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Assessing environmental impacts of Research and Innovation Policy

Research and Innovation

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A SHORT GUIDE TO ASSESSING ENVIRONMENTAL IMPACTS OF RESEARCH AND INNOVATION POLICY

TABLE OF CONTENTS

1. LINKING RESEARCH AND INNOVATION POLICY TO ENVIRONMENTAL IMPACTS 2

1.1 What is research and innovation policy? 2

1.1.1 Effects of R&I policy 3

1.1.2 Determinants of impacts of R&I policy 4

1.2 What are environmental pressures and impacts? 5

1.2.1 Introducing environmental pressures and impacts 5

1.2.2 Measuring environmental pressures and impacts 8

1.3 How to connect R&I policy effects to environmental pressures and impacts? 10

1.3.1 Qualitative impact pathways 10

1.3.2 Constructing methodologies and selecting methods of IA 17

2. ENVIRONMENTAL DIMENSION IN THE ANALYTICAL STEPS OF IMPACT ASSESSMENT 21

2.3.1 Ex-ante impact assessments 24

2.3.2 Ex-post impact assessments 30

GENERAL MESSAGES 33

REFERENCES 35

TABLE OF FIGURES

FIGURE 1. Main components of the IA framework......................2

FIGURE 2. Main environmental impact categories......................7

FIGURE 3. Main indicators of environmental pressures.............8

FIGURE 4. Main indicators of environmental impacts...............9

FIGURE 5. The IA canvas: extended visualisation of the IA framework...12

FIGURE 6. The IA canvas: two examples of instrument-level impact pathways.................................14 – 15

FIGURE 7. Using IA canvas for illustrating cumulative R&I impact pathways 16

FIGURE 8. Linking R&I policy effects and environmental assessment methods..................................... 18-20

FIGURE 9. Impact asessment cycle 21

FIGURE 10. Environmental dimension of the impact assessment cycle 23

FIGURE 11. Policy intervention and levels of IA 24

FIGURE 12. Methodology of impact assessment applied by the Green Investment Bank (GIB), UK.........................25

FIGURE 13. Assessment criteria used in (ex-ante) IA using RIAM method..27

FIGURE 14. Indicators collected for monitoring and IA of the Dutch EET programme 29

FIGURE 15. “Technology tracking” system of the AMO 32

ABOUT THIS GUIDE

IMPACT ASSESSMENT (IA) is a routine practice at the European Commission. In its Impact Assessment Guidelines (EC 2009), the Commission calls for an integrated approach taking into account various dimensions of impacts, notably economic, social and environmental implications of planned public interventions. This publication responds to the need to better account for environmental impacts in assessing research and innovation policy. The guidebook complements the official EC guidelines by focusing on the specific challenges and methodological issues of accounting for environmental impacts in IA. The publication extends the scope of the guidelines by considering both ex-ante and ex-post assessments.

THE PUBLICATION is addressed primarily to the EC officials and IA practitioners involved in the EC impact assessments of research and innovation policy. The overall approach proposed in the guidebook may be of interest also for national, regional or even local governments and practitioners conducting integrated IAs of R&I policies.

THE GUIDEBOOK tackles the difficult task of combining various traditions of research and different approaches to IA. The framework connects methods known and used in social science research with evidence and approaches of the natural and concrete sciences. This suggests that the IAs should be not only integrated but trans-disciplinary efforts bringing diverse expertise around the table. This publication should be seen as a modest step in establishing coherent IA framework making use of best available knowledge and evidence from all relevant disciplines.

THE GUIDE provides an original framework and methodological advice on how to identify, scope and assess the environmental pressures and impacts of research and innovation policy. The central assumption in the overall framework is that any integrated assessment seeking to identify and measure environmental impacts of R&I need to be based on a robust understanding of the socio-economic effects of public intervention. Without evidence on how fast innovative products diffuse in society and how they are used, for example, we cannot estimate their environmental impact. The central element of the guide is the notion of impact pathways allowing for the scoping of challenging IA assignments in which the link to the environment may seem remote at first sight. The publication features an innovative IA tool – the IA canvas – used to visualise impact pathways.

THE PUBLICATION OFFERS GUIDANCE ON THE FOLLOWING QUESTIONS:

- How to identify, scope and assess impacts of R&I policy relevant to the environment;
- How to account for environmental impacts in the analytical steps of ex-ante and ex-post IA;
- How to identify and measure environmental pressures and impacts of R&I:
  - How to establish impact pathways between R&I policy and environmental impacts;
  - How to identify and assess external determinants of impacts;
  - How to classify and measure environmental pressures and impacts, including examples of methodologies and methods, indicators and sources of data.

THE GUIDEBOOK COMPRISES TWO MAIN SECTIONS:

- Section I "Linking research and innovation policy environmental impacts" introduces an overall IA methodological approach to identify, scope and attribute environmental impacts to research and innovation policy. It also presents a short review of methodologies and metrics that can be used in IA practice to measure the environment-related outcomes and impacts of R&I policy.
- Section II "Environmental dimension in the analytical steps of Impact Assessment" introduces the step-wise approach to IA and highlights main environmental questions in the analytical steps of ex-ante and ex-post IA.

THE PUBLICATION IS A DIGEST OF A MORE EXTENSIVE IA GUIDEBOOK featuring detailed methodological material, practical examples of IA methods and further reading sections on various aspects of assessing environmental impacts of research and innovation policy. The full version of the guidebook can be downloaded from http://europa.eu/!Xm84ND.

1. LINKING RESEARCH AND INNOVATION POLICY TO ENVIRONMENTAL IMPACTS

THIS GUIDE introduces a framework that focuses on the direct and indirect links between public intervention in research and innovation (R&I) with environmental pressures and impacts. The underlying assumption of the methodological framework is that in order to attribute environmental impacts to public intervention in R&I, there is a need to identify relevant tangible and intangible outcomes and socio-economic impacts of R&I policy. The latter lead (directly or indirectly) to environmental pressures and impacts.

