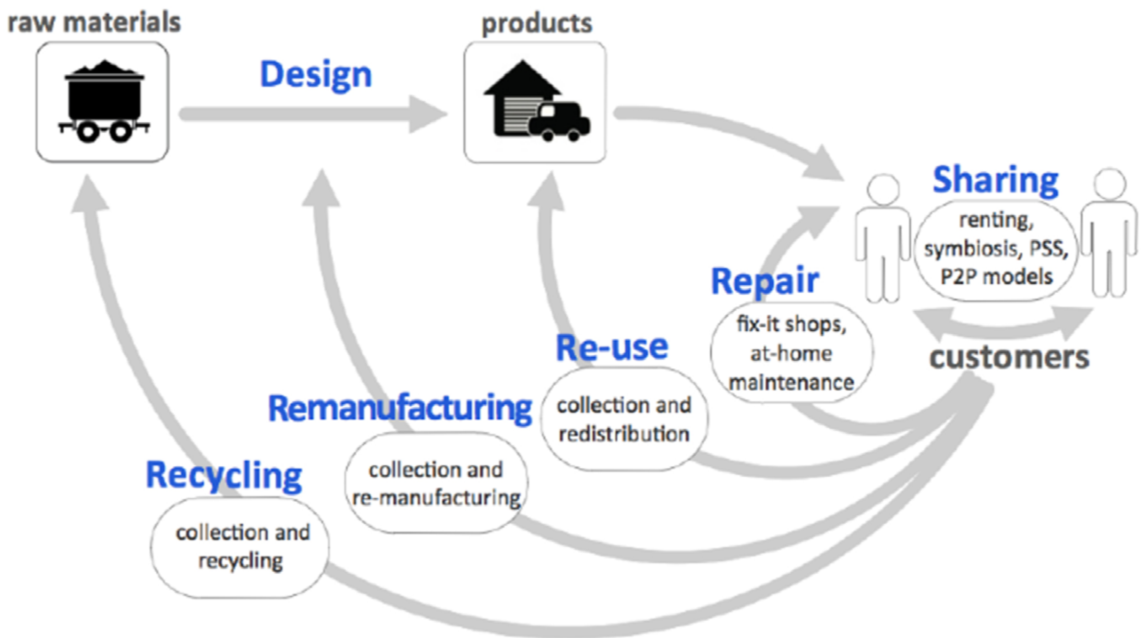
A visual representation of the circular economy is given in Figure 9. 1

The closing of material loops, an important part of a circular economy, will reduce the use of virgin materials, while other parts of the circular economy such as recycling and repair would reduce demand for resources. The expected cost savings from these activities are likely to create rebound effects (**see Chapter 1**), unless people engage in downshifting (opt for a life style in which they work and consume less).

Table 9.1. Evolving understanding of environmental challenge, policy responses and assessment approaches since the 1970s and 1980s

Characterisation of key challenges	Key features	In the spotlight in	Policy approaches (examples)	Assessment approaches and tools (examples)
Specific	Linear cause-effect, large (point) sources often local	1970s / 1980s (continuing today)	Targeted policies and single-issue instruments	Datasets, indicators
Diffuse	Cumulative causes, multiple sources often regional	1980s / 1990s (continuing today)	Policy integration and raising public awareness	DPSIR Data sets, indicators, environmental accounts, outlooks
Systemic	Systemic causes, interlinked sources often global	1990s / 2000s (continuing today)	Policy coherence and systemic approaches (e.g. green economy)	DPSIR, STEEP Indicators and accounts, systems analysis, foresight, stakeholder participation

Figure 9.1. A simplified illustration of the Circular Economy



Source: EIO (2016, p. 11)

System innovations are likely to influence each other, in ways that are so far poorly explored. Integrated assessment models (IAM) could be used to explore interactions among environmental impacts and well-being. These models should be combined with sociotechnical analysis of innovation pathways and practice-based action research (Geels et al., 2016).

A circular economy can be approached via resource efficiency and via circularity strategies within the production chains. Ideally, the measurement system should go beyond the measurement of resource efficiency and waste reduction, by considering the environmental impacts of resource extraction and the linkages between the circular economy, human well-being and sustainable development. Work on this has begun but is still at an early stage. Two studies have considered the types of indicators that are required to measure and track a circular economy. The first is a study by the Ellen MacArthur foundation (EMF), a think tank whose mission is to accelerate the transition to a circular economy. The EMF developed a toolkit for policymakers and engages in estimates of the contribution of a circular economy to economic growth, job creation and reduction of GHG emissions. In so doing, the study links the circular economy to a green economy. The EMF proposes the collection of indicators for resource productivity, energy, and greenhouse gas emissions (**see Chapter 7**), as well as indicators for circular activities such as recycling, repair and reuse. The EMF advocates a sector-by-sector analysis for addressing the opportunities and challenges for transitioning towards a circular economy. The EMF also discusses institutional approaches, such as tax incentives for the use of secondary materials.

The EU Resource Efficiency Scoreboard (EURES, 2014) provides an alternative set of indicators for the circular economy, drawing on statistics from Eurostat, the European Environment Agency (EEA) and other EU/international sources (see Table 9.2). The circular economy is approached via the angle of resource efficiency and emissions, instead of the angle of circularity. Next to dashboard indicators for resource productivity, land use, water use and carbon emissions; it includes indicators for transforming the economy, nature and eco-systems; and indicators for the areas of food, household energy consumption and green mobility.

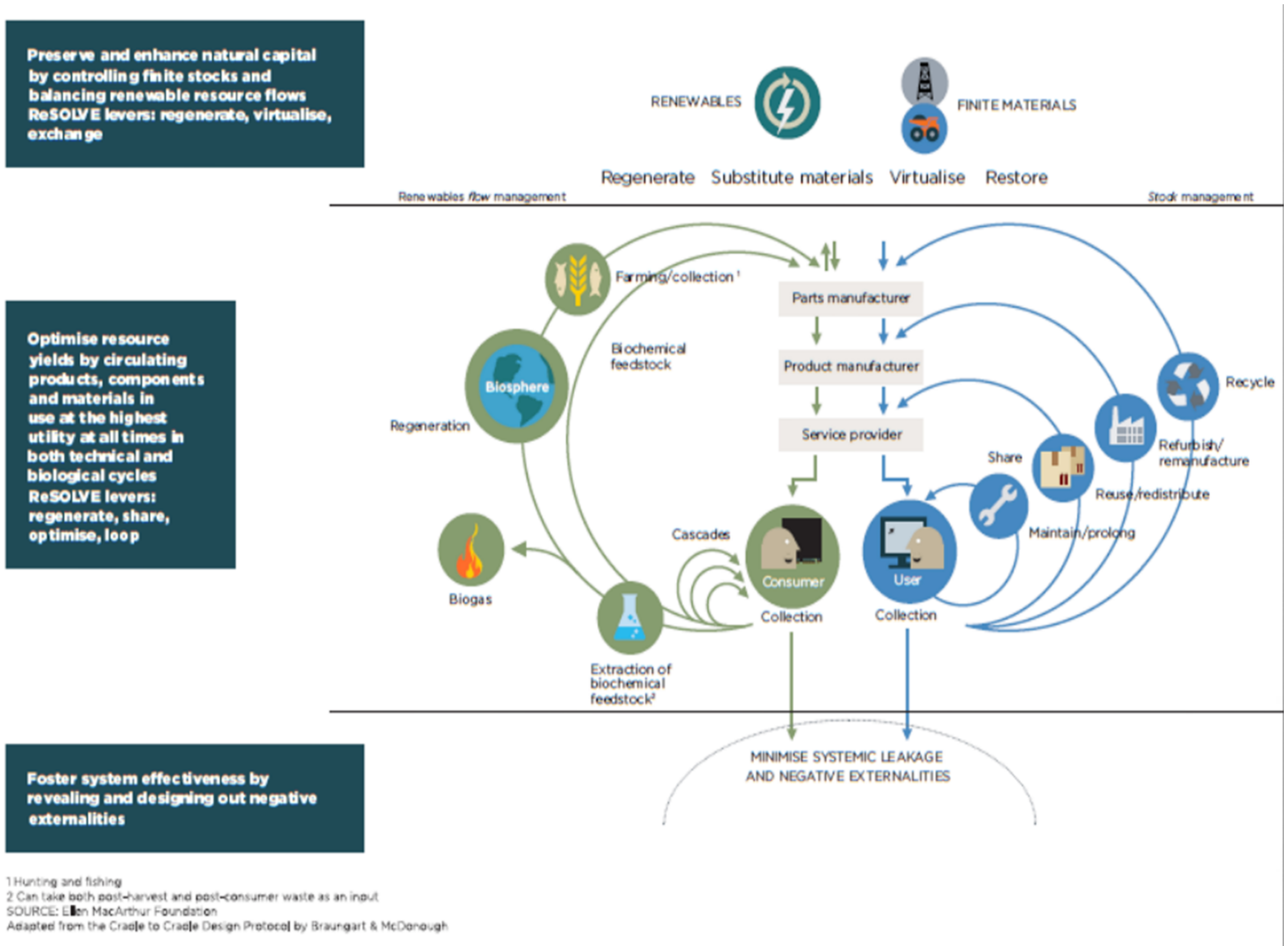
A limitation of the EURES indicators is that they do not cover information on company activities, experiences, plans, perceptions of possibilities and institutional barriers to the seven strategies for achieving a circular economy. Nor do the indicators provide an assessment of opportunities, as with the EMF approach.

When measuring company circularity activities through a survey, it is sensible to inquire into four things: the nature of circularity, progress achieved and plans (as dynamic elements), characteristics of the firm (to be gauged against those of others in the sector and those in other sectors), and finally motivational issues and capability aspects. The motivational aspects consist of positive and negative motivations.

For measuring the degree of circularity in processes and products, the following proxies may be used:

- Internal re-use of waste
- Use of or experimentation with circular economy revenue models, and if so whether the firm has plans to apply the model to other products
- Involvement in partnerships for circularity
- Share of product sales from remanufacturing
- Adjustments to products to facilitate repair and re-use, including by independent parties
- End-of-life waste management of products by the original equipment manufacturer or by a contractor

Figure 9.2. Circularity strategies within the production chain, in order of environmental priority



Source: Ellen MacArthur Foundation, (2015) Delivering the Circular Economy. A Toolkit for Policymakers, p. 20.

Table 9.2. Resource efficiency indicators in EURES

Indicator classification	Sub-theme	Indicator
Lead indicator	Resources	Resource productivity
Dashboard indicators	Land	Built-up areas
		Productivity of artificial land
	Water	Water exploitation index
		Water productivity
	Carbon	greenhouse gas emissions per capita
		Energy productivity
		Energy dependence
		Share of renewable energy
Thematic indicator 1:	Waste into a resource	Generation of waste
Transforming the economy		Landfill rate of waste
		Recycling rate of municipal waste
		Recycling rate of e-waste
	Supporting research and innovation	Eco-innovation index
	Getting the prices right	Environmental tax revenues
		Energy taxes
Thematic indicator 2:	Biodiversity	Common farmland bird species
Nature and Ecosystems		Areas under organic farming
		Landscape fragmentation
	Safeguarding clean air	Urban exposure to particulate matter (PM10 and PM25)
	Land and soils	Soil erosion
		Gross nutrient balance in agricultural land-nitrogen and phosphorus
Thematic indicator 3:	Addressing food	Daily calorific intake per capita
Key areas	Improving buildings	Household energy consumption by fuel
	Ensuring efficient mobility	Average carbon dioxide emissions per kilometre from new cars
		Pollutant emissions from transport (NO_x, PM10, volatile organic compounds)
		Modal split of passenger transport
		Modal split of freight transport

Source: EASAC (2016, p14.)

The proxies can be developed into a composite index and used as individual proxies in dedicated analysis into those aspects.

An attempt at grouping motivational factors and capability aspects (with possible proxies) is given in Table 9.3. The tables (developed by two of authors of this report) are based on the idea that innovation is the result of push and pull factors plus capability. Capabilities have an internal and external element. Push and pull depend strongly on external factors.

In a project of the PBL in the Netherlands, Potting et al. (2016) developed a set of diagnostic topics for measuring and monitoring progress towards a circular economy. It includes questions on means (capabilities), activities, achievements and effects. Data on means and activities can be obtained through an economy-wide survey of firms that asks about the interest of firms in the circular economy, with further questions on the nature of such activities, their experiences and their plans for the future with regard to particular circular economy strategies. National, sector-specific and company-specific barriers can be assessed via specialised surveys and expert consultations. All diagnostic questions in Table 9.4 are of value for policy deliberations (including those that are not prone to good measurement). The authors also developed a framework for evaluating policy effects (Potting and Hanemaaijer, 2018).

Table 9.3. Conditions for circularity and proxies for measurement

Type of condition	Conditions	Proxies
Pull	Strong waste management policies of the government, high prices for virgin resources, demand from consumers	Bans to landfilling waste from production, extended producer responsibility, high prices for virgin materials and burning waste, Circular economy is an official policy goal or part of strategic policy documents, a flourishing market for refurbished products
Push	Attention to circularity in the media	Discourse analysis of sector magazines and other news sources
Push	End-of-life product management	Collection of end-of-life products for dismantling for re-use
Capability	Experience and expertise in dealing with environmental issues	Year of introduction of Environmental Management and Auditing System, experience with green product design, use of Design for Sustainability (D4S) methodologies and tools
Capability	Partnership approach to innovation	Innovation collaboration with suppliers, experience with cross-sector partnerships

Table 9.4. Diagnostic Questions for Measuring Circular Economy

	Diagnostic questions
Means	**Mobilisation of means** - Are all relevant product chain partners actively involved in realising CE solutions? - Is there sufficient funding for realising CE solutions? - Are there specific physical means limiting the realisation of CE solutions?
	Knowledge development - Does the available knowledge suffice to develop CE solutions (with regard to technology, patents, consumer and chain actor behaviour)?
Activities	**Knowledge exchange** - Is the level of knowledge exchange on CE solutions high enough in the product chain?
	Experimenting by entrepreneurs - Are entrepreneurs experimenting sufficiently with CE solutions and revenue models? - Is upscaling of CE solutions already taking place?
	Giving direction to search (vision, expectations of governments and core-actors, regulations) - Is there a clear vision among product chain partners of the pursued circularity strategy? - Do product chain partners broadly share this circularity strategy? - Does this circularity strategy structure the activities of the product chain partners?
	Opening markets - Are product chain partners active in creating consumer awareness of CE solutions? - Are companies investing sufficiently? - Does the government have supplementary policies, and do they help in opening markets?
	Overcoming resistance - Is there resistance against CE solutions (among product chain partners, or in the form of regulatory barriers)? - Is sufficient action being taken to overcome resistance against CE solutions?
Achievements	**CE design** - What is the present lifespan of a product and has it increased compared to its original lifespan? - Have products become easier to disassemble? - Does the design foresee the use of recycled materials? - Are the components designed for high-grade recycling (without increasing environmental pressure)?
	Production - Is the overall (primary and secondary) consumption of materials by companies decreasing? - Do companies use fewer substances which are hazardous to human health and ecosystems? - Is production moving towards lower levels of waste generation? - Are companies moving to CE revenue models with increased reuse of products and components, or models based on providing a service rather than offering a product?
	Consumption - Is the consumption of CE products increasing (compared to conventional products)? - Do CE products have a longer lifespan or are they used more intensively? - Is reuse of products leading to less waste?
	Waste - Is the volume of landfill decreasing in favour of incineration? - To what extent is high grade-recycling applied? - To what degree is recycling effective with regard to costs and environment?
Effects	**Circularity** (resource efficiency) - Is primary material consumption decreasing (in kg per functional product unit)? - Is primary material consumption decreasing for the whole sector (in kg)? - Is energy consumption in MJ_{pr} for recycling lower than cumulative energy consumption in MJ_{pr} ?
	Environment For all product groups (over the whole life cycle of a product): - Is cumulative energy consumption in MJ_{pr} decreasing per functional product unit? - Is cumulative energy consumption in MJ_{pr} decreasing for the whole sector? Environmental pressure caused by specific product groups (over the whole life cycle of a product): - Is cumulative environmental pressure decreasing per functional product unit? - Is cumulative environmental pressure decreasing for the whole sector?
	Economy - Is the added value of products and product services increasing? - Are employment levels in the product chain increasing?

Source: Potting et al. 2016, p.22 (based on EEA (2016b); Hekkert et al. (2011); Huijbregts et al. (2006))

In addition to data collection for firms, it would be useful to measure government contributions to a circular economy. The STIR framework based on expert appraisals (see Chapter 4.4) could be used to address the following topics:

- The inclusion of a transition to a circular economy in strategic policy documents, including definitions of a circular economy, recommendations for policy actions and level of long-term support.
- The use, if any, of binding targets for circular economy activities.
- The types of government ministries and agencies involved in supporting circular economy activities.
- Coordination of circular economy activities.
- Degree of commitment to product repair, refurbishment and waste avoidance.
- Assessment of barriers and opportunities, and any actions to address them.
- Monitoring activities for a circular economy.
- Use of open and inclusive policies to support the circular economy
- Use of evidence to support policy on the economy
- Resilience of public investment priorities for a circular economy
- Use of policy experimentation for a circular economy
- Regulations to support product life-time extensions and waste avoidance

In addition, the STIR framework could be used to collect data on non-governmental actors:

- Support of stakeholders for a long-term vision of a circular economy.
- Capabilities of actors to develop circular economy business models.

The oversight of a systems transition needs to be a shared responsibility in order to accommodate the different interests of stakeholders and support system learning (Kemp et al., 2007; Kern and Howlett, 2009; Kemp, 2010). In the Netherlands, the implementation of the energy transition accord is overseen and monitored by a dedicated commission involving NGOs, business sector organisations, government agencies and representatives from ministries, the association of local councils, and the association of water boards. Data collection should cover the legal status of commissions to oversee systems transitions and the variety of stakeholders with a seat on the commission.

Involving businesses throughout the transition process is important for three reasons: i) acquiring insights and knowledge to identify the most relevant circular economy opportunities and barriers in each focus sector; ii) creating early alignment on a common direction for the country and the focus sectors; and iii) demonstrating economics benefits to businesses and building skills and capacity. Data can be collected on the opinions of businesses on these topics, for scrutiny by independent experts. Next to partnerships, there also needs to be framework conditions that encourage firms to engage in resource efficiency and circularity strategies. Relevant conditions are: carbon prices (taxes), bans for landfilling certain waste streams, landfill taxes, extended producer responsibility, and zero-energy building requirements.