THE KEY COMPONENTS OF THE FRAMEWORK INCLUDE:

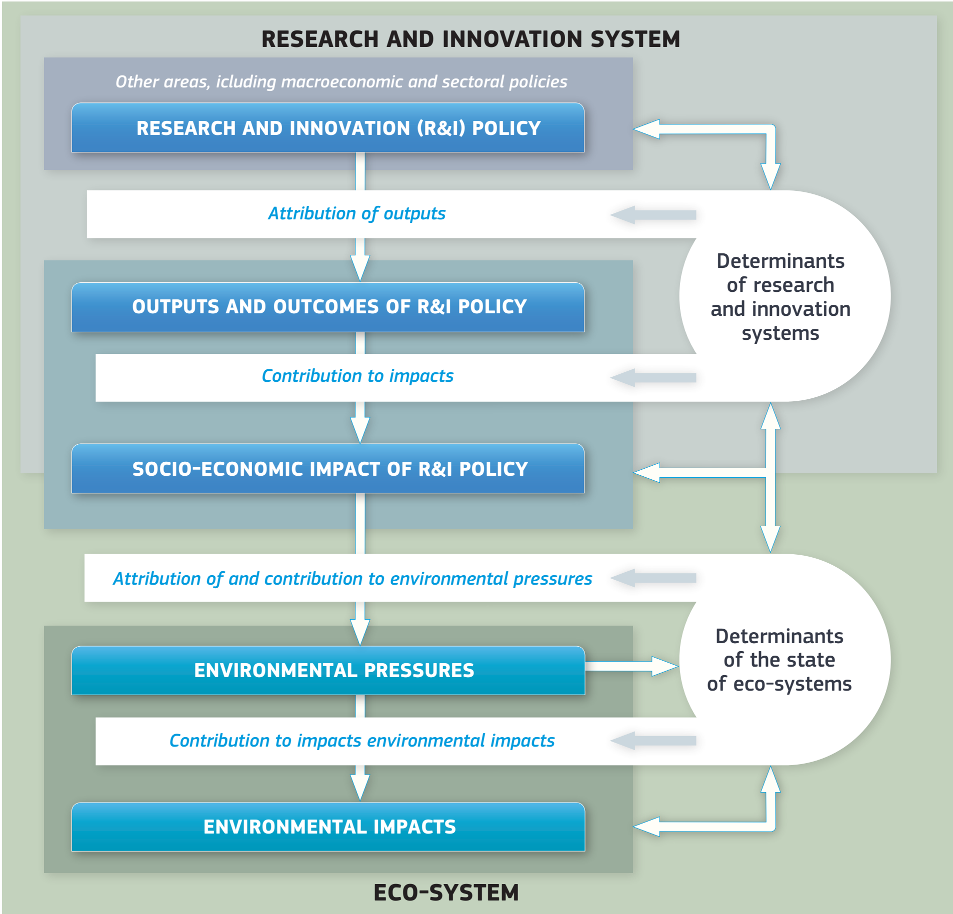
- Public intervention in R&I;
- Outputs, outcomes and impacts of R&I policy;
- Environmental pressures and impacts of R&I policy;
- Causal mechanisms and impact pathways (attribution and contribution claims);
- Determinants, including market forces and framework conditions, influencing outcomes and impacts of R&I policy and their environmental impacts.

FIGURE 1 introduces the overall logic of the IA framework.

1.1 WHAT IS RESEARCH AND INNOVATION POLICY?

Research and innovation policy supports a range of activities from blue-sky research to providing direct and indirect support to technology diffusion. The rationale behind the public intervention in research and innovation (R&I) lies in the presence of market failures that hamper private investments in socially desirable research and innovation and "systems failures" that impede creativity, effectiveness and efficiency of research and innovation systems.

FIGURE 1. Main components of the IA framework



The limited consideration of the environment in R&I or the negative environmental impacts of R&I are examples of both market and systems failures. The rationale of a sustainable R&I policy incorporates the dimension of economic, social and environmental impacts. In response to failures, the policy strives to ensure that its outcomes and impacts contribute to or at the very least do not impede the long-term sustainability. Environmental impacts are not considered "external" but are either addressed as a problem or are purposefully avoided.

The need for public support of R&I also derives from the system nature of innovation. The system model emphasises that the performance of the economy depends also on the linkages and flows of information and knowledge between the different actors in the innovation system. The different parts of the system are in many respects interdependent, hence the poor performance of any one component puts the performance of the system as a whole at risk. For instance, market take-up of new mobility schemes, like car sharing, is of a systemic nature and will not happen if they are not addressed in relation to availability public transport infrastructure and city planning (e.g. changes in parking facilities and fees). The public sector often has to take the lead in addressing such "bottlenecks" – continuously identifying and rectifying structural imperfections by supporting coordination of effort, promoting division of labour and agenda-setting, investing in human capital and networks to ensure the absorption of knowledge.

1.1.1 EFFECTS OF R&I POLICY

FROM INPUTS TO IMPACTS

Measuring impacts of policy intervention is performed in order to establish whether and to what extent the intervention is contributing to the specific and overall objectives set out by policy makers. In order to draw lessons for better policy design, evaluation and impact, assessment should cover both intended and unintended outcomes and impacts of policies.

In terms of effects of a policy intervention, IA studies differentiate between different effects that range from short-term outputs, being direct "products" of an intervention, to wider impacts on societies, economies and environment. While outputs can be directly attributed to policy intervention, impacts are longer-term and indirect effects of policies. Impacts are often studied at the level of entire economies and societies in which policies are but one of driving forces. Any IA study has to introduce a dimension of input: that is, of what has been invested or mobilised in order to achieve intended effects.

This guide is based on the following understanding of inputs and effects of policy intervention:

- Input: resources mobilised for the implementation of a policy intervention; resources comprise e.g. funding, personnel, infrastructure as well as natural resources;
- Output: product or service produced as a direct output from policy intervention; outputs are typically short-term and are intended to lead to results and contribute to intended long-term impacts);
- Outcome: results of policy intervention contributing to achieving overall objectives of policy; as such they to lead to desired changes that initially motivated policy intervention;
- Impact: typically long-term changes a policy intervention contributes to (impacts can be analysed in many dimensions including socio-economic, technological, cultural, political or environmental). Depending on when they occur, impacts can range from short- to long-term.

CLASSIFYING OUTCOMES AND SOCIO-ECONOMIC IMPACTS OF R&I

This guide proposes a simple classification of main types of outputs, outcomes and socio-economic impacts of supported research and innovation activities. Understanding the nature of effects of R&I policy will allow to create a link between the dimension of socio-economic impacts and environmental pressures and impacts.

Typical outputs and outcomes of R&I policy interventions can be grouped in three broad types including new or modified:

- Knowledge;
- Individual and social practices;
- Products, technologies or infrastructures.

New or modified knowledge is an essential outcome of R&I policy. Knowledge comes in many forms. It can be theoretical or applied. It can be explicit (codified and transferable) or tacit (informal and intuitive). Knowledge can be generated, modified and diffused. Knowledge is created in a social process of interaction and learning between many actors. It is the mix of old and new, implicit and explicit knowledge that is most likely to influence new policies, practices or products.

New or modified social practices and new forms of organisation comprise the second broad type of outcomes. Put simply, this type focuses on R&I outcomes that influence behaviour and forms of organisation of people. One can differentiate between changes at the individual (i.e. consumer, household), organisational (i.e. company) or, more broadly, societal level (e.g. social group).

New or modified products, technologies or infrastructures are most common tangible effects of innovation policies. The types of related outcomes can range from developing and testing a product prototype, through introducing a new technology to the market, to supporting a wide diffusion of existing technologies.

Outcomes of R&I policy are expected to contribute to wider socio-economic impacts. This guide scopes the impact into five areas:

- Knowledge production and learning system;
- Policy, regulation and governance system;
- Social practice and consumption patterns;
- Production system and business models;
- Technical infrastructures and built environment.

Knowledge production and learning system refers to a system where individuals and organisations engage in collective processes of learning and knowledge production. The system includes both public and private actors and formal and informal exchanges between them. Wider changes in this area may occur in relation to new knowledge generated with support of R&I policy or with new practices. Influencing this system is one of the key overall objectives of R&I policy, as exemplified by the EU support for the ERA

The second type of impacts of R&I policy are in the area of policies, regulation and governance. Policies and strategies may be influenced by many factors. Outputs and outcomes of R&I policy may influence public strategies and policies by pointing to new evidence about social or economic processes (e.g. highlighted in a new study) as well as by mobilising the emergence of new visions of economic and social development (e.g. foresight exercises). Modified or new policies may in turn influence products and practices of economic and social actors. Regulation and standards, for example, have a direct impact on product design and research and innovation activites of the whole industries.

Social practice and consumption patterns relate to the dimension of individual and social practices and consumption patterns in societies. This includes relations between individuals and organisations, but also between individuals and organisations and artefacts (e.g. products and infrastructures) and between individual and organisation and nature. The latter is especially relevant for environmental impacts. Policy intervention on waste, for example, may foster new processes in companies. High prices or bans on certain waste streams may lead firms to introduce new processes and practices (e.g. material substitution) and forms of organisation (e.g. new collaborations). R&I polices may lead to widely-disseminated new practices in households. This can be linked with dissemination of new knowledge (e.g. on daily hygiene) or specific technology (e.g. ICT). Behavioural changes are rarely determined by policies alone. In general, we can observe that over time, a bundle of policies and single events (e.g. outbreak of disease, natural or manmade catastrophe) contribute to a behavioural change.

The area of production system and business models concentrates on how the production system delivers value to users. This includes the production processes (e.g. design and manufacturing of products and technologies) as well as service systems associated with products. On the level of impacts, the focus is on how new or modified goods or services supported by R&I policy diffuse and whether and to what extent they substitute existing products, services or product-service systems (e.g. new mobility systems).

Technical infrastructures and built environment are closely related to the production system, but the focus is on how new or modified products (notably new materials and technologies) influence lasting infrastructures and the built environment. The area is introduced to emphasise the relevance of infrastructures for generating or avoiding environmental pressures and impacts.

1.1.2 DETERMINANTS OF IMPACTS OF R&I POLICY

Implementation of R&I policy does not occur in isolation. There are many factors and mechanisms that determine the outcomes and wider impacts of policy intervention. These factors can both enable or hinder intended and unintended effects of policy. The determinants of R&I policy and environmental impacts should be studied in a systemic way taking into account various relevant dimensions and time-horizons.

Determinants can be grouped in several dimensions following an extended STEEP* framework, including:

- Socio-cultural determinants
  - Knowledge and learning (capacity to learn and to generate knowledge)

*STEEP stands for Social, Technological, Economic, Environmental and Political and is typically used as an analytical structure for studying external factors that influence a studied phenomenon.

- Networking (ability to collaborate and capacity to take collective action)
- Organisational capacity (ability to create and manage organisations)
- Cultural aspects (including value systems influencing consumer behaviour, attitudes towards change and risk etc.)

- Technical and technological determinants (e.g. quality of technical infrastructures);
- Economic determinants (e.g. market position, demand, access to capital, resource prices);
- Environmental determinants (access to material and natural resources, the state of eco-systems);
- Policy and regulatory framework (including legal system, standards and norms, intellectual property rights, fiscal policies, public procurement).

There are different internal and external factors playing out at different stages of the intervention. Determinants play different role at micro- (e.g. a firm or a household), meso- (e.g. a sector or value chain) or macro-level.

Outputs, outcomes and wider impacts of policies are all to different extents dependent on internal and external determinants. The outputs are the most controllable effects of an intervention as they depend to a large extent on internal capacity (e.g. the competence of the research team, access to equipment or good management). Outcomes and wider impacts of policy intervention depend on external determinants to a larger extent. In general, the further away from immediate outputs, the stronger is the inter-dependence of what is intended to be an outcome of an intervention with the external determinants. External, by definition, is not fully controllable and, therefore, implies a degree of risk or uncertainty.

1.2 WHAT ARE ENVIRONMENTAL PRESSURES AND IMPACTS?

1.2.1 INTRODUCING ENVIRONMENTAL PRESSURES AND IMPACTS

The relationships between environmental pressures resulting from changes in human production and consumption activities and their impacts on the natural systems are manifold and complex. Importantly, human activities can be both harmful and favourable for the natural environment (i.e. they can generate or alleviate the pressures).

Economic activities in terms of production and consumption require inputs of natural resources (such as materials, energy, water and land) to maintain their functioning (input side). Extraction and processing of these natural resources create environmental pressures, such as material or water extraction or land use change. As a result of socio-economic activities, waste and emissions are released back to nature, also causing environmental pressures on the output side. Both resource extraction and generation of waste and emissions lead to a variety of environmental impacts, such as water scarcity or climate change. These various environmental impacts then have feedbacks to the economy and society, for example, in the form of negative impacts on human health or by necessitating investments into pollution abatement. This framework considers both environmental pressures and environmental impacts. Such a framework also allows us to consider life cycle thinking in the environmental assessment approach.

ENVIRONMENTAL PRESSURES

Four categories of environmental pressures are considered the most important:

- Materials as resource inputs and waste outputs;
- Water, including emissions to water;
- Land, including emissions to soils;
- Carbon and air emissions.

When evaluating the overall environmental consequences, it is important to pay particular attention to the inter-linkages between the categories. Only when all types of environmental

ENVIRONMENTAL PRESSURES

Pressures refer to developments in the use of natural resources (materials, energy, water, land) as inputs to human activities, as well as the release of substances on the output side (waste, GHG emissions, air and water pollution). These pressures exerted by society are transported and transformed in a variety of natural processes and cause changes in environmental conditions.