10

CONCLUSIONS

René Kemp and Anthony Arundel

This section discusses the need for an international standard of the definition of eco-innovation and the creation of a four-pillar measurement system for assessing the contribution of eco-innovation to the green economy.

Our knowledge of eco-innovation largely comes from the extensive case study literature and from a few one-off surveys that focus on management and organizational responses to environmental issues (Arundel et al., 2006). In the last 10 years, three national sets of indicators on eco-innovation have been developed, based on available data. This work has contributed to our understanding of the differentiated nature of eco-innovation and its historical evolution. But more is needed.

First, a standard definition of eco-innovation, accepted and applied by all countries, is needed to provide guidance for collecting and interpreting eco-innovation data and to ensure international comparability. This requires an equivalent of the Oslo Manual definition of innovation. The definitions provided in Chapter 2 of this manual follow the Oslo Manual definitions while focusing on eco-innovation. They will therefore be familiar to National Statistical Offices and to innovation researchers. However, to keep the work current, there must be a body, similar to the National Experts and Science and Technology Indicators (NESTI) responsible for the Oslo Manual, to monitor and evaluate the use of the definition and guidelines proposed in this manual and to update them when necessary. To ensure legitimacy, the body that maintains the definition and the guidelines must have international support.

Second, statistical agencies and research organisations should collect data on the following topics for use in research and benchmarking:

- System innovations and social innovations. Examples include the circular economy, decentralized renewable energy systems, zero carbon transportation systems, product sharing systems, green lifestyles involving co-housing, product sharing and down shifting, etc.

- Life Cycle Assessment data for innovations and existing goods and services. These data can be used in economic and socio-technical system analysis to determine whether a good, service or system is an eco-innovation and for obtaining information about the nature and magnitude of environmental benefits.

- The characteristics of product and process eco-in novations in terms of staff involved, difficulties en countered, organizational enablers, management of trade-offs, product design tools, economic benefits and costs, critical events and spill-over effects.

- Rate of replacement of current products or processes by eco-innovations, for instance by sector and industry

- Ratio of eco-innovations to non-green innovations by number, percentage of sales, process output, etc.

- Information on stocks of capital goods and products with details on their environmental characteristics.

- Eco-innovation improvements (increases in energy efficiency, pollution control efficiencies, improvements in resource efficiency, etc.).

- Undesirable externalities and side-effects of eco-innovations.

- Trade-data about eco-innovations which are not included in Environmental Goods and Services (EGSS).

- Environmental health conditions.

- Policies relevant to eco-innovation (as drivers or barriers, etc.).

- Time series for environmental indicators. Environmental indicators should be measured in absolute terms and not only in relevant terms. Negative environmental impacts depend on abso lute emissions and consequently their elimination requires reductions in absolute emissions. A set of eco-innovation indicators needs to contain direct measures for eco-innovation (i.e. investment in renewable energy), in addition to indirect measures and inputs (i.e. patents). Eco-innovation requires continuous improvement. More attention should therefore be given to systemic conditions that affect the performance of eco-innovations.

In this manual we propose a four-pillar measurement system for assessing the contribution of eco-innovation to the green conomy:

- Environmental indicators
- Eco-innovation indicators,
- Eco-policy indicators,
- Socio-economic well-being indicators.

The logic behind the 4-pillar indicator systems is as follows. The environmental indicators provide **the baseline** for measuring the effects (with suitable time lags) of eco-innovation activities and eco-policies. Measures of eco-policies are needed to determine the influence of policies on environmental performance via eco-innovation and **for identifying policy gaps** where policy action is needed. Indicators on **socio-economic well-being** constitute a fourth type that do not cover the innovation-outcome chain, but which can play a valuable role in ensuring that shifts to a sustainable economy do not result in undesirable side-effects such as greater inequality. We also **need models and frameworks for understanding the links,** as shown by the DPSIR framework that integrates eco-innovation (see Chapter 1).

The inclusion of eco-policies as a pillar allows for policy learning. However, producing eco-policy indicators is a challenge. Policies, even with the same objective, such as R&D tax credits, are implemented in different ways in different countries. Nevertheless, efforts to obtain policy data are likely to be worthwhile, since the cost of policy measurement and evaluation is considerably less than the costs of policy failure. The STIR framework can be used to analyse policy effects, appraise policy mixes and build capacities for better policy making. Evaluations can be conducted for specific policies, policy mixes and policy strategic frameworks (such as the transition framework for the circular economy).

Data collection for policy evaluation should be designed as part of a policy learning system. To ensure systemic learning, the system has to include formal monitoring and evaluation studies as well as a learning environment in which research results are interpreted and used in policy design.

The challenges for eco-innovation policy are more complex than those for innovation policy because it is not a simple matter of producing innovations and encouraging their uptake. Eco-innovation policy needs to avoid rebound effects while replacing less environmentally benign processes, goods and services. The latter requires control policies that are bound to meet with resistance and require special knowledge of sectors. It is worth recalling the conclusion of Chapter 4 that the capacity to learn and adapt policies to new knowledge and circumstances depends on two pillars: evidence-based evaluations that allow policy lessons to be drawn, and an ability to make societal actors accept environmental protection policies. Platforms for interaction can facilitate useful exchanges between researchers and public and private actors about innovation possibilities and potentially useful policies.

Data collection should support both quantitative and qualitative research methods. While quantitative methods (e.g. modelling) are useful for predicting environmental impacts under specific scenarios, their applications may be limited in practice by context-specific variables. Qualitative data are often necessary to understand contexts and the variety of contextual factors that can influence eco-innovation or environmental outcomes. In particular, policy evaluation needs to pay more attention to the context-specific mechanisms through which a policy wields influence and assess, where relevant, the reasons why a policy lacks influence. The data and research requirements of dealing with those challenges are formidable but necessary to undertake. Eco-innovations address wide-ranging environmental problems, calling for eco-innovation assessment and appropriate policy mixes.

END NOTES

[1] It is difficult for policy makers to commit to de-growth. Yet degrowth is not to be understood as an end in itself, but as a criticism of GDP growth as something desirable in itself.

[2] Confusingly, the term “blue economy” is also used for an economy based on sustainability innovations that are attractive to consumers (including the poor). This economy is called blue because from space the earth looks blue (Pauli, 2004 and 2016).

[3] Available from: http://theconversation.com/time-for-degrowth-to-save-the-planet-we-must-shrink-the-economy-64195

[4] Only a small part of the blue economy belongs to the green economy (ocean energy, off shore wind, and algae for food when produced in greener ways than land-based food).

[5] A longer list of eco-innovation definitions is provided in Annex 1.

[6] “Without radical innovation, incremental innovation reaches a limit. Without incremental innovation, the potential enabled by radical change is not captured” (Norman and Verganti, 2014, p. 84).

[7] See https://www.innovationpolicyplatform.org/

[8] Source: https://www.researchgate.net/publication/317617887_Household_energy_consumption_and_behavioural_change_-_the_UK_perspective

[9] ibid.

[10] Blohmke et al. (2016) explore how to disentangle the causal structure behind environmental policy.

[11] Source: https://en.wikipedia.org/wiki/Life-cycle_assessment

[12] Source: https://differential.com/insights/the3typesofinnovation/

[13] Source: https://www.theguardian.com/environment/green-living-blog/2010/feb/17/top-10-green-iphone-apps

[14] Source: https://agfundernews.com/what-is-precision-agriculture.html/

[15] For example, the concept of a Sustainable City can be viewed as a system adaptation if it consists of a (interconnected) series of incremental changes. In terms of Sustainable Mobility, a change towards a ‘sharing mobility’ based on electro-mobility and a prohibition of individual transport in cities can be viewed as radical change, whereas improving fuel efficiency, increasing the average number of persons per car or increasing the share of public transport is an incremental change.

[16] Corporate Social Innovation (CSI) differs from traditional Corporate Social Responsibility efforts in involving contributions of money and manpower that are strategically managed for the sake of competitive advantage, involving external partners such as nongovernmental organizations (NGOs) or community groups, and being less oriented towards goodwill and enhancement of corporate reputation (Marvis et al., 2016, p. 5014-5015). Like CSI, corporate social value is about creating value for society, next to creating value for the company (Porter and Kramer, 2011). There is no clear dividing line between corporate social innovation and corporate social value.

[17] A manual for Technological Innovation Systems (TIS) analysis for policy purposes is produced by Hekkert et al. (2011), http://www.innovation-system.net/wp-content/uploads/2013/03/UU_02rapport_Technological_Innovation_System_Analysis.pdf The manual combines measurement activities with expert judgement.

[18] OECD (2017). OECD Estimates of government tax relief for business R&D 2014. Deliverable 2.1, TAX4INNO Project. OECD, Paris.

[19] The functions are: Knowledge development and diffusion, Influence on the direction of search, Entrepreneurial experimentation, Market formation, Legitimation, Resource mobilization, Development of positive externalities (Bergek et al., 2008).

[20] Source: http://www.innovation-system.net/wp-content/uploads/2013/03/UU_02rapport_Technological_Innovation_System_Analysis.pdf The manual combines measurement activities with expert judgement.

[21] Available from: https://www.oecd.org/sti/outlook/e-outlook/stipolicyprofiles/stipolicygovernance/evaluationofstipolicies.htm

[22] Available from: http://www.sgi-network.org/2017/Methodology

[23] Innovation vouchers are small lines of credit provided by governments to small and medium-sized enterprises (SMEs) to purchase services from public knowledge providers with a view to introducing innovations (new products, processes or services) in their business operations (from http://www.oecd.org/innovation/policyplatform/48135973.pdf).

[24] See https://www.researchgate.net/publication/228900679_Japanese_Top_Runner_Approach_for_energy_efficiency_standards

[25] See https://unep.ch/etb/publications/EIA_2ed/EIA_E_top13_hd1.PDF

[26] Evaluation of policy programmes can be done in different ways. Pawson (2002) compares three types: Meta-evaluation (widely used in medicine), narrative evaluation and critical synthesis. Meta-analysis tends to pay little attention to contextual conditions. Narrative review (as a configurational approach) takes into account compatibility between the target group, setting, programme stratagem, programme content, implementation details, stakeholder alliances and so on. Realist synthesis uses a ‘generative’ approach to causation which is assumed to be contingent, depending on the nature of the subjects of a programme and the circumstances of the initiative. In the case of realist synthesis, policy makers receive a ‘transferable theory’ instead of a “best practice” programme, allowing them to tailor policies suited to the context of the application”. In realist synthesis, data extraction takes the form of “an interrogation of the base-line inquiries for information on ‘what-works-for-whom-in-what-circumstances’ (Pawson, 2002, p. 2-3). Imbens and Wooldridge (2009) and Abadie and Cattane (2017) offer a discussion of econometric methods for programme evaluation.

[27] Source: https://ec.europa.eu/environment/ecoap/etv_en

[28] Source: https://www.madaster.com/en/about-us/why-a-materials-passport

[29] A trade journal or trade magazine is a periodical, magazine or publication printed with the intention of marketing to a specific industry or type of trade/business. Trade refers to business, not to exports and imports.

[30] They found that the direction (but not the rate) of innovation was responsive to energy price changes and that the responsiveness increased substantially when energy-efficiency labelling was required. The data used are shown in Figure 6.1 in the Annex to Chapter 6.

[31] Source: https://unstats.un.org/unsd/classifications/unsdclassifications/cpcv21.pdf

[32] Coombs et al. (1996) and Kleinknecht (1993).

[33] Source: https://en.wikipedia.org/wiki/Car_classification

[34] See Annex Chapter 2 for environmental indicators systems Environmental Performance Index and SDG Index.

[35] For a compendium of toxic substances and the regulations that apply at the international level the reader may check the following OECD compendium: http://www.oecdsaatoolbox.org/Home/Regulations

[36] Source: http://www.who.int/mediacentre/factsheets/fs313/en/

[37] Source: http://www.npi.gov.au/substances/fact-sheets

[38] Source: http://www2.dmu.dk/AtmosphericEnvironment/Expost/database/docs/AQ_limit_values.pdf

[39] Source: http://www.npi.gov.au/substances/fact-sheets

[40] Source: https://unstats.un.org/sdgs/indicators/indicators-list/

[41] Source: http://apps.who.int/gho/data/node.imr.SDGPM25?lang=en

[42] Source: http://geodata.grid.unep.ch/

[43] Source: https://odims.ospar.org/

[44] Source: http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en

[45] Source: http://statistics.gemstat.org/gems.php

[46] Source: https://unstats.un.org/sdgs/metadata

[47] Source: http://www.isric.org/projects/global-assessment-human-induced-soil-degradation-glasod

[48] Source: http://www.fao.org/faostat/en/

[49] Source: http://www.iucnredlist.org/about/summary-statistics#How_many_threatened

[50] Source: http://www.fao.org/fishery/resources/en

[51] Source: http://geodata.grid.unep.ch/options.php?selectedID=1871&selectedDatasettype=1

[52] Source: https://unstats.un.org/sdgs/metadata/files/Metadata-08-04-01.pdf

[53] Source: https://unstats.un.org/sdgs/indicators/indicators-list/

[54] Source: http://data.un.org/Data.aspx?d=SDGs&f=series%3aEN_MAT_DOMCMPG

[55] Source: http://databank.worldbank.org/data/

[56] Source: https://www.iea.org/

[57] Source: https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html

[58] Source: http://databank.worldbank.org/data/

[59] The environmental dimension of quality of life consists of indicators for exposure to air pollution and access to drinking water and sewage treatment. Economic opportunities and policy responses are measured on the basis of patent information and data on environmental taxes and transfers

[60] Source: http://www.greengrowthknowledge.org/about-us

[61] Source: https://www.ceps.eu/publications/measuring-progress-eco-innovation

[62] Source: http://ec.europa.eu/eurostat/web/microdata/european-union-statistics-on-income-and-living-conditions

[63] The authors of this chapter found one document with an explicit mention of examples of eco-innovations as drivers of the blue economy (Plan Bleu, 2016). In some measurement frameworks there are brief mentions to the use of patents and R&D data as proxy measures of blue innovation (e.g. in the European Blue Economy Report 2019). However, the existence of data and data sets explicitly linking innovation and the blue economy are rare. Most evidence is anecdotal.

[64] Reliability analysis of data is a common function in commercial software and plug-ins for performing statistical analysis e.g. STATA, SPSS, SAS/QC, XLSTAT, StatistiXL, etc.

[65] Available at http://new.inno4sd.net/eco-innovation-manual

REFERENCES

Abadie, A., Cattaneo, M.D. (2017). Econometric Methods for Program Evaluation, MIT paper. Available from: https://economics.mit.edu/files/13924

Ahlqvist T., Valovirta V. and Loikkanen T (2012). Innovation policy roadmapping as a systemic instrument for forward-looking policy design. Science and Public Policy 39(2): 178–190. Available from: https://academic.oup.com/spp/article-lookup/doi/10.1093/scipol/scs016.

Amit, R., & Zott, C. (2012). Creating value through business model innovation. MIT Sloan Management Review, 53(3), 41-49.

Andersen, M.M. (2016). The Sustainable Development Goals – Pathways to Eco-innovation and a Global Green Economy? Globelics Conference 2016, 12-14 October Bandung, Indonesia.

Arundel, A., Kemp, R., & Parto, S. (2006). Indicators for environmental innovation: what and how to measure. The international handbook on environmental technology management, 324-339

Arundel, A., Kemp, R, and Machiba, T. (2009). Measuring eco-innovation: Existing Methods for Macro-Level Analysis, in OECD publication Eco-Innovation in Industry: Enabling Green Growth, pp. 147-179, OECD, Paris.

Arundel, A., Bassi, A, Janzen, J, Kemp, R., Türkeli, S., Gatenby-Clark, S., Rammer, C., Tapia Garcia, C., Miedzinski, M, Mazzanti, M, Diaz Lopez F. (2017). Measuring eco-innovation, green growth and the green economy, deliverable 2.4 of green.eu project.

Ashford, N.A., Ayers, C., Stone, R.F., (1985). Using regulation to change the market for innovation. Harvard Environmental Law Review 9, 419–466.

Azar, C., Sandén, B.A. (2011), 'The elusive quest for technology-neutral policies', Environmental Innovation and Societal Transitions, 1 135-39.

Baranzini, A., van den Bergh, J. C. J. M., Carattini, S., Howarth, R. B., Padilla, E. and Roca, J. (2017). Carbon pricing in climate policy: seven reasons, complementary instruments, and political economy considerations. WIREs Clim Change, 8: n/a, e462. doi:10.1002/wcc.462

Barbieri, N., Ghisetti, C., Gilli, M., Marin, G., & Nicolli, F. (2016). A survey of the literature on environmental innovation based on main path analysis. Journal of Economic Surveys, 30(3), 596-623.

Barry, B. (1999). "Sustainability and Intergenerational Justice" in Dobson, Andrew (ed.), Fairness and Futurity, (Oxford: Oxford University Press, 1999): 93-117.

Bassi, A.M., F. Sheng (2012). Measuring Progress Towards an Inclusive Green Economy. UNEP, Geneva. 2012.

Beaudry, C., Heroux-Vaillancourt M, Rietsch, C. (2016). Validation of a web mining technique to measure innovation in high technology Canadian industries, OECD Blue Skies Conference, Ghent Belgium, September.

Benson, J. (2001). Environmental Ethics: An Introduction with Readings. Routledge, London.

Bergek, A. Jacobsson, S. Carlsson, B. Lindmark, S., and Rickne, A. (2008). Analyzing the functional dynamics of technological innovation systems: A scheme of analysis, Re search Policy, (37), 3, 407-429. http://dx.doi.org/10.1016/j.respol.2007.12.003

Bergek, A., Berggren,C. (2014). ‘The impact of environmental policy instruments on innovation: A review of energy and automotive industry studies’, Ecological Economics, 106 112-23.
Berkes, F., Colding, J.,,. Folke,C. (2000).. Rediscovery of traditional ecological knowledge as adaptive management. Ecological Applications 10:1251–1262.
Bianchi, A., Marin, G., Zanfei, A, (2018). New perspectives in public service innovation. In Gallouj, F. and Djellal, F. (Eds) A Research Agenda for Service Innovation, pp 166-186, Edward Elgar, Cheltenham.
Bjørn, A., Margni, M., Roy, P.-O., Bulle, C., Hauschild, M.Z.,(2016). A proposal to measure absolute environmental sustainability in life cycle assessment. Ecol. Indic. 63, 1–13. doi:10.1016/j.ecolind.2015.11.046
Blohmke, J., Kemp, R., Türkeli, S. (2016). Disentangling the causal structure behind environmental regulation, Technological Forecasting and Social Change, 103: 174-190.
Bloomberg New Energy Finance (2017). Global Trends in Clean Energy Investment.
Bocken, N., Farracho, F., Bosworth, R., Kemp, R. (2014). The front-end of eco-innovation for eco-innovative small and medium sized companies, The International Journal of Engineering and Technology Management, 31: 43–57
Bonou, A., Laurent, A., Olsen, S.I., (2016) Life cycle assessment of onshore and offshore wind energy-from theory to application, Applied Energy, 180: 327-337
Boon, W.P.C., Bakker, S. (2016). Learning to shield – Policy learning in socio-technical transitions, Environmental Innovation and Societal Transitions, 18: 181-200.
Boons, F., & Lüdeke-Freund, F. (2013). Business models for sustainable innovation: state-of-the-art and steps towards a research agenda. Journal of Cleaner production, 45, 9-19.
Borrás, S. (2012). Three tensions in the governance of science and technology. The Oxford handbook of governance, 429-440.
Bosetti, V., M. Catenacci, G. Fiorese and E. Verdolini (2012). “The Future Prospect of PV and CSP Solar Technologies: An Expert Elicitation Survey”, Energy Policy 49: 308–317.
Bosetti, V. et al. (2011). ‘What should we expect from innovation? A model-based assessment of the environmental and mitigation cost implications of climate-related R&D’, Energy Economics, 33 (6), 1313-20.
Bossel, H. (1999). Indicators for sustainable development: theory, method, applications. A Report to the Balaton Group.
Botta, Enrico and Tomasz Kozluk (2014). ‘Measuring Environmental Policy Stringency in OECD Countries: A Composite Index Approach’, OECD Economics Department Working Papers, 1177
Bovea, M., & Pérez-Belis, V. (2012). A taxonomy of ecodesign tools for integrating environmental requirements into the product design process. Journal of Cleaner Production, 20(1), 61-71.
Brouwer, E. et al. (2002). WBSO nader beschouwd, onderzoek naar de effectiviteit van de WBSO. PWC/ Dialogic/ TU Delft, Utrecht.
Bruggink, A., van der Hoeven, D. (2017). More with less. Welcome to the Precision Economy, Biobased Press, Amsterdam.

Cainelli, G., De Marchi, V., & Grandinetti, R. (2015). Does the development of environmental innovation require different resources? Evidence from Spanish manufacturing firms. Journal of Cleaner Production, 94, 211-220.

Canadian Index of Wellbeing. (2016). How are Canadians Really Doing? The 2016 CIW National Report. Waterloo, ON: Canadian Index of Wellbeing and University of Waterloo.

Cantner, U. et al. (2016). 'Inventor networks in renewable energies: The influence of the policy mix in Germany', Research Policy, 45 (6), 1165-84.

Carbone, M. (2008). 'Mission Impossible: the European Union and Policy Coherence for Development', Journal of European Integration, 30 (3), 323-42.

Cecere, G., Corrocher, N., Gossart, C., & Ozman, M. (2014a). Lock-in and path dependence: an evolutionary approach to eco-innovations. Journal of Evolutionary Economics, 24(5), 1037-1065.

Cecere, G., Corrocher, N., Gossart, C., & Ozman, M. (2014b). Technological pervasiveness and variety of innovators in Green ICT: A patent-based analysis. Research Policy, 43(10), 1827-1839.

CEC (2002), Report from the Commission to the Council. Analysis of the 'open list' of environment-related headline indicators, COM(2002) 524 Final.

Charter, M., Clark, T. (2007). Sustainable Innovation. Key conclusions from Sustainable Innovation Conferences 2003–2006 organised by The Centre for Sustainable Design, The Centre for Sustainable Design.

Chesbrough, H. (2010). Business model innovation: opportunities and barriers. Long range planning, 43(2-3), 354-363.

Climate Transparency (2016). Brown to Green: Assessing the G20 transition to a low-carbon economy, Berlin

CML, PSI, and CSM (2008). A framework for measuring eco-innovation: typology of indicators based on causal chains, Final report, (ECO-DRIVE project, FP6-2005-SSP-5-A)

Colantonio, A., Dixon, T. (2011). Urban Regeneration & Social Sustainability: Best Practice from European Cities, Blackwell Publishing.

Costantini, V., Crespi, F., Palma, A. (2017). 'Characterizing the policy mix and its impact on eco-innovation: A patent analysis of energy-efficient technologies', Research Policy, 46 (4), 799-819.

Coombs, R., Narandren, P., & Richards, A. (1996). A literature-based innovation output indicator. Research policy, 25(3), 403-413

Côté, G., Stanciauskas, V. (2018). Provision and analysis of key indicators in research and innovation: Year 1 Interim data and analytical report (Innovation), Science-Metrix, Montreal, 30 October.

Cunningham, Paul, et al. (2013). Innovation policy mix and instrument interaction: a review, (Nesta Working Paper, 13/20; NESTA).

Davis, A., and J. R. Wagner. (2003). Who knows? On the importance of identifying ''experts'' when researching local ecological knowledge. Human Ecology 31:463–489.

D'Amato , D , Droste , N , Allen , B , Kettunen , M , Lähtinen , K , Korhonen , J , Leskinen , P , Matthies , B D & Toppinen , A (2017). ' Green, circular, bio economy : A comparative analysis of sustainability avenues ' Journal of Cleaner Production, 168: 716-734

Deci, E. L., & Ryan, R. M. (2008). Facilitating optimal motivation and psychological well-being across life's domains. Canadian Psychology, 49:14–23. doi:10.1037/0708-5591.49.1.14

DEFRA (2015). Valuing impacts on air quality: Updates in valuing changes in emissions of Oxides of Nitrogen (NOX) and concentrations of Nitrogen Dioxide (NO2). Department for Environment, Food and Rural Affairs. London, UK. Available from: www.gov.uk/air-quality-economic-analysis.

D'Este, P., Iammarino, S., Savona, M., & von Tunzelmann, N. (2012). What hampers innovation? Revealed barriers versus deterring barriers. Research policy, 41(2), 482-488.

De Marchi, V. (2012). Environmental innovation and R&D cooperation: Empirical evidence from Spanish manufacturing firms. Research Policy, 41(3), 614-623.

De Vries, F.P., Withagen, C. (2005). Innovation and environmental stringency: the case of sulfur dioxide abatement, Discussion Papers / CentER for Economic Research; Vol. 2005-18). Tilburg: Microeconomics.

Del Rio, P., Romero-Jordán, D., Peñasco, C. (2017). Analysing firm-specific and type-specific determinants of eco-innovation, Technological and Economic Development of Economy, 23:2, 270-295,

Del Rio, P. (2017). 'Why does the combination of the European Union Emissions Trading Scheme and a renewable energy target makes economic sense', Renewable and Sustainable Energy Reviews, 74 824-34.

Del Río, P., Bleda, M. (2012). 'Comparing the innovation effects of support schemes for renewable electricity technologies: A function of innovation approach', Energy Policy, 50 272-82.

Delhey, J. (2010). From materialist to post-materialist happiness? National affluence and determinants of life satisfaction in cross-national perspective. Social Indicators Research 97(1): 65-84.

Diaz Lopez, F.J. (2008). Environment, technological change and innovation. The case of the Mexican chemical industry. Faculty of Social Sciences. School of Development Studies. Norwich, University of East Anglia. Unpublished PhD thesis. 302 p.

Diaz Lopez, F.J. & C. Montalvo. (2015a) The evolving and cumulative nature of eco-innovation in the chemical industry. Journal of Cleaner Production. 102 (2015), p. 30-43.

Diaz Lopez, F.J. & C. Montalvo (2015b). Qualitative data mining of large datasets: The case of long waves of eco-innovation in the chemical industry (1901-2011). TNO Working Paper Series, No. 2015-04. May, Delft, 34 p

Doranova A., M Miedzinski, G Van der Veen, A Reid, LR Leon, M Ploeg, M Carlberg, L Joller (2012) Business models for systemic eco-innovations. Final report, Technopolis group, Brussels

EASAC (2016). Indicators for a circular economy, EASAC Policy report 30.

EEA (2015). The European environment — state and outlook 2015: synthesis report, European Environment Agency, Copenhagen.
EEA (2016). The European Environment. State and outlook 2015 – 4. Resource efficiency and the low carbon economy.
EEA (2018) Perspectives on transitions to sustainability, EEA Report No 25/2017, European Environmental Agency, Luxembourg: Publications Office of the European Union.
Egli F, Johnstone N.(2015). Emerging technologies and firm dynamics: the implications of green growth. Green growth and sustainable development forum, 14-15 December 2015, OECD, Paris.
EIO. (2010). "Methodological Report." Financed by the European Commission, DG Environment. Brussels: Eco-Innovation Observatory.
EIO. (2012). "Closing the eco-innovation gap: An economic opportunity for business. Annual Report 2011. Financed by the European Commission, DG Environment. " Brussels: Eco-Innovation Observatory.
EIO (2013). Europe in transition: Paving the way to a green economy through eco-innovation. Eco-Innovation Observatory. Funded by the European Commission. DG Environment. Brussels.
EIO. (2016). Policies and Practices for Eco-Innovation Up-take and Circular Economy Transition. Financed by the European Commission, DG Environment." Brussels: Eco-Innovation Observatory
EIO. (2017). Socio-economic outcomes of eco-innovation. Financed by the European Commission, DG Environment." Brussels: Eco-Innovation Observatory
Ellen MacArthur Foundation (EMF) (2014a). A New Dynamic: effective business in a circular economy. Lovins, A.,Braungart, M., Stahel, W. A., Birkeland, J., Goerner, S., Spicer, D., & Tuppen, C. EMF, 172
Ellen MacArthur Foundation (EMF) (2014b). "Towards the Circular Economy: Accelerating the Scale-up across Global Supply Chains." 3. Retrieved from URL http://www3.weforum.org/docs/WEF_ENV_TowardsCircularEconomy_Report_2014.pdf
Ellen MacArthur Foundation, (2015) Delivering the Circular Economy. A Toolkit for Policymakers.
Ellen MacArthur Foundation (EMF) (2016). "Intelligent Assets: Unlocking the Circular Economy Potential." Retrieved from URL http://www.ellenmacarthurfoundation.org/assets/downloads/publications/EllenMacArthurFoundation_Intelligent_Assets_080216.pdf
Elzen, B., Geels, F.W. and Green, K. (eds.) (2004). System Innovation and the Transition to Sustainability: Theory, Evidence and Policy, Cheltenham: Edward Elgar.
Epicoco, M., Oltra, V., & Saint Jean, M. (2014). Knowledge dynamics and sources of eco-innovation: Mapping the Green Chemistry community. Technological Forecasting and Social Change, 81, 388-402.
ESCAP (2009). Eco-efficiency Indicators: Measuring Resource-use Efficiency and the Impact of Economic Activities on the Environment, UN Environment and Development Division, Bangkok, Thailand.

EURES (2014). EU Resource Efficiency Scoreboard. Available from: http://ec.europa.eu/environment/resource_efficiency/documents/re_scoreboard_2014.pdf
EURES (2015). EU Resource Efficiency Scoreboard. Available from: http://ec.europa.eu/environment/resource_efficiency/targets_indicators/scoreboard/pdf/EU%20Resource%20Efficiency%20Scoreboard%202015.pdf
European Commission, Eco-innovation scoreboard, http://www.eco-innovation.eu/index.php?option=com_content&view=article&id=2&Itemid=34.
European Commission (2019). Blue Economy Report 2019. Office of Publications. Brussels.
Eurostat (2005). Environmental Expenditure Statistics: Industry Data Collection Handbook, Luxembourg: Office for Official Publications of the European Communities.
Eurostat (2017). Final report of the expert group on quality of life indicators. Luxembourg: Publications Office of the European Union.
Fahnestock, J. (2015). The use of concepts related to sustainable development in political and strategic documents, Innovation for sustainable development network, ZEW, Mannheim
FAO (2017). Harmonized World Soil Database. http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/harmonized-world-soil-database-v12/en/ Accessed 2/11/2017.
fDi Intelligence. (2016). The fDi Report 2016 – Global Greenfield Investment Trends.

Fischer, C., Newell, R.G. (2008). 'Environmental and technology policies for climate mitigation', Journal of Environmental Economics and Management, 55 (2), 142-62
Flanagan, K., Uyarra, E., and Laranja, M. (2011). 'Reconceptualising the 'policy mix' for innovation', Research Policy, 40 (5), 702-13.

Font Vivanco, D., Kemp, R., van der Voet, E. (2015). The relativity of eco-innovation: environmental rebound effects from past transport innovations in Europe. Journal of Cleaner Production, 101: 71–85
Font Vivanco, D., Kemp, R., van der Voet, E., Heijungs, R.. (2014). Using LCA-based decomposition analysis to study the multi-dimensional contribution of technological innovation to environmental pressures, Journal of Industrial Ecology, 19(3): 380-392.
Font Vivanco, D., Kemp, R., van der Voet, E. (2016). 'How to deal with the rebound effect? A policy-oriented approach', Energy Policy, 94 114-25
Font Vivanco, D., McDowall, E., Freire-González, J., Kemp, R., van der Voet, E. (2016). Foundations of the environmental rebound effect and its contribution towards a general framework, Ecological Economics, 125: 60–69.
FORA (2010). Green paper: Green business models in the Nordic Region. A key to promote sustainable growth.Copenhagen.
Foxon, T.J. (2007). 'Technological lock-in and the role of innovation', in Handbook of Sustainable Development, G. Atkinson, S. Dietz and E. Neumayer (eds.), Edward Elgar, Cheltenham
Freidlingstein P., Andrew, R.M., Rogelj, J. (2014). Persistent growth of CO2 emissions and implication for reaching climate targets, Nature Geoscience, DOI:10.1038/NGEO2248

Freire, P. (2016) Enhancing innovation through behavioral stimulation: The use of behavioral determinants of innovation in the implementation of eco-innovation processes in industrial sectors and companies, Journal of Cleaner Production, 170,2018, p. 1677-1687.

Fussler, C., James, P. (1996). Driving Eco-Innovation: A Breakthrough Discipline for Innovation and Sustainability, 1997.

Geels, F.W. (2005). Technological Transitions and System Innovations: A Co-evolutionary and Socio-Technical Analysis, Cheltenham: Edward Elgar.

Geels, F.W., Kemp, R. (2012). The transition perspective as a new perspective for road mobility study, in Automobility in Transition? A sociotechnical analysis of sustainable transport, edited by F. Geels, R. Kemp, G. Dudley and G. Lyons, Routledge, New York, pp. 49-79

Geels, F.W., Berkhout, F., van Vuuren, D.P. (2016). Bridging analytical approaches for low-carbon transitions, Nature Climate Change, 6: 576-583

George, G., & Bock, A. J. (2011). The business model in practice and its implications for entrepreneurship research. Entrepreneurship theory and practice, 35(1), 83-111.

GGKP (2013), Moving towards a Common Approach on Green Growth Indicators. A Green Growth Knowledge Platform Scoping Paper.

Giesselmann, M., Hilmer, R., Siegel, N.A., and Wagner, G.G., (2013). Measuring Well-Being: W3 Indicators to Complement GDP, DIW Economic Bulletin 5.2013.

Giljum, S. et al. (2014). The Eco-Innovation Scoreboard 2013. Technical Note. Eco-Innovation Observatory. http://www.eco-innovation.eu/images/stories/Eco-Innovation_Scoreboard_2013_Technical_Note.pdf.

Givoni, M., Macmillen, J., Banister, D., Feitelson, E., (2013). From policy measures to policy packages. Transport Reviews 33 (1), 1–20.

Griessler, E., & Littig, B. (2005). Social sustainability: a catchword between political pragmatism and social theory. International Journal for Sustainable Development, 8(1/2), 65-79.

Grin, J., Rotmans, J., & Schot, J. (2010). Transitions to sustainable development: new directions in the study of long term transformative change. Routledge.

Gok, A., Waterworth, A., Shapira, P. (2015). Use of web mining in studying innovation, Scientometrics 102:653-671.

Gunningham, N., Kagan, R.A., Thornton, D. (2003). Shades of Green: Business, Regulation, and Environment, Stanford University Press.

Gupta, A. K. (2010). "Grassroots green innovations for inclusive, sustainable development." The Innovation for Development Report 2009–2010. Palgrave Macmillan, London, 137-146.

Hansen J, Sato M, Kharecha P (2016). Young people's burden: requirements of negative CO2 emissions, mimeo

Hardin, Garrett, (1968). The Tragedy of the Commons, Science, Vol. 162, No. 3859 (December 13, 1968), pp. 1243-1248.

Hascic I, Migotto, M. (2015). Measuring environmental innovation using patent data, OECD environmental working papers No. 89, OECD, Paris.