ENVIRONMENTAL IMPACTS

The changes in environmental conditions lead to impacts on the social and economic functions on the environment, such as the provision of adequate conditions for health, resources availability and biodiversity. Impacts often occur in a sequence: for example, GHG emissions cause global warming (primary effect), which causes an increase in temperature (secondary effect), leading to a rise of sea level (tertiary effect), finally leading to loss of biodiversity.

Adapted from: (EEA, 1999)

pressures are analysed in parallel within one framework can one avoid pursuing partial solutions, which minimise pressures in one category through shifting problems to another. This aspect is of particular importance when assessing the overall environmental effects of R&I projects, programmes and policies.

Materials

The category of materials comprises all renewable (biotic) and non-renewable (abiotic) material resources. Renewable materials are divided into the harvested products from agriculture, forestry and fishery. Non-renewable materials comprise fossil fuels, metal ores and industrial and construction minerals. A full material accounting balance comprises both the inputs of materials for production and consumption activities, as well as the production of waste on the output side. The unit of measurement for materials are mass units, e.g. kilogrammes for assessments on the product level and metric tonnes for assessments on the level of sectors and countries.

Water

The pressure category "water" refers to the uptake (abstraction) and consumption of water by human activities. Generally, two main types of water are distinguished: blue water resources, which refer to surface and ground water; and green water resources, which is the rainwater consumed by plants in agricultural production. In some concepts, grey water is also included as a third category, indicating the pollution of freshwater (Hoekstra and Mekonnen, 2012). Water use is measured in volume units, such as m^3 for national studies or litres for product studies. It is mostly expressed with regard to a certain time (e.g. water consumption per year) or in relation to a certain product (e.g. water footprint to produce one cup of coffee).

Land

Land cover and land use assessments illustrate the amount of land being appropriated for various human purposes. The total land area is disaggregated into various categories, including arable land for agricultural production, forest areas for timber extraction, pastures for grazing of animals, as well as various types of artificial surfaces used e.g. for mining of materials, infrastructure, manufacturing or private housing (EEA, 2010). It is also important to track the change of land cover, such as the spread of urban areas to the detriment of agricultural areas. Land-related assessments are measured in area units, such as km^2 or hectares for national studies or m^2 for product studies.

Carbon and air emissions

Activities that add greenhouse gases (GHGs, principally CO2, Methane, nitrous oxides and HCFCs) to the atmosphere induce climate change impact on a number of ecosystems, as well as having an effect on economic activities, health and the demands and supplies of energy. Overall emissions of GHGs are reported nationally by all European countries to the UNFCCC. In the context of R&I assessments, more important are the emissions by activity, measured in carbon dioxide equivalent terms, based on the current and proposed use of fossil fuels and technologies. The aim is to estimate life cycle emissions, i.e. from each stage of the production of the fuel through its use, to its final disposal. In addition to the emissions of greenhouse gases, activities that generate carbon are also activities that produce a number of local pollutants that damage human health, crops and materials. Other local pollutants that have a notable level of impacts through a number of complex chemical reactions include SOx, NOx and ozone. Estimates of life cycle emissions from different fossil sources and technologies and details of methodologies used are available (Markandya, 2010).

ENERGY
is not considered as a separate environmental pressure category. The reason is that the various environmental pressures generated by energy use are already covered by the other four categories: material aspects (e.g. fossil fuels or biomass) are covered as materials, aspects related to GHG emissions (from fossil fuel combustion or from land use change related to bio-energy production) are included in the carbon/emissions section, water and land requirements for bio-energy production are considered in the water and land categories.

ENVIRONMENTAL IMPACTS

Environmental assessments include a number of different environmental impact categories. In particular methodologies of Life Cycle Assessments (LCA) provide a comprehensive consideration of the various environmental impacts of production and consumption activities. Figure 5 provides a tentative clustering of the most common environmental impact categories, including short descriptions of the nature of each impact. Three areas can be identified, where impacts occur: they can negatively affect human health, the natural environment (ecosystems) and natural resources (Sala et al., 2012).

FIGURE 2. Main environmental impact categories

IMPACT CATEGORY	BRIEF DESCRIPTION OF IMPACT CATEGORY	HAS IMPACT ON:
Climate Change	The potential of environmental pressures exerted by GHG emissions (such as carbon dioxide from combustion of fossil fuels or methane from agricultural production) to cause changes in the temperature of the atmosphere and thus to contribute to climate change.	Human health Natural environment
Photochemical ozone creation	Photochemical ozone is created by radiation from the sun and some chemical substances, which result from incomplete combustion of fossil fuels (such as nitrogen oxides and hydrocarbons), leading to negative impacts on both human health and agricultural production.	Human health Natural environment
Ozone depletion	While photochemical ozone is created on ground levels, other ozone-depleting substances (such as CFCs and halons used in refrigerators) lead to stratospheric ozone depletion, which reduces the potential of the atmosphere to hold back harmful radiation, in particular ultra violet radiation, from space.	Human health Natural environment
PM, Respiratory emissions	Emissions of particulate matter as well as secondary particles resulting from chemical reactions with nitrates and sulphates are harmful to health. They are the by-product of combustion of fossil fuels	Human health
Ecotoxicity	Ecotoxicity is caused by persistent chemical substances, i.e. substances, which are not degradable by the natural systems and exert toxic effects. They include, for example, dioxins from waste incineration, asbestos from insulation materials and heavy metals from various products.	Human health Natural environment
Ionising Radiation	Ionising radiation can stem from both human sources, such as nuclear power plants, as well as natural sources, such as space radiation. The impact of exposure to radiation depends on the accumulated dosage derived from inhalation, water and food.	Human health Natural environment
Acidification	Acidification is caused by chemical substances (such as nitric acid or sulphuric acid, e.g. from electrolytes in lead-acid batteries and from cleaning agents) and can damage water bodies, fish stocks, soils and forests.	Natural environment
Eutrophication	Eutrophication occurs when excessive amounts of nutrients, such as nitrate or phosphate, reach ecosystems, e.g. through the application of fertilisers or sewage. This leads e.g. to “algae blooms” in waters.	Natural environment
Human toxicity	This aggregated impact category illustrates the negative health impacts on humans stemming from the emission of toxic chemicals and substances.	Human health
Abiotic resource depletion	Abiotic resource depletion refers to reductions in the available stocks of fossil fuels, metal ores and other minerals, potentially causing raw material shortages on markets and related price increases.	Natural resources
Water scarcity	Water scarcity occurs in a situation, where the abstraction of fresh water is exceeding the rate of renewal in the respective water body, leading to water shortages or droughts.	Natural resources
Land use competition	Land use competition is generally increasing and a result of multiple and growing demands, such as land for the production of food, feed, biofuels and biomaterials. This growing demand meets a limited stock of available productive land.	Natural resources
Loss of fertile land	Loss of fertile land, e.g. due to soil erosion, is one commonly observed result of land being used too intensively	Natural resources