Haxeltine, A., Avelino, F., Pel, B., Dumitru, A., Kemp, R., Longhurst, N., ... & Wittmayer, J. M. (2016). A framework for transformative social innovation. TRANSIT working paper, 5, 2-1.
Hekkert, M.P., Negro, S., Heimeriks, G., & Harmsen, R. (2011). Technological innovation system analysis. Technological innovation system analysis,(November), 16.
Hekkert, M.P., Suurs, R.A.A., Negro, S.O., Kuhlmann, S., Smits, R.E.H.M.,(2007). Functions of innovation systems: A new approach for analysing technological change. Technological Forecasting and Social Change 74, 413-432
Hojnik, J., Ruzzier, M. (2016). What drives eco-innovation? A review of an emerging literature, Environmental Innovation and Societal Transitions 19: 31–41
Horbach, J., (2008). Determinants of environmental innovation — new evidence from German panel data sources. Research Policy 37, 163–173.
Horbach, J., Rammer, C., Rennings, K. (2012). Determinants of eco-innovations by type of environmental impact — The role of regulatory push/pull, technology push and market pull, Ecological Economics, 78: 112–122
Horbach, J., (2016). Empirical determinants of eco-innovation in European countries using the community innovation survey, Environmental Innovation and Societal Transitions 19: 1–14.
Horbach, J. (2016). Empirical determinants of eco-innovation in European countries using the community innovation survey, Environmental Innovation and Societal Transitions 19: 1–14.IEA (2010). Energy technology perspectives 2010. Paris: OECD and IEA.
Huppes, G., Kleijn, R., Huele, R., Ekins, P., Shaw, B., Esders, M., & Schaltegger, S. (2008). Measuring eco-innovation: framework and typology of indicators based on causal chains: final report of the ECODRIVE Project.
Hyvärinen, A., Keskinen, M., Varis, O. (2016). Potential and Pitfalls of Frugal Innovation in the Water Sector: Insights from Tanzania to Global Value Chains, Sustainability 8(9): 888
IEA (2017). Policy and measures databases. Available from: https://www.iea.org/policiesandmeasures/
Imbens, G.W., Wooldridge, J.M. (2009). "Recent Developments in the Econometrics of Program Evaluation," Journal of Economic Literature, 47(1): 5-86.
Jacobsson, S., Johnson, A.(2000). The diffusion of renewable energy technology: An analytical framework and key issues for research. Energy Policy 28: 625–40.
Jakobsen S, Clausen TH (2016). Innovating for a greener future: the direct and indirect effects of firms' environmental objectives on the innovation process. Journal of Cleaner Production 128:131-141
Janicke, M., Lindemann, S. (2010). Research Note: Governing environmental innovations, Environmental Politics, 19(1):127–141
Jeffrey, K., Seaford, C. (2015). Report on definitions of the Green Economy and progress towards it. Deliverable 2.1 NETGREEN project, May 2015.
Jo, J.-H., Roh, T.W., Kim, S., Youn, Y.-C., Park, M.S., Han, K.J., Jang, E.K. (2015). Eco-innovation for sustainability: Evidence from 49 countries in Asia and Europe, Sustainability, 7:16820-16835

Johnstone, N. (2007). Environmental policy and corporate behaviour. Edward Elgar Publishing.

Johnstone, N., Hascic, I. (2008). Encouraging Sustainable Manufacturing and Eco-Innovation, DSTI/IND(2008)8, OECD, Paris.

Kaiser, R., Prange, H. (2004). The reconfiguration of national innovation systems—the example of German biotechnology. Research Policy, 33(3), 395-408.

Kahan, D. M., E. Peters, M. Wittlin, P. Slovic, L. L. Ouellette, D. Braman, and G. Mandel, (2012). The polarizing impact of science literacy and numeracy on perceived climate change risks. Nature Climate Change, 2(10), 732-735,

Kanerva, M., Arundel, A., Kemp, R. (2009). Environmental innovation: Using qualitative models to identify indicators for policy, UNU-MERIT working paper series 2009-047.

Kasser, T. (2002). The high price of materialism. Cambridge, MA: MIT Press.

Keller H. (2016). Psychological autonomy and hierarchical relatedness as organizers of developmental pathways. Phil. Trans. R. Soc. B 371: 20150070. http://dx.doi.org/10.1098/rstb.2015.0070

Kemp, R. (1994). Technology and the transition to environmental sustainability: the problem of technological regime shifts. Futures, 26(10), 1023-1046.

Kemp, R. (2010) The Dutch Energy Transition Approach, International Economics and Economic Policy, 7: 291–316.

Kemp, R. (2011). Ten Themes of Eco-Innovation Policies in Europe, S.A.P.I.E.N.S. (Surveys and Perspectives Integrating Environment & Society) vol 4.2,, http://sapiens.revues.org/1169

Kemp, R., Arundel, A. and Smith K. (2001). Survey Indicators for Environmental Innovation, paper for international conference Towards Environmental Innovation Systems, 27-29 Sept, 2001, Garmisch Partenkirchen, Germany.

Kemp, R., Loorbach D. and Rotmans, J. (2007) Transition management as a model for managing processes of co-evolution for sustainable development , The International Journal of Sustainable Development and World Ecology (special issue on (co)-evolutionary approach to sustainable development) 14: 78-91.

Kemp, R., Never, B. (2017). Green transition, industrial policy, and economic development, Oxford Review of Economic Policy, 33(1): 66–84. https://doi.org/10.1093/oxrep/grw037

Kemp, R., Pearson, P. (2007). Final report MEI project about measuring eco-innovation, (MEI-Measuring eco-innovation project).

Kemp, R., Pontoglio, S. (2011). The innovation effects of environmental policy instruments—A typical case of the blind men and the elephant?, Ecological Economics, 72: 28-36

Kemp, R., Weaver, P.M., Golland, A., Strasser, T, Backhaus, J. (2018). Socio-economic transformations: insights for sustainability, chapter 4 of Perspectives on transitions to sustainability, EEA Report No 25/2017, European Environment Agency, European Commission, pp. 70-96.

Kern, F., and Howlett, M. (2009). 'Implementing transition management as policy reforms: a case study of the Dutch energy sector', Policy Sci, 42 (4), 391-408.

Kern, F., Kivimaa, P., and Martiskainen, M. (2017). 'Policy packaging or policy patching? The development of complex energy efficiency policy mixes', Energy Research & Social Science, 23 11-25.

Kieft, A., Harmsen, R., Hekkert, M.P. (2017)., Interactions between systemic problems in innovation systems: The case of energy-efficient houses in the Netherlands, Environmental Innovation and Societal Transitions 24: 32–44

King, A. M., Burgess, S. C., Ijomah, W. and McMahon, C. A. (2006). Reducing waste: repair, recondition, remanufacture or recycle?. Sustainable Development, 14: 257–267.

Kinne, J, Axenbeck, J. (2018). Web mining of firm websites: A framework for web scraping and a pilot study for Germany. ZEW Discussion Paper No. 18-033, Mannheim.

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. Resources, Conservation and Recycling, 127, 221-232.

Kivimaa, P. and Kern, F. (2016). 'Creative destruction or mere niche support? Innovation policy mixes for sustainability transitions', Research Policy, 45 (1), 205-17.

Kleinknecht, A. (1993). 'Why Do We Need New Innovation Output Indicators? An Introduction', in A. Kleinknecht and D. Bain (eds.), New Concepts in Innovation Output Measurement, New York: St.Martin's Press, 1-9.

Kleinknecht, A., Van Montfort, K., & Brouwer, E. (2002). The non-trivial choice between innovation indicators. Economics of Innovation and new technology, 11(2), 109-121.

Knight, P., & Jenkins, J. O. (2009). Adopting and applying eco-design techniques: a practitioners perspective. Journal of cleaner production, 17(5), 549-558

Kupka D., Cervantes M (2015). Capturing innovation complementarities for green growth. Green growth and sustainable development forum, 14-15 December 2015, OECD, Paris.

Kwon, S., Porter, A., & Youtie, J. (2016). Navigating the innovation trajectories of technology by combining specialization score analyses for publications and patents: graphene and nano-enabled drug delivery. Scientometrics, 106(3), 1057-1071.

Lenzen, M. (2000). Errors in Conventional and Input-Output—based Life—Cycle Inventories. J. Ind. Ecol. 4, 127–148. doi:10.1162/10881980052541981

Magro, Edurne and James R. Wilson (2013). 'Complex innovation policy systems: Towards an evaluation mix', Research Policy, 42 (9), 1647-56.

Malone, E.L., Betsill, M., Hughes, S., Kemp, R., Lutzenhiser, L, Moezzi, M., Preston, B.L., West, T.O. (2018). Chapter 6: Social science perspectives on carbon. In Second State of the Carbon Cycle Report (SOCCR2): A Sustained Assessment Report [Cavallaro, N., G. Shrestha, R. Birdsey, M. A. Mayes, R. G. Najjar, S. Reed, P. Romero-Lankao, and Z. Zhu (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 264-302,

Mastini, M. (2017). Degrowth: the case for a new economic paradigm, Open Democracy, Available from: https://www.opendemocracy.net/riccardo-mastini/degrowth-case-for-constructing-new-economic-paradigm

Marques, António Cardoso and José Alberto Fuinhas (2012). 'Are public policies towards renewables successful? Evidence from European countries', Renewable Energy, 44 109-18.

Matthews D, Galdeira K (2008). Stabilizing climate requires near-zero emissions, Geophysical Research Letters 35, doi:10.1029/2007GL032388

Marvis, P., Baltazar Herrera, M.E., Googins, B., Albareda, L. (2016). Corporate social innovation: How firms learn to innovate for the greater good. Journal of Business Research, 69(11), 5014-5021,

Maxwell, J. A. (2004). Causal explanation, qualitative research, and scientific inquiry in education. Educational Researcher, 33 (2), 3-11.
Mazzucato, M. (2013). The Entrepreneurial State. Debunking Public vs. Private Sector Myths, Anthem books, London.
McDowall W, Diaz-Lopez F, Seiffert L (2015). Environmental macro-indicators of innovation: policy, assessment and monitoring: Final report of the EMININN project. European Commission EMININN (2015) Environmental macro-indicators of innovation: policy, assessment and monitoring - EMInInn Final Report.
McDowall, W., Geng, Y., Huang, B., Barteková, E., Bleischwitz, R., Türkeli, S., Kemp, R. and Doménech, T. (2017), Circular Economy Policies in China and Europe. Journal of Industrial Ecology, 21: 651–661. doi:10.1111/jiec.12597
MacCallum, R., K. Widaman, S. Zhang and S. Hong (1999). "Sample size in factor analysis." Psychological Methods 4(1): 84-99
Miedzinski, M., et al. (2013), 'A short guide to assessing environmental impacts of research and innovation policy', DG Research and Innovation, EC
Miedzinski, M. (2015), 'Public policy for long-term societal challenges? The reframing of policy narratives and the Roadmap to a Resource Efficient Europe', (University of Manchester).
Miedzinski, M. (2017). Session background report "Evidence library on eco-innovation policy", Deliverable D3.2 for WP 3 – Eco-innovation policy agendas: global knowledge synthesis of rationales and evidence, UCL.
Miedzinski M. McDowall W., Kemp R. , Türkeli S. (2017) An expert-based participatory evaluation of public policies for sustainability transitions, IST 2017 Conference, 18-21 June 2017 in Gothenburg, Sweden
Millar, M.M., Dillman, D. A. (2011). Improving response to web and mixed-mode surveys. Public opinion quarterly, 75(2), 249-269.
Moll, S., & Gee, D. (Eds.). (1999). Making sustainability accountable: eco-efficiency, resource productivty and innovation: proceedings of a workshop on the occasion of the Fifth Anniversary of the European Environment Agency (EEA) 28-30 October 1998 in Copenhagen (No. 11-1999). Office for Official Publications of the European Communities.
Montalvo, C. (2002). Environmental Policy and Technological Innovation. Why Do Firms Adopt or Reject New Technologies? Cheltenham, Northampton, Edward Elgar.
Murray, R., Caulier-Grice, J., & Mulgan, G. (2010). The open book of social innovation (p. 2). London: National endowment for science, technology and the art.
NRC Canada (2003). Design for Environment Guide. National Research Council, Canada. Available from: http://dfe-sce.nrc-cnrc.gc.ca/home_e.html; 2003
National Research Council of the National Academy of Sciences (2015). Climate Intervention: Carbon Dioxide Removal and Reliable Sequestration, National Academies Press.
NESTA (2018). European Innovation Scoreboard 2018: Exploratory report B: Toward the in corporation of big data in the European Innovation Scoreboard, European Commission, Luxembourg, June 14, 2018.

Newell, R.G., Jaffe, A.B., Stavins, R. (1999). The induced innovation hypothesis and energy-saving technological change. Quarterly Journal of Economics 114, 941–975.
Newell, R. G. (2010). 'The role of markets and policies in delivering innovation for climate change mitigation', Oxford Review of Economic Policy, 26 (2), 253-69
Nie, H., Kemp, R. (2014). Index decomposition analysis of residential energy consumption in China: 2002-2010, Applied Energy, 121: 10–19.
Nie, H., Kemp, R., Font Vivanco, D., Vasseur, V. (2016). Structural decomposition analysis of energy-related CO2 emissions in China from 1997 to 2010, Energy Efficiency. DOI 10.1007/s12053-016-9427-x.
Norman, D.A., Verganti, R. (2014). Incremental and Radical Innovation: Design Research vs. Technology and Meaning Change, Design Issues: 30(1): 78-96.
Nowotny, H. (2003). Democratising expertise and socially robust knowledge. Science and Public Policy 30: 151–157.
Numminen, S., Lund, P.D. (2016). Frugal energy innovations for developing countries – a framework, Global Challenges, 1(1): 9-19. https://doi.org/10.1002/gch2.1012
OECD (1991). Environmental labelling in OECD countries. Salzman, J., OECD.
OECD (1996), Building Policy Coherence: Tools and Tensions. Organisation for Economic Cooperation and Development, Paris.
OECD (2003), Policy Coherence. PUMA series. Organisation for Economic Cooperation and Development, ParisOECD (2001). Extended Producer Responsibility: A Guidance Manual for Governments. Paris.
OECD (2003), Policy coherence, 27th Session on the Public Management Committee, (GOV/PUMA(2003)4, OECD, Paris).
OECD (2004). "The OECD-JRC Handbook on Practices for Developing Composite Indicators", paper presented at the OECD Committee on Statistics, 7-8 June 2004, OECD, Paris.
OECD. (2008). Handbook on constructing composite indicators: Methodology and user guide.
OECD (2009). Green Growth Indicators. http://www.oecd.org/greengrowth/green-growth-indicators/ OECD, Paris
OECD (2010). Glossary of Key Terms in Evaluation and Results Based Management. Organisation for Economic Cooperation and Development, Paris
OECD (2011). Towards Green Growth: Monitoring Progress, OECD, Paris
OECD (2012). The future of eco-innovation: the role of business models in green transformation. OECD background paper, in Proceedings of the OECD/European Com mission/Nordic Innovation Joint Workshop. Copenhagen. https://www.oecd.org/innovation/inno/49537036.pdf.
OECD (2015). Frascati manual 2015: guidelines for collecting and reporting data on research and experimental development. OECD Publishing.
OECD (2017). How's Life? 2017: Measuring Well-being. How's Life?, OECD Publishing. Available from: https://www.oecd-ilibrary.org/content/publication/how_life-2017-en.
OECD (2017). Green Growth Indicators 2017, OECD Publishing, Paris. http://dx.doi.org/10.1787/9789264268586-en.
OECD (2019). Rethinking innovation for a Sustainable Ocean Economy, OECD Publishing, Paris. https://doi.org/10.1787/9789264311053-en

OECD / Eurostat (2018). Oslo Manual: Guidelines for Collecting, Reporting and Using Data on Innovation, 4th Edition, OECD Publishing, Paris/Eurostat Luxembourg.
Pauli, G., (2004) The Blue Economy: 10 years - 100 innovations - 100 million jobs, report to the Club of Rome
Pauli, G., (2016) The Blue Economy version 2.0, Academic foundation.
Pawson, R. (2002). Evidence-Based Policy: The Promise of 'Realist' Synthesis, Evaluation, 8(3): 340-358.
Pearce, D.W., Markandya, A. & Barbier, E., (1989). Blueprint for a Green Economy, London: Earthscan.
Phills, J. A., Deiglmeier, K., & Miller, D. T. (2008). Rediscovering social innovation. Stanford Social Innovation Review, 6(4), 34-43.
Pilgrim, S., Smith, D., & Pretty, J. (2007). A CROSS-REGIONAL ASSESSMENT OF THE FACTORS AFFECTING ECOLITERACY: IMPLICATIONS FOR POLICY AND PRACTICE. Ecological applications, 17(6), 1742-1751.
Planet Bleu, 2016. Blue economy for a healthy Mediterranean- Measuring, Monitoring and Promoting an environmentally sustainable economy in the Mediterranean region. Scoping Study. Blue Economy Project. 46 p.
Planet Bleu (2017). Towards a Blue Economy for a Sustainable Mediterranean. Indicators and recommendations. Plan Blue Notes # 34. 4 p.
Polzin, F., et al. (2015). 'Public policy influence on renewable energy investments—A panel data study across OECD countries', Energy Policy, 80 98-111.
Porter, M.E. and Kramer, M.R. (2011). Creating shared value, Harvard Business Review, Vol. 89, Nos 1/2, pp. 62-77
Potting, J., Hanemaaijer, A. (eds) (2018). Circulaire economie: wat we willen weten en kunnen meten. Systeem e nulmeting voor monitoring van de voortgang van de circulaire economie in Nederland.
Potting, J., Hekkert, M., Worrell, E., Hanemaaijer, A. (2016). Circular economy: Measuring innovation in the product chain, English translation of the report 'Circulaire economie: Innovatie meten in de keten', © PBL Netherlands Environmental Assessment Agency, The Hague.
Ragin, C. (1987). The Comparative method. Moving Beyond Qualitative and Quantitative Strategies, Berkeley: University of California Press.
Ragin, C.C. (2008). Redesigning social inquiry: Fuzzy sets and beyond. Chicago: University of Chicago Press.
Ramani, S.V. (ed.) (2014), Innovation in India: Combining Economic Growth with Inclusive Development. Cambridge University Press.
Ramani, S.V., SadreGhazi, S., Gupta, S. (2017). "Catalysing innovation for social impact: The role of social enterprises in the Indian sanitation sector." Technological Forecasting and Social Change, 121: 216-227.
Rammer, C., Czarnitzki, D., & Spielkamp, A. (2009). Innovation success of non-R&D-performers: substituting technology by management in SMEs. Small Business Economics, 33(1), 35-58.

Raupach M, Davis SJ, Peters GP (2014). Sharing a quota on cumulative carbon emissions. Nature Climate Change, DOI:10.1038/NCLIMATE2384.
Rennings, K., Zwick, T. (2003). Employment Impacts of Cleaner Production, ZEW Economic Studies 21, SpringerLink, Berlin.
Reichardt, K., Rogge, K. (2016). How the policy mix impacts innovation: Findings from company case studies on offshore wind in Germany, Environmental Innovation and Societal Transitions, 18: 62-81.
Reichardt, Kristin, et al. (2016), 'Analyzing interdependencies between policy mixes and technological innovation systems: The case of offshore wind in Germany', Technological Forecasting and Social Change, 106 11-21.
Reid, A and M Miedzinski (2008), Eco-innovation. Final Report for Sectoral Innovation Watch, (SYSTEMIC project).
Rennings, K. (2000). Redefining innovation—Eco-innovation research and the contribution from ecological economics, Ecological Economics 32, 319–322.
Rizos V, Behrens A, Taranic I (2015). Measuring progress in eco-innovation. NETGREEN Policy Brief No. 1
Rockström J, Steffen W, Noone K (2009). A safe operating space for humanity, Nature 461, 472-475
Rodrik, D. (2014). Green Industrial Policy, Oxford Review of Economic Policy 30: 469-491.
Rogers, E.M. (2003) Diffusion of Innovations, 5th Edition, Free Press.
Rogge, K.S. ,Reichardt, K. (2016). 'Policy mixes for sustainability transitions: An extended concept and framework for analysis', Research Policy, 45 (8), 1620-35.
Rogge, K.S., Schneider, M., Hoffmann, V.K. (2011). 'The innovation impact of the EU Emission Trading System — Findings of company case studies in the German power sector', Ecological Economics, 70 (3), 513-23.
Rosenström, U., (2009). Sustainable development indicators: Much wanted, less used?, Monographs of the Boreal Environment Research. Boreal Environment Research.
Rovan J. (2011). Composite Indicators. In: Lovric M. (eds) International Encyclopedia of Statistical Science. Springer, Berlin, Heidelberg
RREUSE (2015). Improving product reparability: Policy options at EU level
Sachs, J. D., Warner, A. M. (1999). The big push, natural resource booms and growth. Journal of development economics, 59(1), 43-76.
Sayre, N.F. (2008). The Genesis, History, and Limits of Carrying Capacity. Ann. Assoc. Am. Geogr. 98, 120–134. doi:10.1080/00045600701734356
Schmidt, T.S., et al. (2012). 'The effects of climate policy on the rate and direction of innovation: A survey of the EU ETS and the electricity sector', Environmental Innovation and Societal Transitions, 2 23-48.
Schmidt, T.S., et al. (2016). 'Do deployment policies pick technologies by (not) picking applications?—A simulation of investment decisions in technologies with multiple applications', Research Policy, 45 (10), 1965-83.
Schot, J., Steinmueller, E. (2016)., 'Framing Innovation Policy for Transformative Change: Innovation Policy 3.0', SPRU Science Policy Research Unit, University of Sussex: Brighton, UK,

Schot, J., Geels, F.W. (2008). 'Strategic niche management and sustainable innovation journeys: theory, findings, research agenda, and policy', Technology Analysis & Strategic Management, 20 (5), 537-54.
Schot, J., Hoogma, R., Elzen, B. (1994), 'Strategies for shifting technological systems', Futures, 26 (10), 1060-76.
Schor, J.B (2001). Why do we consume so much? Lecture, October 22, 2001, Saint John's University
Schor, J.B., (2010). Plenitude: The New Economics of True Wealth, Penguin books
Schreurs, J. (2010). Living with Less: Prospects for Sustainability. PhD Maastricht University
Seaford C., Jeffrey, K. (2015). Headline indicators of progress for a green economy, NETGREEN Policy Brief No. 4, July 2015.
SEEA, U. (2012). The System of Environmental-Economic Accounts (SEEA): measurement framework in support of sustainable development and green economy policy, Briefing Paper.
Sennett, R., (1998). The Corrosion of Character – The Personal Consequences of Work in the New Capitalism, New York/London: W. W. Norton & Company.
Seyfang, G., Smith, A. (2007). "Grassroots innovations for sustainable development: Towards a new research and policy agenda." Environmental politics 16(4): 584-603.
Smith, A, Voss, J-P., Grin, G. (2010). 'Innovation studies and sustainability transitions: The allure of the multi-level perspective and its challenges', Research Policy, 39 435-48.
Smith, K. (2000). Innovation as a systemic phenomenon: rethinking the role of policy. Enterprise and innovation management studies, 1(1), 73-102
Smith, K. (2010). 'Innovation as a Systemic Phenomenon: Rethinking the Role of Policy', Enterprise and Innovation Management Studies, 1 73-102.
Smith, P., Davis, S.J., Creutzig, F. et al (2015). Biophysical and economic limits to negative CO2 emissions, Nature Climate Change, DOI:10.1038/NCLIMATE2870
Spieth, P, Schneider, S (2016). Business model innovativeness: designing a formative measure for business model innovation, Journal of Business and Economics, 86: 671–696.
Stanners, D., Bosch, P., Dom, A., Gabrielsen, P., Gee, D., Martin, J., ... & Weber, J. L. (2007). Frameworks for environmental assessment and indicators at the EEA. Sustainability Indicators–A Scientific Assessment..
Stewart, J., Hyysalo, S. (2008). Intermediaries, users and social learning in technological innovation. International Journal of Innovation Management, 12(03), 295-325.
Stiftung, Verlag Bertelsmann (2017). Sustainable Governance Indicators 2017 Verlag Bertelsmann Stiftung
Stiglitz J.E., Sen A., Fitoussi J-P,.(2009). Report of the Commission on the Measurement of Economical Performance and Social Progress. Available from: www.stiglitz-sen-fitoussi.fr.
Suh, S. (2004). Functions, commodities and environmental impacts in an ecological–economic model. Ecological Economics. 48, 451–467. doi:http://dx.doi.org/10.1016/j.ecolecon.2003.10.013.
Suh, S., Huppes, G. (2005). Methods for life cycle inventory of a product. Journal of Cleaner Production. https://doi.org/10.1016/j.jclepro.2003.04.001

Suurs, R., Hekkert, M. (2009) Cumulative causation in the formation of a technological innovation system: The case of biofuels in the Netherlands, Technological Forecasting & Social Change 76: 1003–1020.
Tashakkori, A. and C. Teddlie (1998). Mixed Methodology. Combining Qualitative and Quantitative Approaches. Thousand Oaks, London, New Delhi, Sage Publications.
Türkeli, S., Kemp, R., Font Vivanco, D. (2015) EmInInn report linking energy- and material-efficiency improvements and indicators to innovations, Deliverable 2.3 EmInInn project.
Türkeli, S., Kemp, R., Huang, B., Bleischwitz, R., & McDowall, W. (2018a). Circular economy scientific knowledge in the European Union and China: A bibliometric, network and survey analysis (2006–2016). Journal of Cleaner Production.
Türkeli, S., & Kemp, R. (2018b). Changing Patterns in Eco-Innovation Research: A Bibliometric Analysis. In New Developments in Eco-Innovation Research (pp. 13-54). Springer, Cham.
UN (2008). System of National Accounts 2008. Available from: https://unstats.un.org/unsd/nationalaccount/docs/SNA2008.pdf
UN (2015). Transforming our world: The 2030 agenda for sustainable development. Resolution adopted by the General Assembly.
UNCTAD. (2010). World Investment Report 2010 – Investing in a Low Carbon Economy
UNEP (2008). Biodiversity and Ecosystem Services. A Financial Sector Briefing. Available from: http://www.unepfi.org/fileadmin/documents/bloom_or_bust_report.pdf
UNEP (2009) Integrated Policymaking for Sustainable Development, A Reference Manual, UNEP, Geneva.
UNEP (2011), Towards a Green Economy, Pathways towards Sustainable Development and Poverty Eradication. A synthesis for policy maker.
UNEP (2014a), Measuring Progress towards a Green Economy. UNEP
UNEP (2014b). A Guidance Manual for Green Economy Policy Assessment. UNEP
UNEP (2017). Green Foreign Direct Investment in Developing Countries. UNEP
UNIDO (2015). Industrial Development Report 2016. The Role of Technology and Innovation in Inclusive and Sustainable Industrial Development. Vienna
United Nations Statistics Division (2016). Framework for the Development of Environment Statistics (FDES 2013). United Nations Statistics Division. Department of Economic and Social Affairs. Available from: http://unstats.un.org/unsd/environment/FDES/FDES-2015-supporting-tools/FDES.pdf.
Unruh, G. C. (2000). Understanding carbon lock-in. Energy policy, 28(12), 817-830
Uyarra, Elvira, Philip Shapira, and Alan Harding (2016), 'Low carbon innovation and enterprise growth in the UK: Challenges of a place-blind policy mix', Technological Forecasting and Social Change, 103 264-72
Van de Ven, A. H. (1986). Central problems in the management of innovation. Management science, 32(5), 590-607.
Van de Ven, A.H. (2017). The innovation journey: you can't control it, but you can learn to maneuver it, Innovation, 19:1, 39- 42, DOI: 10.1080/14479338.2016.1256780
Van den Bergh, J.C.J.M. (2011). Environment versus growth – A criticism of "degrowth" and a plea for "a-growth". Ecological Economics, 70(5), 881-890.

Van den Bergh, J.C.J.M. (2012). Effective climate-energy solutions, escape routes and peak oil, Energy Policy 46: 530–536.
van den Bergh, J.C.J.M. (2013). ‘Environmental and climate innovation: Limitations, policies and prices’, Technological Forecasting and Social Change, 80 (1), 11-23.
van Mierlo, B., M. Arkesteijn and C. Leeuwis (2010). Enhancing the reflexivity of system innovation projects with system analyses. American Journal of Evaluation 31(2): 143-161
Verhaeghe, P. (2014). What about me? The struggle for identity in a market-based society, Scribe, Melbourne and London
Veugelers, R. (2012)., ‘Which policy instruments to induce clean innovating’, Research Policy, 41 (10), 1770-78.
von Hippel E. (2017). Free Innovation (2017): How citizens create and share innovations, MIT Press, Cambridge.
WBCSD, A. (2000). Eco-efficiency. Creating more value with less impact. World Business Council for Sustainable Development, Geneva, 32.
Weaver, P., Jansen, L., van Grootfeld, g., van Spiegel, E., Vergragt, P. (2000). Sustainable Technological Development, Sheffield: Greenleaf Publishing.
Weaver, P., Marks, M.., Hogan, L., Wittmayer, J., Ruijsink, S., Becerra, L., Cozan, S., Kemp, R., Strasser, T., Zuijderwijk, L. (2017) Resourcing, Monitoring and Evaluation: Scaling Challenges and Pathways, TRANSIT brief 5.
Weber, K. Matthias and Harald Rohracher (2012), ‘Legitimizing research, technology and innovation policies for transformative change’, Research Policy, 41 (6), 1037-47.
Weng, X., Z. Dong, Q. Wu, and Y. Qin. (2015). China’s path to a green economy: Decoding China’s green economy concepts and policies. London: International Institute for Environment and Development.
Weidema, B. P., Pizzol, M., Schmidt, J. H., & Thoma, G. (2018). Attributional or consequential Life Cycle Assessment: A matter of social responsibility. Journal of Cleaner Production, 174, 305-314. DOI: 10.1016/j.jclepro.2017.10.340
Wiedmann, T. O., Schandl, H., Lenzen, M., Moran, D., Suh, S., West, J., & Kanemoto, K. (2015). The material footprint of nations. Proceedings of the National Academy of Sciences, 112(20), 6271-6276.
Zamagni, A., Guinée, J., Heijungs, R., Masoni, P., & Raggi, A. (2012). Lights and shadows in consequential LCA. International Journal of Life Cycle Assessments, 17, 904–918. https://doi.org/10.1007/s11367-012-0423-x

ANNEXES - Annex Chapter 1

Table A1.1 Overview of eco-innovation definitions (2000-2017)

Definition	Source
"Eco-innovations are all 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 or to ecologically specified sustainability targets."	Rennings (2000), p322
"Eco-innovation 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 Commission (2006)
"The creation of novel and competitively priced goods, processes, systems, services, and procedures designed to satisfy human needs and provide a better quality of life for everyone with a life-cycle minimal use of natural resources (materials including energy and surface area) per unit output, and a minimal release of toxic substances."	European Commission DG Enterprise and Industry (2006)
"Eco-innovation 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 Commission (2007), p17
"Eco-innovation is the production, assimilation or exploitation of a product, production procaine, service or management or business method that is novel to the organisation (developing or adopting it) and which results, throughout its life cycle, i.e. a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives"	Kemp& Pearson (2007), p7
"Eco-innovation is the commercial application of knowledge to elicit direct or indirect ecological improvements."	EEA (2007)
"Eco innovation is "the creation of novel and competitively priced goods, processes, systems. services, and procedures designed to satisfy human needs and provide a better quality of life for everyone with a life-cycle-wide minimal use of natural resources (materials including energy and surface area) per unit output, and a minimal release of toxic substances" resources"	Reid & Miedzinski (2008), p2
"Any innovation that makes progress towards the goal of sustainable development by reducing impacts on the environment, increasing resilience to environmental pressures or using natural resources more efficiently and responsibly"	European Commission (DG Environment / Eco-Innovation Action Plan) (Eco-innovation Observatory, 2011)
"Any innovation that reduces the use of natural resources and decreases the release of harmful substances across the whole life-cycle."	Eco-Innovation Observatory (2011)
"Eco-innovation means bringing a new product (good or service) to the market or implementing a new solution in the production or organisational processes of a company. What distinguishes it from other innovations, however, is that eco-innovation results in both economic and environmental benefits." Eco-innovation is not simply about reducing input of resources into a single product, but about an overall better use of resources used to deliver certain utility or service" "Eco-innovation means bringing a new product (good or service) to the market or implementing a new solution in the production or organisational processes of a company. What distinguishes it from other innovations, however, is that eco-innovation results in both economic and environmental benefits." Eco-innovation is not simply about reducing input of resources into a single product, but about an overall better use of resources used to deliver certain utility or service"	Eco-innovation Observatory (2011)

Definition	Source
"Any form of innovation resulting in or aiming at significant and demonstrable progress towards the goal of sustainable development through reducing impacts on the environment, enhancing resilience to environmental pressures, or achieving a more efficient and responsible use of natural resources."	European Commission Eco-Innovation Action Plan Dec. 2011 (European Commission, 2011)
"Eco-innovation as the introduction of any new or significantly improved product (good or service). process organisational change or marketing solution that reduces the use of natural resources (including materials, energy, water and land) and decreases the release of harmful substances across the whole lifecycle"	Eco-Innovation Observatory (2012), p8
"The creation of new, or significantly improved, products (goods and services), processes, marketing methods, organisational structures and institutional arrangements which - with or without intent - lead to environmental improvements compared to relevant alternatives"	OECD (2012)
"Eco-innovation refers to all forms of innovation –technological and non-technological– that create business opportunities and benefit the environment by preventing or reducing their impact, or by optimizing the use of resources.	European Commission (2012)
"Eco-innovation is any innovations resulting in significant progress towards the goal of sustainable development, by reducing the impacts of our production modes on the environment, enhancing natures resilience to environmental pressures or achieving a more efficient and responsible use of natural resources"	European Commission (2013),p1
"The development and application of a business model, shaped by a new business strategy that incorporates sustainability throughout all business operations based on life-cycle thinking and in cooperation with partners across the value chain. It entails a coordinated set of modifications or novel solutions to products (goods / services), processes, market approach and organizational structure which leads to a company's enhanced performance and competitiveness."	UNEP (2014a, 2014b), Eco-Innovation Manual
"Any form of innovation aiming at significant and demonstrable progress towards the goal of sustainable development. This can be achieved either by reducing the environmental impact or achieving a more efficient and responsible use of resources."	European Commission (2015)
"Eco-innovation is the development and application of a business model, shaped by a new business strategy that incorporates maintainability throughout all business operations based on life cycle thinking and in cooperation with partners across the value chain. It entails a coordinated set of modifications or novel solutions to products (goods / services), processes, market approach and organisational structure which leads to a company, enhanced performance and competitiveness"	UNEP (2017), p16

Source: Authors' compilation

Table A1.2 - The questions in the Community Innovation Survey of 2008 about eco-innovation

10. Innovations with environmental benefits			
An environmental innovation is a new or significantly improved product (good or service), process, organizational method or marketing method that creates environmental benefits compared to alternatives			
• The environmental benefits can be the primary objective of the innovation or the result of other innovation objectives			
• The environmental benefits of an innovation can occur during the production of a good or service, or during the after sales use of a good or service by the end user.			
10.1 During the three years 2006 to 2008, did your enterprise introduce a product (good or service), process,organisational or marketing innovation with any of the following environmental benefits?			
	YES	**NO**	
Environmental benefits from the production of goods or services within your enterprise			
Reduced material use per unit of output	☐	☐	ECOMA
Reduced energy use per unit of output	☐	☐	ECOEN
Reduced CO_2 footprint (total: CO_2 production) by your enterprise	☐	☐	ECOCO
Replaced materials with less polluting or hazardous substitutes	☐	☐	ECOSUB
Reduced soil, water, noise, or air pollution	☐	☐	ECOPOL
Recycled waste, water or materials	☐	☐	ECORE
Environmental benefits from the after sales use of a good or service by the end user			
Reduced energy use	☐	☐	ECOEN
Reduced air, water, soil or noise pollution	☐	☐	ECOPO
Improved recycling of product after use	☐	☐	ECOREA
10.2 During 2006 to 2008 did your enterprise introduce an environmental innovation in response to:			
	YES	**NO**	
Existing environmental regulations or taxes on pollution	☐	☐	ENREG
Environmental regulations or taxes that you expected to be introduced in the future	☐	☐	ENREGF
Availability of government grants, subsidies or other financial incentives for environmental	☐	☐	ENGRA
Current or expected market demand from your customers for environmental motivations	☐	☐	ENDEM
Voluntary codes or agreements for environmental good practice within your sector	☐	☐	ENAGR
10.3 Does your enterprise have procedures in place to regularly identify and reduce your enterprise's environmental impacts? (For example preparing environmental audits, setting environmental performance goals, ISO 14001 certification, etc.).			
ENVID			
☐ Yes, implemented before January 2006			
☐ Yes, implemented or significantly improved after January 2006			
☐ No			

Source: http://ec.europa.eu/eurostat/documents/203647/203701/CIS_Survey_form_2008.pdf/e06a4c11-7535-4003-8e00-143228e1b308