Source: Adapted from Sala et al. (2012)

1.2.2 MEASURING ENVIRONMENTAL PRESSURES AND IMPACTS

The indicators that measure this pressure can be considered at three levels:

- The micro level, which covers two areas:
  - products or services where R&I can change environmental pressures per unit produced
  - individuals, households or organisations, where R&I may involve changes that alter the impact of households, consumers and other user institutions on the environment;
- The meso level (industries, value chains), where the R&I may change standards and practices;
- The macro level (countries, regions) where an aggregation of effects at the micro and meso -levels feed through to pressures that change national indicators of environmental pressure.

FIGURE 3 presents main indicators of environmental pressures currently being used for the three main levels of economic activities. The indicators vary in their degree of methodological refinement and standardisation. Indicators at the product and the national level are generally more advanced and more frequently applied than indicators at the level of households or industries. Note that most of the indicators take a life cycle perspective and thus are robust against dislocation of environmental burden, e.g. through outsourcing from one country to another.

FIGURE 3. Main indicators of environmental pressures

	MICRO LEVEL		MESO LEVEL	MACRO LEVEL
	PRODUCTS / SERVICES	CONSUMERS / HOUSEHOLDS / ORGANISATIONS	INDUSTRIES / VALUE CHAINS	COUNTRIES / REGIONS
Materials[1] (mass units: kg or tonnes)	Material Input per Service unit (MIPS)	Material use per consumer, household or organisation	Material use by industry	Domestic/Raw/ Total Material Consumption (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 or institution by type of water	Use by industry by type of water	National water abstraction Water Exploitation Index (withdrawal 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 demand per households or institution by type of land (brownfield vs. greenfield)	Demand by type of land (brownfield versus greenfield)	Degree of urban spread. 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 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)

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, blue and grey water. Changes in emissions of harmful pollutants to water may be relevant in some cases.
3. Land use change may be more environmentally damaging in some locations than others. Some indicator of importance of land affected 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.

Considering all levels of economic activities is of key importance, in order to evaluate the overall environmental effects of R&I activities. R&I investments often lead to the development of more resource efficient products and services, thus reducing the material or energy costs for the producer and/or the consumer.

For companies this can help to increase production and market share, as the products become more competitive. For consumers, this may lead to a change in behaviour, in which a product or service is used more intensively (because it is cheaper to use) or other products and services are consumed with the money saved. These often unintended effects of technological improvements are known as "rebound effects". Supporting R&I to improve the environmental performance of products and services alone may not lead to the desired improvement for society as a whole.

In the FP5 project "MOSUS" (Modelling opportunities and limits for restructuring Europe towards sustainability), the effects of expected increases in material productivity of industrial sectors were simulated with an economic-environment model. Based on empirical evidence from environmental consultants that up to 20% of material costs can be saved without compromising profitability (Fischer et al., 2004), the team modelled the economy-wide impacts of a consultancy programme, which supports companies to exploit this potential. The overall economic effects of implementing such a programme were positive, as material cost reductions stimulated economic growth and employment. However, the measures did not lead to an absolute reduction of material use due to rebound effects. It was therefore concluded, that in order to balance economic and environmental goals, strategies to increase material efficiency in the production sphere need to be complemented by macro-economic measures such as material input taxes or other fiscal measures (Giljum et al., 2008).

FIGURE 4. Main indicators of environmental impacts

AREA	ON THE NATURAL ENVIRONMENT	CONSUMERS / HOUSEHOLDS / ORGANISATIONS	ON NATURAL RESOURCES	ON AMENITY AND ECONOMY
MATERIALS	Concentration of heavy metals Concentrations of PAH, PCB and mercury	Concentration of heavy metals Concentration of PAH, PCB and mercury Concentration of dioxins, lead Concentrations of radioactive materials	Rates of extraction relative to deposits	Costs of treatment of wastes generated Prices of extracted materials
WATER	Salinity of aquifers Index of eutrophication Entry of invading species SO2 and NOx deposition	Faecal concentrations in recreational waters Nitrate concentrations	Rates of abstraction relative to rates of recharge	Costs of treatment of water as a function of pollution loadings.
LAND[3]	Wetland loss due to drainage Estimated loss of genetic resources SO2 and NOx deposition Surface disposal of mineral working deposits Accidental fires	Deposition of radioactive materials on soil Deposition of heavy metals on soil Leaching of waste from landfills	Loss of greenfield areas	Erosion Changes in fertility Costs of treatment of wastes to land
CARBON AND AIR EMISSIONS	Stratospheric ozone concentration Loss of land due to sea level rise	Concentrations of local air pollutants (PM, VOCs) Concentration of tropospheric ozone		Costs of insurance against extreme events

Source: adapted from (Markandya and Dale, 2001)

FIGURE 4 provides a summary of the main indicators of environmental impacts, classifying them under the four headings of materials, water, land and carbon/air. These areas are mapped into the impact categories of human health, the natural environment and natural resources. In addition a fourth category of impacts has been added, which is the economy. This is included to pick up the costs of different areas of impact on economic agents

1.3 HOW TO CONNECT R&I POLICY EFFECTS TOENVIRONMENTAL PRESSURES AND IMPACTS?

1.3.1 QUALITATIVE IMPACT PATHWAYS

This section introduces the overall logic of how to identify and analyse outcomes and impacts of R&I that are likely to decrease or increase environmental pressures and impacts. In general, the further "upstream" is supported research and innovation activity, i.e. the further it is from its final application, the higher is the uncertainty related to assessing its wider outcomes and impacts, including its environmental impacts. In other words, the more assumptions one has to make about potential environmental impact of the investment in R&I. This uncertainty is reduced in ex-post assessments, but the complexity and practical difficulty of attributing environmental impacts to research activities remain significant (e.g. considerable time lags, cumulative causation etc).