Table A1.3 - Eco-innovation Scoreboard of the Eco-innovation Observatory

Existing Indicator Systems for Eco-Innovation

Eco-Innovation Scoreboard (Eco-IS)	Source	Year
Eco-innovation inputs		
1. Governments environmental and energy R&D appropriations and outlays (% of GDP)	EUROSTAT	2014
2. Total R&D personnel and researchers (% of total employment)	EUROSTAT	2014
3. Total value of green early stage investments (USD/capita)	Cleantech	2012-2015
Eco-innovation activities		
4. Firms having implemented innovation activities aiming at a reduction of material input per unit output (% of total firms)	EUROSTAT	2008
5. Firms having implemented innovation activities aiming at a reduction of energy input per unit output (% of total firms)	EUROSTAT	2008
6. ISO 14001 registered organisation (per min population)	ISO Survey of certifications	2014
Eco-innovation outputs		
7. Eco-innovation related patents (per min population)	PATSTAT	2012
8. Eco-innovation related academic publications (per min population)	Scopus	2014
9. Eco-innovation related media coverage (per numbers of electronic media)	Meltwater	2015
Resources efficiency outcomes		
10. Material productivity (GDP/Domestic Material Consumption)	EUROSTAT	2013
11. Water productivity (GDP/Water Footprint)	Water Footprint Network	1996-2005
12. Energy productivity (GDP/Gross Inland Energy Consumption)	EUROSTAT	2013
13. GHG emissions intensity (CO2e/GDP)	EEA	2013
Socio-economic outcomes		
14. Exports of products from eco-industries (% of total exports)	EUROSTAT	2014
15. Employment in eco-industries and circular economy (% of total employment across all companies)	Orbis	2014
16. Revenue in eco-industries and circular economy (% of total revenue across all companies)	Orbis	2014

Source: https://ec.europa.eu/environment/ecoap/indicators/index_en

Table A1.4 - ASEM Eco-Innovation Index

ASEM Eco-Innovation Index	Source	Year Collected	Collected
Eco-Innovation Capacity			
1.1. Potential to improve national competitiveness	GCI (WEF)	2014- 2015	YES
1.2. General innovation Capacity of nation	GII (INSEAD)	2014	YES
1.3. Green R&D Capacity of Research Institutes	Cleantech	-	NO
1.4. Number of companies with green innovative technology	Cleantech	-	NO
1.5. Awareness level of company's sustainable management	United Nations	2015.03	YES
Eco-Innovation Support Environment			
2.1. Government expenditure on green R&D	OECD	2013	YES
2.2. Implementation of environmental regulations	WEF	2014-2015	YES
2.3. Green technology industry investment environment	Cleantech	-	NO
2.4. Green innovative technology investment level for SMEs	Cleantech	-	NO
Eco-Innovation Activities			
3.1. Number of companies with commercialized green technology	Cleantech	-	NO
3.2. Participation level in environmental management	ISO	2013	YES
3.3. Economic influence of major eco-friendly corporates	Trucost & Sustainalytics	2014	YES
3.4. Green patent	OECD (WIPO)	2011	YES
3.5. Distribution of renewable energy	PEA	2014	YES
Eco-Innovation Performances			
4.1. Quality of life related to environmental factors	EPI	2014	YES
4.2. Greenhouse gas emission intensity	PEA	2014	YES
4.3. Energy sustainability level	ESI (WEC)	2014	YES
4.4. Water resource consumption intensity	IMD	2014	YES
4.5. Employment rate in green technology industry	Cleantech	-	NO
4.6. Green market size	UK BIS	2011	YES

Source: http://www.aseic.org/resources/download/asei/result_2015/2015_ASEM_Eco-Innovation_Index_Final_Report.pdf

Table A1.5 - Indicators and data source of GCII 2017

Global Cleantech Innovation Index (GCII)				
Indicator	**Source**	**Data**	**Definition**	**Weighting**
General innovation drivers				
General innovation inputs	INSEAD Global Innovation Index	2016	Institutions, human capital, infrastructure, market sophistication and business sophistication facilitating	50%
Entrepreneurial culture	Global Entrepreneurship Monitor	2016	Positive attitudes towards entrepreneurship and early stage entrepreneurial activity	50%
Cleantech-specific innovation drivers				
Cleantech-friendly government policies	REN21 -Renewables 2016 Global Status Report; World Bank Group - State and trends of carbon pricing 2016, OECD & Bloomberg Philthi	2015-2016	Selected government policies supporting clean technology including tax incentives, feed-in tariffs, green bonds, renewable energy mandates and others	25%
Government R&D expenditure in cleantech sectors	OECD-IEA database, UN GERD database	2013-2015	Total budget for cleantech R&D as a proportion of GDP (PPP)	25%
Access to private finance for cleantech start-ups	Cleantech Group data	2014-2016	Number of cleantech investors and cleantech-focused funds recently raised weighted by GDP	25%
Country-attractiveness of Renewable Energy Infrastructure	Ernst & Young Renewable Energy Country Attractiveness Index	2015	Index score covering national renewable energy markets, renewable energy infrastructures and their suitability for wind, solar, biomass and other	20%
Cleantech cluster programs & initiatives	Cleantech Group research	2016	Number of industry associations, physical clusters and economic initiatives supporting the cleantech industry as a proportion of GDP (PPP)	5%
Evidence of emerging cleantech innovation				
Patents in cleantech sectors	OECD database	2013	Environment-related technology patents covered by the Worldwide Patent Statistical Database (PATSTAT) weighted	45%
Early-stage private investment	Cleantech Group data	2014-2016	Amount of venture capital invested in cleantech companies as a proportion of GDP (PPP)	45%
High impact cleantech start-ups	Cleantech Group data	2014-2016	Number of compares included in the Global Cleantech 300 weighted by GDP (PPP)	45%

Evidence of commericalised cleantech innovation				
Trade of cleantech commodities	UN Comtrade	2015	Trade value of national export (25% weighting) and import (25% weighting) of cleantech-related commodities, weighted b GDP (PPP)	50%
Renewable energy consumption	BP Statistical Review of World Energy 2016	2016	Total renewable energy consumption as % of Primary Energy Consumption	20%
Late-stage private investment and exits	Cleantech Group data	2014-2016	Number of cleantech private equity deals M&As and IPOs weighted by GDP (PPP)	15%
Successful pubic cleantech companies	Cleantech Group, FTSE, Ardour and WilderHill indices of public cleantech	2016	Number of publically listed cleantech focused corporates weighted by GDP (PPP)	10%
Renewable Energy Jobs	IRENA Renewable Energy and Jobs Annual Review	2016	Number of direct and indirect employees related to renewables as % of total labor force	5%

Source: https://s3.amazonaws.com/i3.cleantech/uploads/additional_resources_pdf/17/117/GCII_GCIP_report_2017_20nov.pdf

Table A2.1- Environmental Performance Index

Environmental Performance Index		
Environmental Health (50%)	Health Impacts (33%)	Environmental Risk Exposure (100%)
	Air Quality (33%)	Household Air Quality (30%)
		Air Pollution - Average Exposure to PM2.5 (30%)
		Air Pollution - PM2.5 Exceedance (30%)
		Air Pollution - Average Exposure to NO2 (10%)
	Water and Sanitation (33%)	Unsafe Sanitation (50%)
		Drinking Water Quality (50%)
Ecosystem Vitality (50%)	Water Resources (25%)	Wastewater Treatment (100%)
	Agriculture (10%)	Nitrogen Use Efficiency (75%)
		Nitrogen Balance (25%)
	Forests (10%)	Change in Forest Cover (100%)
	Fisheries (5%)	Fish Stocks (100%)
	Biodiversity and Habitat (25%)	Terrestrial Protected Areas (National Biome Weights) (20%)
		Terrestrial Protected Areas (Global Biome Weights) (20%)
		Marine Protected Areas (20%)
		Species Protection (National) (20%)
		Species Protection (Global) (20%)
	Climate and Energy (25%)	Trend in Carbon Intensity (75%)
		Trend in CO2 Emissions per KWH (25%)
	*NOT USED FOR CALCULATION OF EPI SCORE	Access to Electricity (N/A)

Source: http://epi.yale.edu/

Table A2.2 Sustainable Development Goals Index and Indicators most relevant to eco-innovation

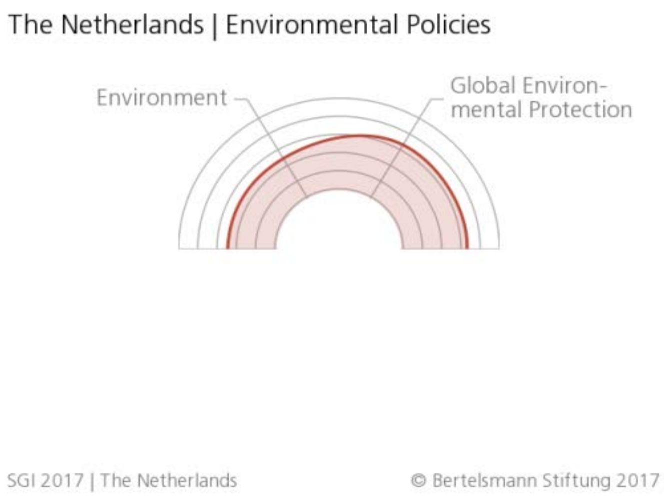
Sustainable Development Goals Index	Source
SDG 6 - Clean Water and Sanitation	
Access to improved water (%)	2011-2015 WHO and UNICEF (2016b)
Access to improved sanitation (%)	2011-2015 WHO and UNICEF (2016b)
Freshwater withdrawal (%)	2002-2017 FAO (2017c)
Imported groundwater depletion (m3/year/capita)	2010 Dalin et al. (2017)
SDG 7 - Affordable and Clean Energy	
Access to electricity (%)	2014 SE4All (2017a)
Access to non-solid fuels (%)	2012SE4All (2017b)
CO_2 from fuels & electricity ($MtCO_2$/TWh)	2014 IEA (2016)
Renewable energy in final consumption (%)	2009-2012 OECD et al. (2017)
SDG 11 - Sustainable Cities and Communities	
PM2.5 in urban areas (μg/m3)	2015 Brauer et al. (2016)
Improved water source, piped (%)	2015 WHO and UNICEF (2016b)
Rent burden (% disposable income)	2011 - 2014 OECD (2017a)
SDG 12 - Responsible Consumption and Production	
E-waste (kg/capita)	2013 UNU-IAS (2015)
Wastewater treated (%)	2014 Hsu et al. (2016)
Production-based SO_2 emissions (kg/capita)	2007 Zhang et al. (2017)
Net imported SO_2 emissions (kg/capita)	2007 - Zhang et al. (2017)
Nitrogen production footprint (kg/capita)	2017 -Oita et al. (2016)
Net imported emissions of reactive nitrogen (kg/capita)	2017 Oita et al. (2016)
Non-recycled municipal solid waste (kg/person/year)	2012 World Bank (2012); OECD (2017a)
Municipal solid waste (kg/person/year)	2012 World Bank (2012)
SDG 13 - Climate Action	
CO2 emissions from energy (tCO_2/capita)	2013 Oak Ridge National Laboratory (2017)
Imported CO2 emissions, tech-adjusted (tCO_2/capita)	2016 Kander et al. (2015)
Climate change vulnerability (0-1)	2014 HCSS (2015)
Effective Carbon Rate (€/tCO_2)	2016 OECD (2017a)
SDG 14 - Life below Water	
Marine sites, mean protected area (%)	2017 BirdLife International et al. (2017)
Ocean Health Index - Biodiversity (0 - 100)	2016 Ocean Health Index (2016)
Ocean Health Index - Clean waters (0-100)	2016 Ocean Health Index (2016
Ocean Health Index - Fisheries (0 -100)	2016 Ocean Health Index (2016)
Fish stocks overexploited or collapsed (%)	2010 Hsu et al. (2016)
SDG 15 - Life on Land	
Terrestrial sites, mean protected area (%)	2017 BirdLife International et al. (2017)
Freshwater sites, mean protected area (%)	2017 BirdLife International et al. (2017)
Red List Index of species survival (0-1)	2017 IUCN and BirdLife International (2017)
Annual change in forest area (%)	2014 Hsu et al. (2016)
Imported biodiversity impacts (species/million people)	2016 Chaudhary and Kastner (2016)

Source: http://www.sdgindex.org/

ANNEXES - Annex Chapter 3

Table A3.1 - The SGI results for environmental policy

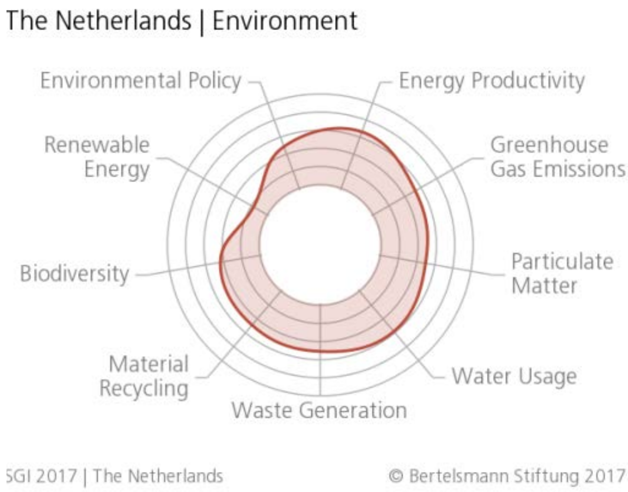
Showing declining public interest in environmental policy, the Netherlands falls into the middle ranks internationally (rank 20) with regard to environmental policies. Its score on this measure has declined by 0.3 points since 2014. The country's population has shown a decreasing sensitivity to environmental issues. However, some new activity has been seen following the Paris accords. A climate change bill with legally binding long-term goal for CO_2 emissions is being developed, along with a climate authority. Actual political commitment is unlikely until after the 2017 elections. Natural-gas reserves are diminishing quickly, with earthquakes and soil subsidence damaging homes where the reserves are located. In general, the government has given GDP growth and job creation priorit over environmental and social-sustainability criteria. The government actively supports EU efforts in the development and advancement of global environmental regimes.



5.0

↗ Environmental Policy
5

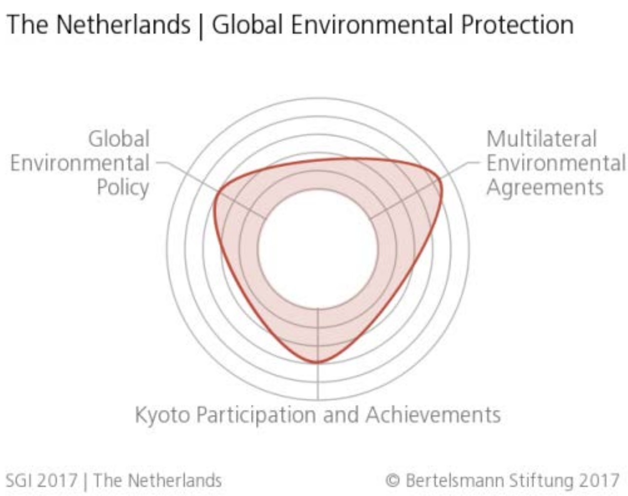
Environmental policy is no longer a significant issue among the public in the Netherlands. According to a 2011 Eurobarometer study, only about half of the population supports a progressive environmental policy (e.g., one that addresses climate change, with a sustainable energy policy). Climate skepticism has won a voice in the States General through the People's Party for Freedom and Democracy (Volkspartij voor Vrijheid en Democratie, VVD) and the Party for Freedom (Partij voor de Vrijheid, PVV). Although government references to sustainable growth are largely rhetorical, as GDP growth and job creation clearly have priority over criteria reflecting environmental and social sustainability…



6.7

↗ Global Environmental Policy
6

The Dutch government has traditionally been a strong supporter of EU leadership in the Kyoto process of global climate policy and advancing global environmental protection regimes like UN Environment Program, IMF World Economic Outlook, Convention on International Trade in Endangered Species and many others. It has also signed related international treaties on safety, food security, energy and international justice…



Source: http://www.sgi-network.org/2017/The_Netherlands/Environmental_Policies

Table A4.1. OECD Environmental Policy Stringency Indicator

OECD Environmental Policy Stringency (EPS) Indicator		
Component	**Explanation**	**Source**
EPS final score	The EPS final score is the aggregate of the EPS Market based indicator and the EPS Non-market based indicator. The market and non-market indicators are given equal weight.	OECD calculation
EPS Market based indicator	The market based component of the EPS include market based instruments, such as: taxes (CO_2, NOx, SOx and diesel); trading schemes (Green Certificate, White certificate and CO_2 TS); Feed-in Tariffs (solar and wind) and Deposit Refund Scheme (waste). Each of these subcomponents (Taxes, TS, FIT and DRS) are given equal weight. Each of the Taxes sub-components are given equal weight. The TS weights are 40% for CO_2, 40% green and 20% white. The white TS is given less weight than its peers due to its novelty and lower diffusion.	OECD calculation
EPS Non-market based indicator	The non-market component of the EPS include non-market instruments, such as: standards (Emission Limit Values (ELV): NOx, SOx, PM) and Sulphur in diesel content limit) and R&D subsidies. The two components are given equal weight. Each sub-component of the Standards is also given equal weight.	OECD calculation
CO2 Tax indicator	This indicator represents the stringency of the CO_2 tax. The raw values have been converted to EUR/ton to facilitate comparison.	OECD\EEA database (http://www2.oecd.org/ecoinst/queries/)
NOX Tax indicator	This indicator represents the stringency of the NOx tax. The raw values have been converted to EUR/ton to facilitate comparison.	OECD\EEA database (http://www2.oecd.org/ecoinst/queries/)
SOX Tax indicator	This indicator represents the stringency of the SOx tax. The raw values have been converted to EUR/ton to facilitate comparison.	OECD\EEA database (http://www2.oecd.org/ecoinst/queries/)
CO2 TS indicator	The average annual price is used to estimate the stringency of the scheme, the higher the price the more stringent the policy. The raw values have been converted to (EUR/ton)/electricity price for industry to facilitate comparison.	EEA: http://www.eea.europa.eu/data-and-maps/figures/eua-future-prices-200520132011); • Bloomberg; •Australian regulation; • EIA (http://www.eia.gov/todayinenergy/detail.cfm?id=1330); • web research for 1995-1999 (EPA Acid Rain Program Compliance Reports 1995-1998)
Green TS indicator	Obligations for green TS are an obligation to source a given percent of electricity from green sources. The higher the percent value the more stringent the policy. Raw values are percent of electricity from green sources.	OECD\EEA database (http://www2.oecd.org/ecoinst/queries/)

White TS indicator	The amount of annual energy saving (expressed in kWh) is used to evaluate the stringency of these schemes. The higher the energy saving the more stringent the policy. Raw values have been converted to kWh to facilitate comparison.	OECD\EEA database (http://www2.oecd.org/ecoinst/queries/)
FIT Wind indicator	This indicator represents the stringency of the feed-in tariff (FIT) for wind energy. The raw values have been converted to EUR/kWh to facilitate comparison.	OECD (2013) Renewable Energy Policy Dataset, version March 2013. Compiled by the Empirical Policy Analysis Unit of the OECD Environment Directorate (Johnstone, N., Haščič, I., Cárdenas Rodríguez M., Duclert, T.) in collaboration with an ad hoc research consortium (Arnaud de la Tour, Gireesh Shrimali, Morgan Hervé-Mignucci, Thilo Grau, Emerson Reiter, Wenjuan Dong, Inês Azevedo, Nathaniel Horner, Joëlle Noailly, Roger Smeets, Kiran Sahdev, Sven Witthöft, Yunyeong Yang, Timon Dubbeling).
FIT Solar indicator	This indicator represents the stringency of the feed-in tariff (FIT) for solar photovoltaic energy. The raw values have been converted to EUR/kWh to facilitate comparison.	
ELV Sulphur content in diesel limit indicator	The indicator represents the stringency of the diesel fuel standard with regard to the maximum concentration of Sulphur in diesel for automobiles. The lower the value the more stringent the policy. The raw values ae ppm (parts per million).	• the UNEP and World Bank files; • Petroleum Products Specifications Regulations 2002 (SR 2002/210) for NWZ; • www.worldenergy.org/documents/annex2automotivefueltrendjapan.pdf for Japan; • clean air initiative and meca for Korea; • Appendix4 global sulfur in diesel limit values: http://www.epa.gov/blackcarbon/2012report/Appendix4.pdf; • DieselNet: What's New Chile introducing ultra low sulfur diesel: https://www.dieselnet.com/news/2011/09cl.php; • WPIEEP delegation to OECD; • UN report: Israel: National Report for CSD-14/15 Thematic Areas: http://www.un.org/esa/agenda21/natlinfo/countr/israel/atmosphere.pdf; • Status of Fuel Quality and Vehicle Emission Standards: Latin America and the Caribbean: http://www.unep.org/transport/pcfv/PDF/Maps_Matrices/LAC/matrix/LAC_combined_March2012.pdf; • IFQC: Automotive Fuel Markets in Eastern/Central Europe & Former Soviet Union (FSU): http://www.un.org/esa/gite/cleanfuels/ee.pdf;

		• Diesel Net: US Federal Diesel Fuel: http://www.dieselnet.com/standards/us/fuel_automotive.php;
		• International Energy Outlook 1998 (EIA) p.45: http://books.google.ca/books?id=TTZZ-0cY86bgC&pg=PA45&lpg=PA45&dq=-sulfur+in+diesel+limit+mexico&source=-bl&ots=8h4L8Jp4cz&sig=FBR2jvGq6-ObG3U-yox2ofqsdBA0&hl=en&sa=X&ei=M9w_VJ7K-G9fbavXmgMAP&ved=0CEMQ6AEwBg#-v=onepage&q=sulfur%20in%20diesel%20limit%20mexico&f=false;
		• Breathing Clean: Considering the Switch to Natural Gas Buses (2001) http://books.google.ca/books?id=VDQ0PTkRxAAC&p-g=PA30&lp=PA30&dq=mexico+sulfur+-diesel+limit+2011&source=l&ots=Mv2N-Qutqtn&sig=eHDnu6chmM8SMfiGh1S-JlNQJ9z4&hl=en&sa=X&ei=L2chVNyaFYn-Y7Ab4iYD4Cg&ved=0CC4Q6AEwAg#v=one-page&q=mexico%20sulfur%20dies el%20limit%202011&f=false;
		• World Bank Technical Paper No.373: Vehicular Air Pollution: Experiences from Seven Latin American Urban Centres p.87, p.146: http://books.google.ca/books?id=X-SUS234DhEsC&pg=PA87&lpg=PA87&d q=sulfur+in+diesel+limit+mexico&source=-bl&ots=HiMA1_h2vP&sig=_YzB8 rPWaQySweVIHG7uaaHfh2w&hl=en&-sa=X&ei=M9w_VJ7KG9fbavXmgM AP&ved=0CEAQ6AEwBQ#v=onepage&q=sul-fur%20in%20diesel%20limit %20mexico&f=false
R&D indicator	The indicator represents the amount spent by the government for R&D of renewable energy relative to the size of the country's nominal GDP; it is calculated by taking the R&D amount and dividing it by the nominal GDP. It is then multiplied by 1000 for readability.	OECD.Stat IEA Energy Technology RD&D in Million USD - Renewable Energy Sources
Diesel Tax indicator	The indicator represents the stringency of the diesel tax. It is calculated by dividing the tax on diesel by the price of diesel. The raw values are USD/L.	• OECD.Stat IEA Energy Price in USD - product Automotive Diesel Fuel (litre);
		• World Bank Data: Pump price for diesel fuel (US$ per litre): http://data.worldbank.org/indicator/EP .PMP.DESL.CD
Deposit Refund Scheme (DRS) indicator	The deposit refund scheme (DRS) indicator is binary variable. It is given a 1 if the DRS scheme is enforced, otherwise it takes the value of 0. The value is then multiplied by 6 to generate the indicator score. It is a qualitative variable.	OECD\EEA database (http://www2.oecd.org/ecoinst/queries/)

ELV NOX indicator	The indicator represents the maximum concentration of nitrogen dioxide (Nox) emissions for a large, newly built coal-fired powerplant. The lower the value the more stringent the policy. The raw values are mg/ m3.	• Protection of the Environment Operations (Clean Air) Regulation 2010, schedule 3;
		• ENVIPOLCON;
		• IEA Clean Coal Centre http://www.iea-coal.org.uk;
		• IED, annex V, part 2;
		• National Emission Guidelines for Thermal Electric Power Generation -New Sources May 1993;
		• New Source Emission Guidelines for Thermal Electricity Generation;
		• REGULATION 496/07 CESSATION OF COAL USE — ATIKOKAN, LAMBTON, NANTICOKE AND THUNDER BAY GENERATING STATIONS;
		• Popp 2004;
		• The impacts of the SOx charge and related policy instruments on technological innovation in Japan;
		• IEA (http://www.iea.org/policiesandmeasures/);
		• IEA coal portaria 282/93;
		• 338 V Y H L Á Š K A Ministerstva životného prostredia Slovenskej republiky z 23. júla 2009, ktorou savykonávajú niektoré ustanovenia zákona o ovzduší (pag 28);
		• RS 814.318.142.1, Annex 2, chap 511;
		• Resmi Gazete Tarihi: 08.06.2010 Resmi Gazete Sayısı: 27605, BÜYÜK YAKMA TESİSLERİ YÖNETMELİĞİ BİRİNCİ BÖLÜM Amaç, Kapsam, Dayanak ve Tanımlar Amaç , annex 1;
		• NSPS, 60.42Da;
		• WSG: News Alert: New Regulations on Air Pollution http://www.worldservicesgroup.com/publications.asp?action=article&artid= 4075;
		• Study on Atmospheric Emissions Regulations in APEC Economies and Their Compliance at Coal-Fired Plants: http://www.egcfe.ewg.apec.org/publications/proceedings/EGCFE/AtmosphericEmissionsRegulations_Study_1997.pdf;
		• Status of Fuel Quality and Vehicle Emission Standards: Latin America and the Caribbean: http://www.unep.org/transport/pcfv/PDF/Maps_Matrices/LAC/matrix/LAC_combined_March2012.pdf;
		• Estonia: Narva Power: Environmental Issues Associated with Narva Power Plants: Executive Summary: http://www.ebrd.com/pages/project/eia/narva.pdf;

ELV SOX indicator	The indicator represents the maximum concentration of sulphur dioxide (SOx) emissions for a large, newly built coal-fired powerplant. The lower the value the more stringent the policy. The raw values are mg/m3.	• NOM-085-1994: http://www.aguascalientes.gob.mx/proespa/pdf/NOM-SEMARNAT-085%20EMISIONES%20A%20LA%20ATM%C3%93SFERA.pdf;
ELV PM indicator	The indicator represents the maximum concentration of particulate matter (PM) emissions for a large, newly built coal-fired powerplant. The lower the value the more stringent the policy. The raw values are mg/m3.	• NOM-085-2012: http://dof.gob.mx/nota_detalle.php?codigo=5232012&fecha=02/02/2012

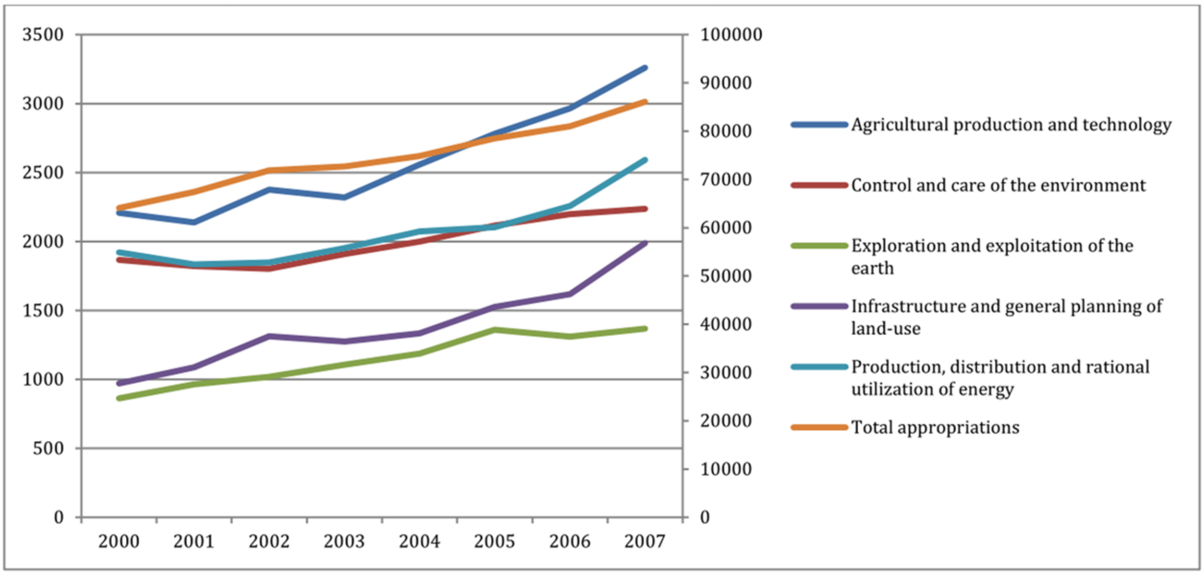
Source: https://www.oecd.org/eco/growth/EPS%20Indicator_Data.xlsx

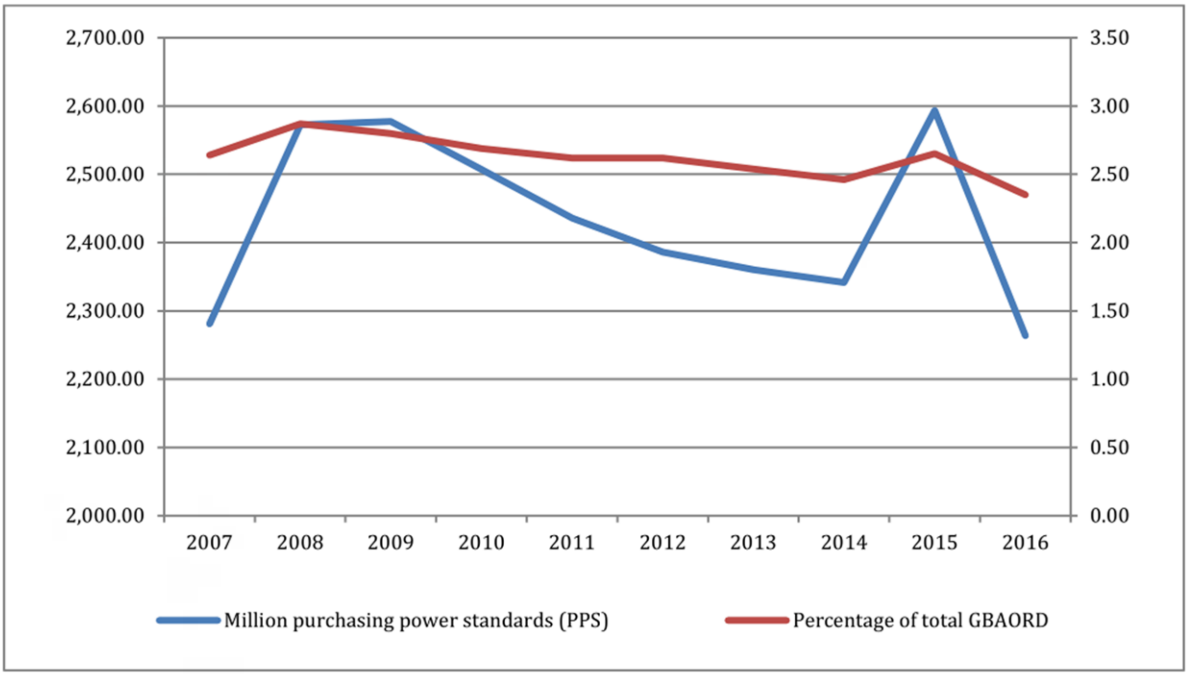
Table A4.2 Sustainability Transitions and Innovation Review (STIR)

STIR - Environmental policy stringency
Discuss referring to evidence (500 words)
Public policy protects the environment and enhances eco-system services
10 - 8: The country has a policy and regulatory framework ensuring the protection of nature and improvement of eco-system services. The framework is based on scientific evidence, and takes a full account of the state of local and global ecosystems. The policy goes beyond obligations stemming from international agreements. While eco-innovation is at the core of the transition policy, all public support for innovation has to recognise the importance of the precautionary principle in order to avoid pursuing innovation pathways that present a considerable environmental and social risks.
7 -5: The country has a policy and regulatory framework ensuring the protection of nature and eco-system services. The framework is based on scientific evidence. The policy complies with obligations stemming from international agreements. Precautionary principle is used in taking policy decisions, however, economic benefits are often considered a priority, and seen as an opportunity to compensate for possible negative environmental impacts.
4-2: The country runs environmental policy with formal objectives to ensure the protection of nature. The policy is largely reactionary and focuses on the acute environmental problems. There is limited use scientific evidence in designing the environmental policy. The policy formally complies with obligations stemming from international agreements, but their implementation is partial.
1: The country runs a rudimentary environmental policy with formal objectives to protect the nature. The country, however, does not provide a legally binding framework for environmental protection and lacks the implementation capacity.
- 0: N/A
Reference data
SGI network indicators - environmental policy (**http://www.sgi-network.org/2016** and **http://www.sgi-network.org/docs/2016/thematic/SGI2016 Environment-pdf**) - OECD database on environmental policy (**http://www2.oecd.org/ecoinst/queries**); LSE Grantham's Global Climate Legislation Database (**http://www.lse.ac.uk/GranthamInstitute/legislation/the-global-climate-legislation-database/**) -EUROSTAT data on implementation of environmental legislation (EU)

ANNEXES - Annex Chapter 5

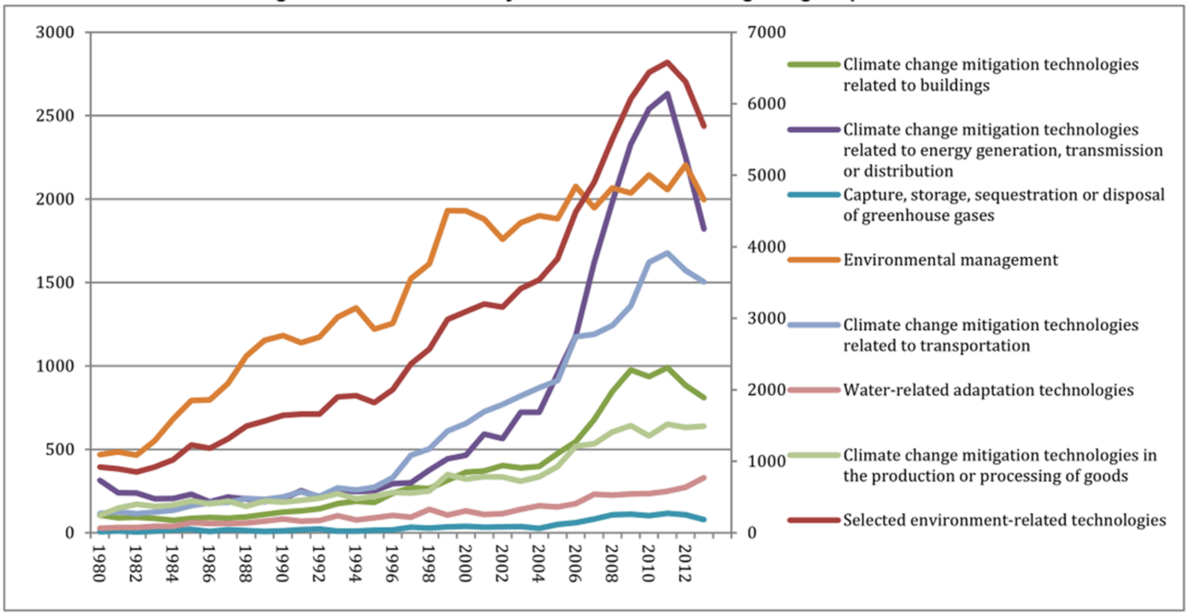
Figure A5.1 – Government Budget Appropriations on R&D (GBARD) trends for the EU-27 (Million purchasing power standards (PPS) and Percentage of total GBAORD (NABS1992)