DIRECT PRESSURES AND IMPACTS OF R&I ON ENVIRONMENT

Direct pressures and impacts on environment are caused by these R&I policy effects that directly contribute to a quantitative change of environmental pressure, notably the use of material, land, water and of the level of emissions of CO2 and other harmful substances. Importantly, the effects of R&I policies can lead to either decreasing or increasing pressure of human activity on the environment. The most evident types of R&I outcomes causing measurable environmental pressures are new or modified products and individual and collective practices. While products require resources and cause emissions throughout their life cycle, individual or collective practices contribute to environmental pressures through consumption processes. Attributing environmental pressures to products and practices on the micro level is a relatively straightforward exercise. A simplified impact pathway in this case is as follows: policy intervention – new product or practice – environmental pressure – environmental impact. Any assessment of environmental pressure should be performed taking into account the whole life cycle of the product or service and associated material and energy use and emissions.

A more challenging scope of IA is to analyse wider socio-economic impacts at the meso (e.g. value chain) or macro level (e.g. a country). Here the analysis needs to take into account the scale and dynamics of diffusion as well as possible substitution and rebound effects related to the diffusion of the new product or service. Environmental pressures and impacts should be thus calculated not by a simple aggregation of micro-level pressures and impacts of the analysed product, but need to take into account how the diffusion of the product influences other existing products fulfilling similar functions.

The assessment of environmental pressures of products should also take into account how the use of artefacts influences individual or collective practices associated with their use and, conversely, how existing practices influence the use of artefacts. Thus the impact pathway comprises: policy intervention – new product or practice – associated practices and patterns of use or associated products – substitution and rebound effects - environmental pressures – environmental impacts.

INDIRECT PRESSURES AND IMPACTS OF R&I ON THE ENVIRONMENT

Indirect pressures and impacts on the environment are caused by these R&I policy effects that have a potential to influence tangible products, infrastructures and individual or collective practices that cause measurable environmental pressures and impacts.

The R&I policy outcomes that can influence the development of products and practices are new or modified knowledge and policies. Knowledge in its many forms plays a fundamental role in development of all new products and practices as well as policies. Tracing exact historical origins of any product back to its original idea and then following its subsequent development is a difficult, perhaps impossible, exercise. Tracing the knowledge origins of new products (and thus their environmental impacts) is, however, possible in the case of ex-post IA. Consequently, an impact pathway that departs from policy intervention with a potential indirect environmental pressure (e.g. support to collaborative research) will be more complex than in the case of interventions with tangible outcomes. This type of exercise, however, can bring novel insights on the role of policy intervention.

Estimating actual environmental pressures of new knowledge can be based on assumptions and projections. The robustness and significance of such ex-ante exercises will depend on "distance" between knowledge and its application (distance to exploitation or distance to market). The precision of IA will be higher when it is known how the knowledge is actually exploited. For example, the estimates may prove more or less accurate for applied knowledge (e.g. industrial design) in terms of material requirement and CO2 emissions of a resulting product prototype (micro level). The actual environmental pressures may be, however, different when the product goes into extensive production. They will further change depending on how the product is diffused and used. Until knowledge 'materialises' in the form of artefact or practice, any IA has to be based on assumptions of what environmental pressures will be caused.

Ex-ante estimates of environmental impacts of basic research face even longer distance to exploitation and thus are even more challenging, if meaningful, to perform. This does not mean that ex-ante IA is not a valuable exercise. Ex-ante IA should not be about precision when precise estimations are unfeasible or speculative. It should be robust enough to indicate an overall direction of intended outcomes and impacts of the intervention. More precise IA in terms of knowledge-oriented interventions may be required when distance to exploitation is very short (e.g. research projects resulting in industrial designs, product prototypes etc).

New findings resulting from research projects may result in new or modified policies. New policies based on these findings can significantly influence both product design as well as individual and collective practices of companies and households. The overall logic of indirect impact of policy is that it may "empower" knowledge by translating it into policy instruments and regulatory framework, including norms and standards.

CUMULATIVE IMPACTS OF R&I POLICY INTERVENTION ON THE ENVIRONMENT

Cumulative impacts result from the combined effects of multiple processes. The impact of a single policy intervention, for example, may not be significant on its own. When combined with other policy interventions or other processes, however, the combined effect may become more significant and better understood. Cumulative impact can be defined as an impact resulting from accumulated effects of various policy interventions and order determinants that affect the process or target group under consideration.

In assessing the cumulative impact of R&I on the environment one needs to consider:

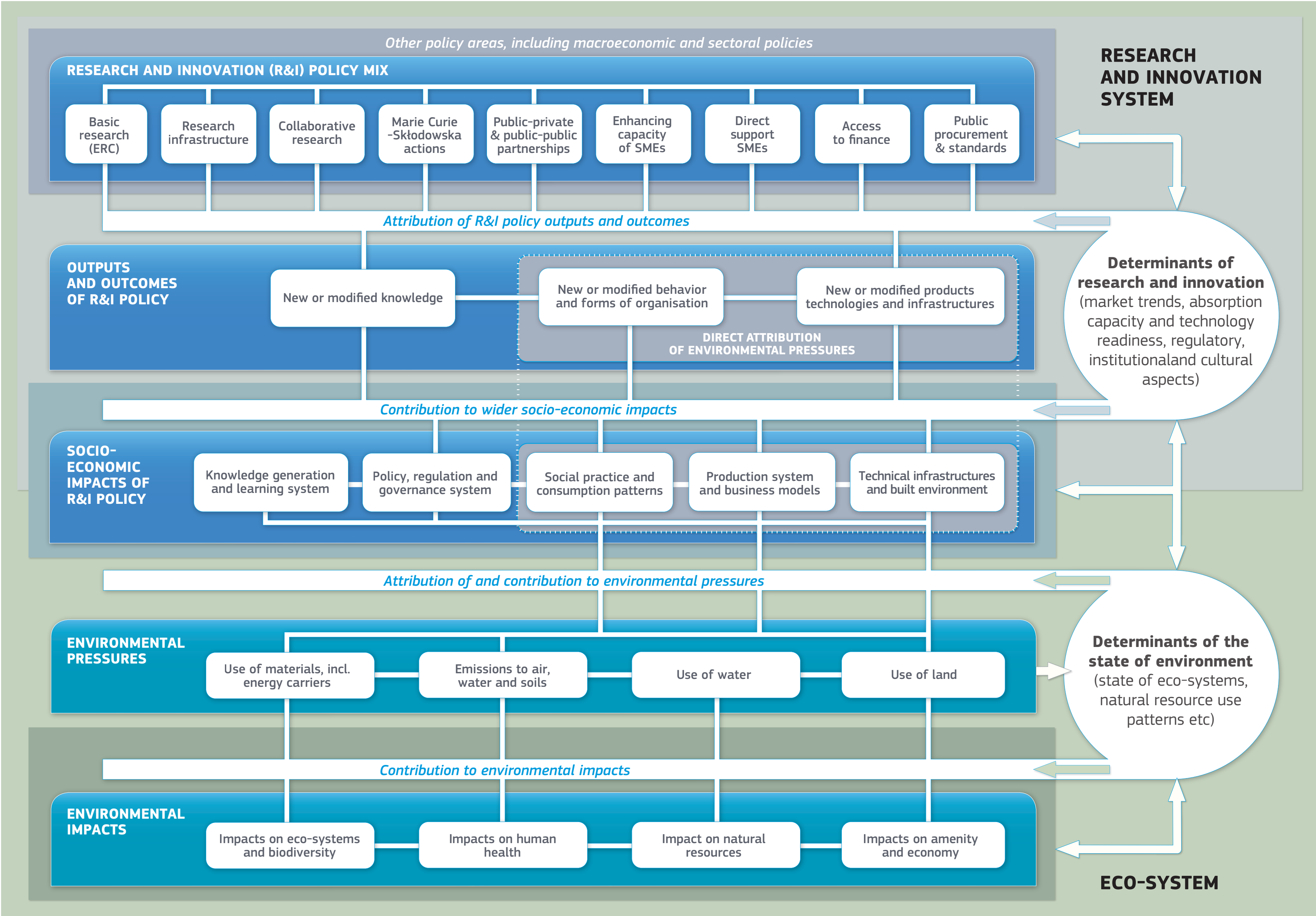
- Policy mix of relevant policy interventions that can influence the impact;
- Determinants of impact in the R&I system and the environmental system which can enable or impede effects of the intervention;
- Temporal perspective (or temporal coherence) in order to capture relevant effects that take place over time and influence the measured environmental impact.