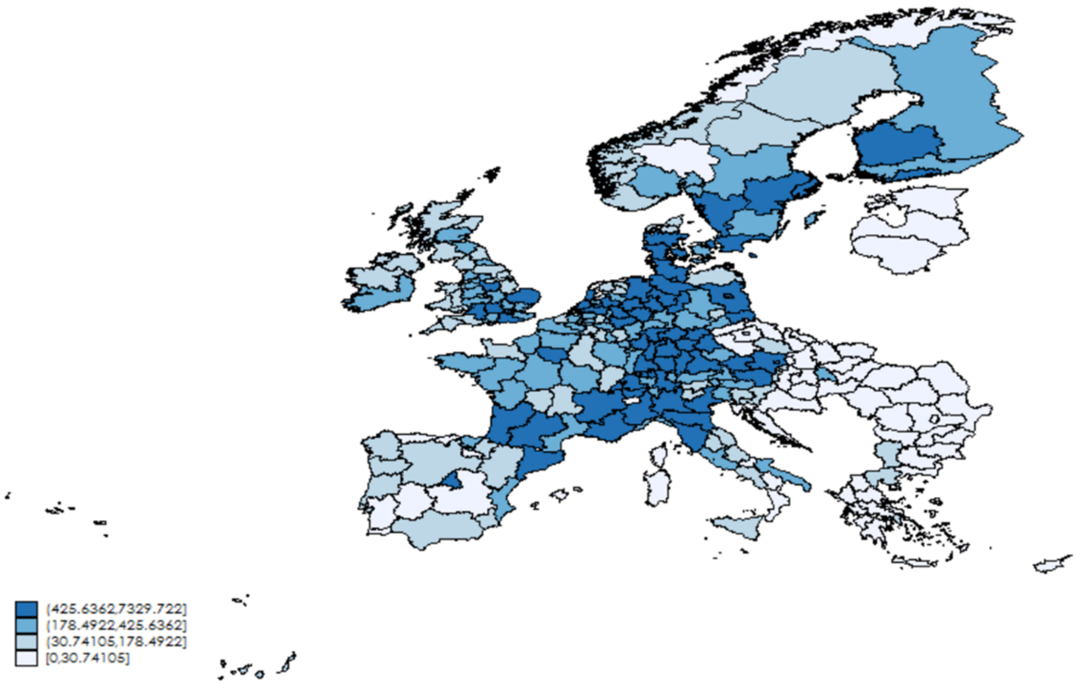
Source: Eurostat (November 2017)

Figure A5.3 – Patents by ENV-TECH technological group EU-28



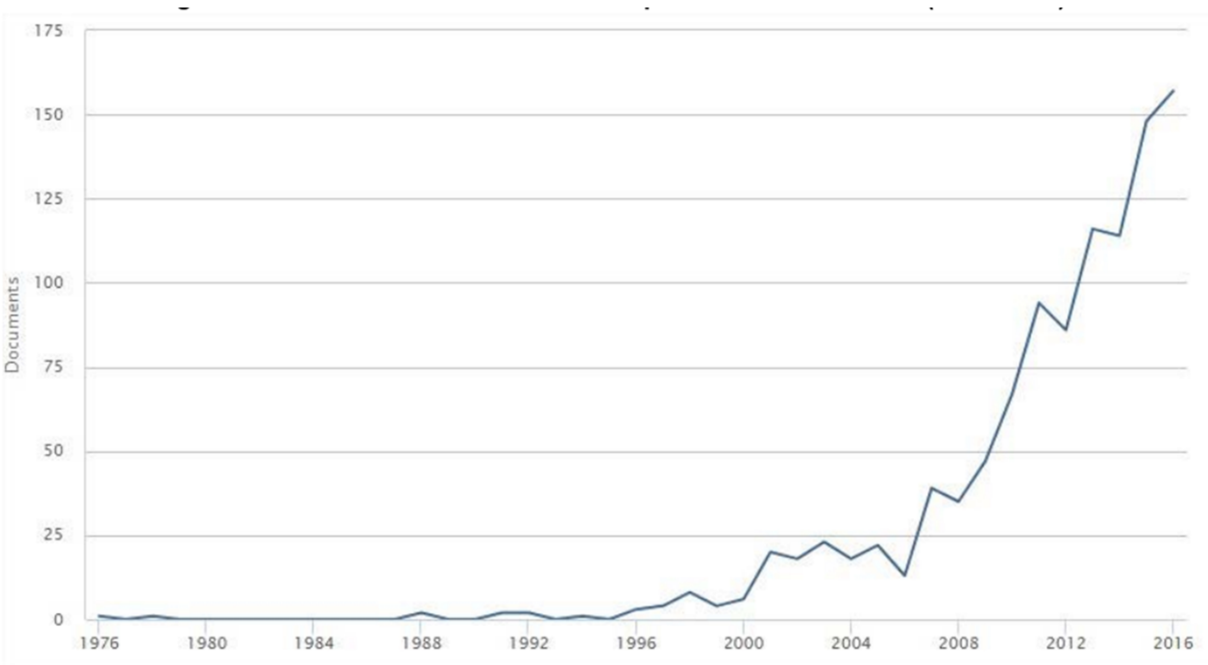
Source: OECD (2017)

Figure A5.4 – Geographical distribution of green patents fractional count at NUTS2 (1980-2012)



Source: Authors' elaboration from PATSTAT 2016

Figure A5.5 – Number of environmental publications over time (1976-2016)



Source: Authors' elaboration from Scopus

Foreign Direct Investment (FDI) as Inputs

Table A5.1- Green Foreign Direct Investment – Definitions and Measures

Source	Term	Definition and Measures	Calculated Amount
UNCTAD Roundtable Note (2008)	Low-carbon FDI	(1) FDI that applies higher environmental standards than required by host-country law (2) FDI into production of EGS	n.a.
UNCTAD (UNCTAD, 2010)	Low-carbon FDI	Greenfield FDI in renewable energy, recycling activities and low-carbon technology manufacturing. Consists of transfer of technologies, practices or products by MNEs to host countries – through equity FDI and non-equity forms of participation – such that their own and related operations, as well as use of their products and services, generate significantly lower GHG emissions than would otherwise prevail in the industry under business-as-usual circumstances.	US$90 billion (2009) US$82 billion (2016)
OECD (Golub et al. , 2011)	Green FDI	FDI in Environmental Goods and Services (EGS), proxy by FDI in electricity, gas and water sectors.	US$41 billion (2005-2007 average)
OECD Policy Framework for Investment (2015)	Green FDI	(1) Green infrastructure or greening of existing infrastructure (2) Sustainable management of natural resources and services they provide (3) Activities in EGSS and across green value chains	n.a.
fDi Intelligence (fDi Intelligence, 2016)	FDI in Renewa-ble Energy	Greenfield FDI in solar, wind, biomass, hydroelectric, geothermal, marine and other renewable power generation	US$76 billion (2015)
Bloomberg New Energy Finance Bloomberg New Energy Finance (2017)	Green FD Investment	Global investment in clean energy, low carbon services and energy smart technologies. Greenfield and M&A activity in renewables (e.g., biofuels, small hydro, wind and solar), clean energy services (e.g., carbon markets), and energy smart technologies (e.g., digital energy, energy efficiency, and energy storage)	US$287 billion greenfield FDI (2016
Related concepts			
System of Environmental-Economic Accounting: Central Framework (CF) EGSS	EGSS	Goods and services produced for (1) environmental protection and (2) resource management	
Climate Bonds Initiative	Climate Bonds	List of 47 investment areas in eight sectors (energy, transport, water, low carbon buildings, ITC, waste and pollution control, nature based assets, industry and energy-intensive com-mercial), with specific criteria for certification.	
Green Bond Principles, 2016	Green Bonds	Recognizes several broad categories of projects eligible for funding from green bonds. The-se categories include, but are not limited to renewable energy; energy efficiency; pollution prevention and control; sustainable management of living natural resources; terrestrial and aquatic biodiversity conservation; clean transportation; sustainable water management; climate change adaptation; eco-efficient products, production technologies and processes.	
Government Policies	Measures to attract green FDI	Means used by governments to attract Green FDI	

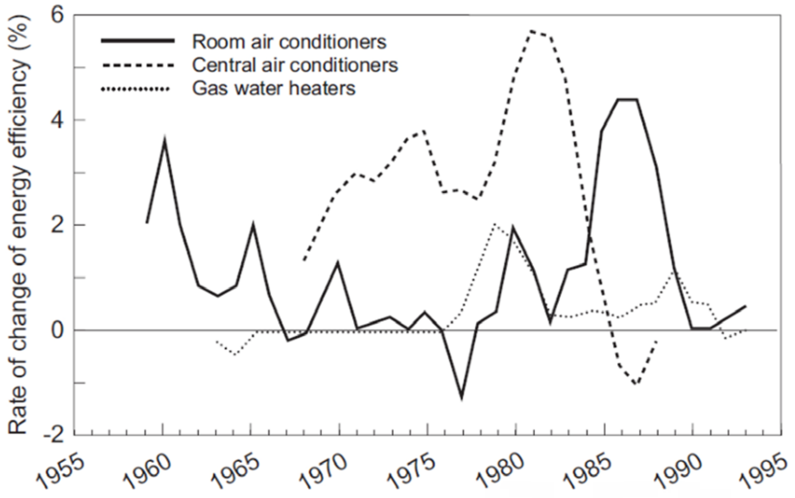
Source: Authors' compilation

Table A6.1 Eco-innovation outcomes (trade-related outcomes)

Indicator
· Exports of products from eco-industries (% of total exports) (Source: Eco-Innovation Scoreboard)
· Trade balance of environmental goods and services sector (EGSS)
· Trade balance of eco-industries (Source: Eco-Innovation Scoreboard)

Source: Authors' compilation

Figure A6.1 Three-year moving average of the annual rate of change of mean energy efficiency of product models offered for sale in the USA.



Source: Newell et al. (1999)

Table A7.1 - OECD Green Growth Indicators (environmental only)

Green Growth Indicators	Variable	Unit
Environmental and resource productivity		
CO2 Productivity	Production-based CO2 productivity, GDP per unit of energy-related CO2 emissions	US dollars per kilogram, 2010
	Production-based CO2 intensity, energy-related CO2 per capita	Tonnes
	Production-based CO2 emissions, index 2000=100	Index, 2000=100
	Production-based CO2 emissions	Tonnes, Millions
	Demand-based CO2 productivity, GDP per unit of energy-related CO2 emissions	US dollars per kilogram, 2010
	Demand-based CO2 intensity, energy-related CO2 per capita	Tonnes
	Demand-based CO2 emissions, index 2000=100	Index, 2000=100
	Demand-based CO2 emissions	Tonnes, Millions
Energy productivity	Energy productivity, GDP per unit of TPES	US Dollar, 2010
	Energy intensity, TPES per capita	Tonnes of oil equivalent (toe)
	Total primary energy supply, index 2000=100	Index, 2000=100
	Total primary energy supply	Tonnes of oil equivalent (toe), Millions
	Renewable energy supply, % TPES	Percentage
	Renewable electricity, % total electricity generation	Percentage
	Energy consumption in agriculture, % total energy consumption	Percentage
	Energy consumption in services, % total energy consumption	Percentage
	Energy consumption in industry, % total energy consumption	Percentage
	Energy consumption in transport, % total energy consumption	Percentage
	Energy consumption in other sectors, % total energy consumption	Percentage
Non-energy material productivity	Non-energy material productivity, GDP per unit of DMC	US dollars per kilogram, 2010
	Biomass, % of DMC	Percentage
	Non-metallic minerals, % of DMC	Percentage
	Metals, % of DMC	Percentage
	Municipal waste generated, kg per capita	Kilograms per capita
	Municipal waste incinerated, % treated waste	Percentage
	Municipal waste recycled or composted, % treated waste	Percentage
	Municipal waste disposed to landfills, % treated waste	Percentage

Natural asset base		
Freshwater resources	Total freshwater abstraction per capita	Cubic meters per capita
	Water stress, total freshwater abstraction as % total available renewable resources	Percentage
	Water stress, total freshwater abstraction as % total internal renewable resources	Percentage
Land resources	Arable and cropland, % total land area	Percentage
	Pastures and meadows, % total land area	Percentage
	Forest, % total land area	Percentage
	Other land, % total land area	Percentage
Forest resources	Forest resource stocks	Cubic meters, Millions
	Forests under sustainable management certification, % total forest area	Percentage
Environmental dimension of quality of life		
Exposure to air pollution	Mean population exposure to PM2.5	Micrograms per cubic meter
	Percentage of population exposed to more than 10 micrograms/m3	Percentage
	Percentage of population exposed to more than 35 micrograms/m3	Percentage
	Mortality from exposure to PM2.5	Per 1 000 000 inhabitants
Access to drinking water and sewage treatment	Population with access to improved drinking water sources, % total population	Percentage
	Population with access to improved sanitation, % total population	Percentage
Economic opportunities and policy responses		
Technology and innovation: Patents	Development of environment-related technologies, % all technologies	Percentage
	Relative advantage in environment-related technology	Ratio
	Development of environment-related technologies, % inventions worldwide	Percentage
	Development of environment-related technologies, inventions per capita	Number
Environmental taxes and transfers	Environmentally related taxes, % GDP	Percentage
	Environmentally related taxes, % total tax revenue	Percentage
	Energy related tax revenue, % total environmental tax revenue	Percentage
	Road transport-related tax revenue, % total environmental tax revenue	Percentage
	Fossil fuel consumption support, % energy related tax revenue	Percentage
	Fossil fuel consumption support, % total tax revenue	Percentage
	Fossil fuel consumption support, % total fossil fuel support	Percentage
	Fossil fuel production support, % total fossil fuel support	Percentage
	Fossil fuel general services support, % total fossil fuel support	Percentage
	Petroleum support, % total fossil fuel support	Percentage
	Coal support, % total fossil fuel support	Percentage
	Gas support, % total fossil fuel support	Percentage
	Total fossil fuel support, % of total tax revenue	Percentage

Source: http://stats.oecd.org/Index.aspx?DataSetCode=green_growth

Table A7.1 - OECD Green Growth Indicators (environmental only)

Quality of Life Indicators		
Dimension	**Indicator**	**Source**
1. Material living conditions	Median income	EU-SILC. yearly
	S80/S20 (inequality of income)	EU-SILC. yearly
	Severe deprivation rate	EU-SILC. yearly
2. Productive or other main activity	Employment rate	EU-LFS; yearly
	Job satisfaction	EU-SILC ahm 2013
3. Health	Life expectancy	Demography, yearly
	Self-perceived health status	EU-SILC. yearly
4. Education	Tertiary educational attainment	EU-LFS. yearly
5. Leisure and social interactions	Satisfaction with time use	EU-SILC ahm 2013
	Help from others	EU-SILC ahm 2013
6. Economic and physical security	Inability to afford unexpected expenses	EU-SILC. yearly
	Homicide rate	Police records, yearly
	Perception of crime, violence or vandalism in the living area	EU-SILC. yearly
7. Governance and basic rights	Trust in the legal system	EU-SILC ahm 2013
8. Natural and living environment	Urban pollution	EEA. yearly
	Perception of pollution, grime or other environmental problems in the living area	EU-SILC. yearly
9. Overall experience of life	Life satisfaction	EU-SILC ahm 2013

Source: http://ec.europa.eu/eurostat/web/products-statistical-reports/-/KS-FT-17-004

Data sources of the Environmental Performance Index (EPI) of Yale University and the Sustainable Governance Indicators (SGI) of Bertelsmann Stiftung

The Environmental Indicators and Data sources of EPI are: for Black Carbon emissions: Emissions Database for Global Atmospheric Research; CO2 emissions - Total: World Resources Institute – Climate Analysis Indicators Tool; CO2 emissions: World Bank , Taiwan EPA ; CO2 emissions per kWh of electricity and heat: International Energy Agency; CH4 emissions: World Resources Institute – Climate Analysis Indicators Tool , World Bank , Taiwan EPA; N2O emissions: World Resources Institute – Climate Analysis Indicators Tool , World Bank ; NOX emissions: Emissions Database for Global Atmospheric Research; DALY rate for Lead exposure: Institute for Health Metrics and Evaluation ; DALY rate for Household Solid Fuels: Institute for Health Metrics and Evaluation; DALY rate for Unsafe Drinking Water: Institute for Health Metrics and Evaluation; Ambient PM2.5 concentrations: Atmospheric Composition Analysis Group, Dalhousie University ; SO2 emissions: Emissions Database for Global Atmospheric Research ; Annual loss of forested land: Global Forest Watch).

The Environmental Indicators and Data sources of SGI are: for Greenhouse gas emissions, tonnes in CO2 equivalents per capita, including land use, land-use change and forestry and indirect CO2) from OECD Online Database, World Bank and World Development Indicators; Particulate Matter (Particulate matter, PM2.5, proportion of the population whose exposure is above WHO threshold 15 micrograms/m3) from OECD Online Database; Water Usage (Gross freshwater abstractions per capita) from OECD Online Database, Eurostat Online Database, World Bank, World Development Indicators; Waste Generation (Municipal waste, generation intensities kg/capita) from UNSD Environmental Indicators and Selected Time Series; and Energy Productivity (GDP in US-$ (constant 2011 PPP) per ktoe primary energy supply) from IEA CO2 Emissions Highlights.

Annex Chapter 8

Notes on Composite and Synthetic Indicators

In measurement literature, a variable is a constructed measure stemming from a process that represents, at a given point in space and time, a shared perception of a real-world state of affairs consistent with a given individual indicator (OECD, 2008). The term indicator is reserved for observable or directly measurable variables. An individual indicator is used as a basis for evaluation in relation to a given objective, where any objective may imply a number of different individual indicators, each indicating its desirability according to expected consequences related to the objective.

A composite indicator is an aggregate of all dimensions, objectives, individual indicators and variables used, and thus is a set of properties underlying its aggregation convention (OECD, 2008).

A composite indicator can encompass synthetic indicators where synthetic indicators technically (but not necessarily conceptually) condense several indicators into one single indicator, and can be called a synthetic index. In this respect there are many overlaps between composite and synthetic indicator approaches as the borderline between is blurred (OECD, 2008). Yet ideally, a composite indicator should be based on a theoretical framework, definition, which allows indicators to be selected, combined and weighted in a manner that reflects the multi-dimensional structure of the phenomena being measured (OECD, 2004).

The construction of neither composite indicators nor synthetic indicators is a straightforward process. It involves both conceptual and technical assumptions which have to be carefully assessed to avoid resulting in a product of dubious analytic rigour (OECD, 2008). Yet multidimensional concepts like welfare, well-being, human development, environmental sustainability, industrial competitiveness, cannot be adequately represented by individual indicators. Therefore, composite indicators are becoming increasingly acknowledged as a useful tool for summarizing complex and multidimensional issues (Rovan, 2011).

Key References on Composite Indicators

OECD (2004). “The OECD-JRC Handbook on Practices for Developing Composite Indicators”, paper presented at the OECD Committee on Statistics, 7-8 June 2004, OECD, Paris.

OECD. (2008). Handbook on constructing composite indicators: Methodology and user guide.

Rovan J. (2011) Composite Indicators. In: Lovric M. (eds) International Encyclopedia of Statistical Science. Springer, Berlin, Heidelberg

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Web: www.inno4sd.net
General enquiries: info@inno4sd.net
Twitter: @inno4sd
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