INTRODUCING THE IA CANVAS

This guide offers a practical tool for illustrating and analysing impact pathways. **FIGURE 5** introduces an extended IA canvas that allows to (literally and figuratively) draw the lines between, on the one hand, outcomes and socio-economic impacts of R&I policy and, on the other hand, the main areas of environmental pressures and impacts. The framework can be used as a drawing board to identify direct or indirect pressures and impacts on environment and to qualitatively analyse complex impact pathways. The speed and scale of effects spreading along impact pathways need to be analysed taking into account internal and external determinants of R&I.

The canvas helps to visualise the distance between the intervention and possible environmental pressures and impacts. It makes it clear that environmental pressures and impact can be only assessed following the analysis of intended and unintended socio-economic outcomes and impacts of the intervention under focus. The tool can be used to illustrate complex impact pathways with feedback loops and iterations between different types of effects and external determinants. Importantly, it allows for identifying second- and higher-order effects and for iterating the impact pathway "up and down" the picture that is between micro, meso and macro level effects.

FIGURE 5. The IA canvas: extended visualisation of the IA framework



There are numerous possible impact pathways between policy intervention in R&I and environmental impacts. The IA canvas allows to visualise diverse impact pathways from outputs to impacts of R&I policy intervention. The tool can be equally useful in supporting the counterfactual analysis and, for example, comparing possible impact pathways of the planned intervention with what would happen in absence of the policy measure.

The visualisations point to where evidence supporting causality assumptions on effects of policy intervention needs to be collected and analysed. One of the useful approaches to describe and analyse impacts pathways can be narratives (or story lines) of impact pathways. Narratives make it easier to indicate where causality assumptions about impact of policy intervention on wider socio-economic and environmental impacts are made.

FIGURE 6 shows illustrative impact pathways of two R&I instruments: funding basic research and direct support for SMEs. These two instruments have very different impact narratives. On the one hand, R&I policy funds curiosity-driven basic research by providing grants to researchers.

Illustrating impact pathways of such an instrument, especially ex-ante, is challenging and often speculative due to an explorative nature of basic research and the long distance and time lag between the supported activity and its wider impacts. The environmental impacts of basic research will depend, inter alia, on whether, how and when the new knowledge generated by research activity influences products, practices or policies (see the top IA canvas in Figure 6).

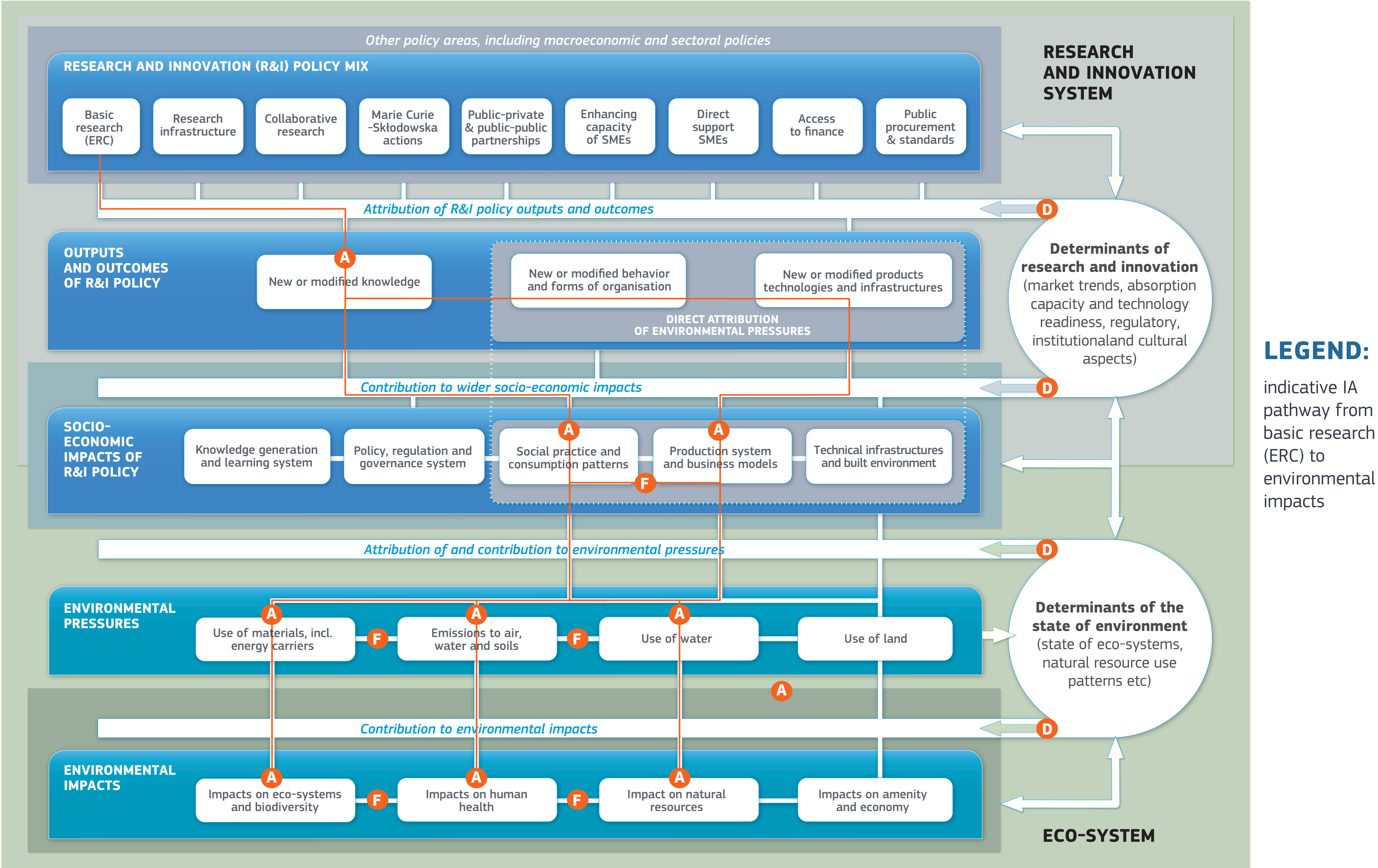
On the other hand, R&I policy may choose to directly support a wider diffusion of existing technological innovation by providing subsidies to SMEs for purchasing environmental technologies. This example demonstrates a more straightforward impact pathway and a shorter impact narrative based on relatively simple causal assumptions. In this case, the environmental impacts will depend, inter alia, on the attributes of the technology supported (e.g. how much material and water it saves compared with existing alternatives) and the projected or achieved ratem of diffusion of technology (e.g. how many companies adopt the technology and how large are their production volumes; see the bottom IA canvas in Figure 6).

Clearly, even such a “simple” narrative may suffer from unexpected developments (e.g. the emergence of alternative more cost-effective solution or market downturn) that can make the public support for the technology obsolete. The complementary use of prospective studies and foresight could help in anticipating unexpected barriers, especially in case of impact pathways of public interventions that deliberately aim at disruption and more radical innovation.

The IA canvas can also be used to visualise cumulative impact pathways. **FIGURE 7** provides an illustration of how to demonstrate potential cumulative effects of two selected instruments: support for basic research and direct support to SMEs. The canvas allows first, to overlay two pathways and, second, to identify phases in which impact pathways may “connect” and create cumulative impact. In the example explored, cumulative effects occur between measures following different timeframes of expected outcomes and impacts. By identifying direct and indirect effects of two instruments, ranging from second- to fifth-order effects, the canvas allows for including a temporal dimension to the analysis (i.e. how long it may take before certain cumulative effects may occur).

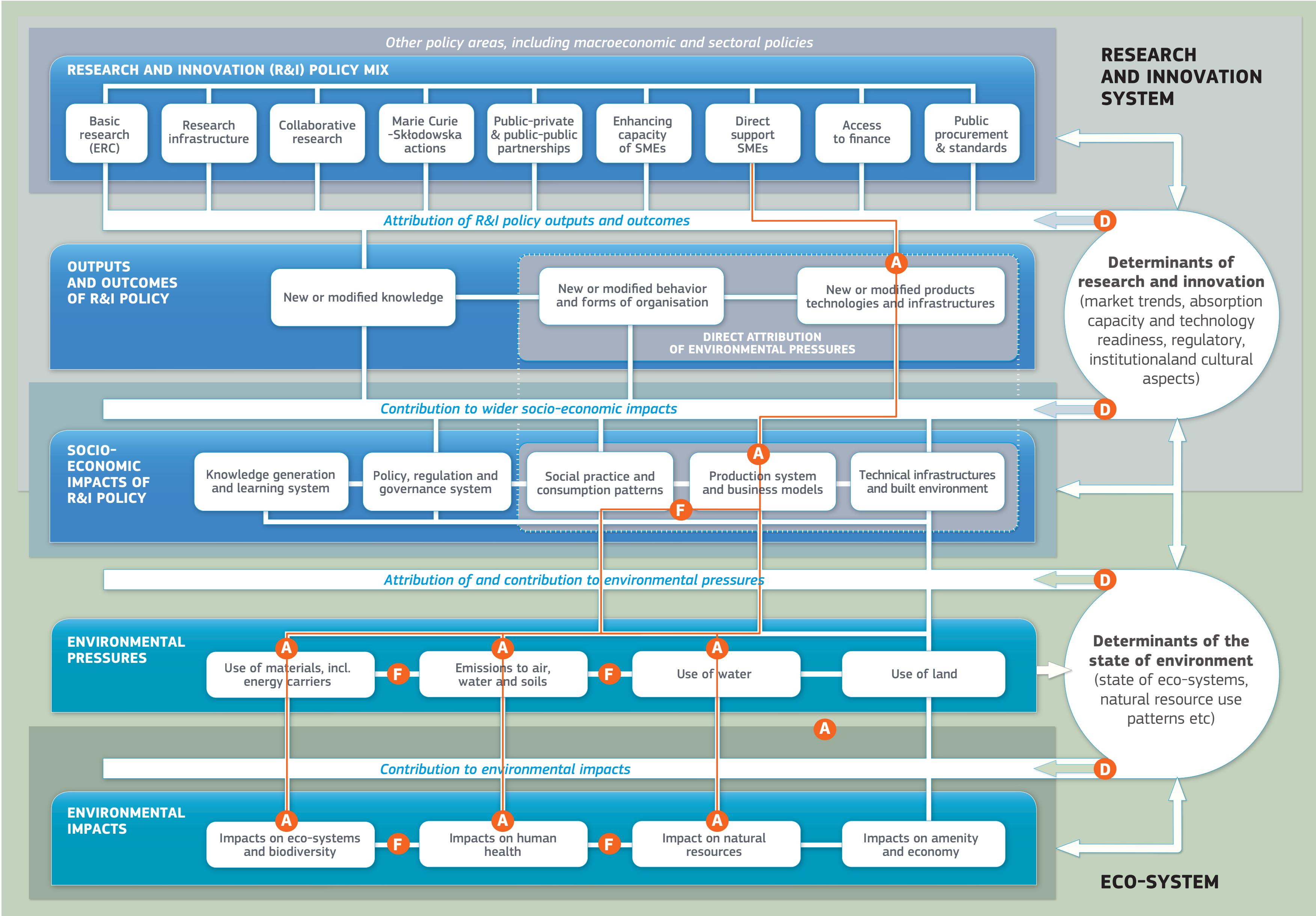
The impact pathways need to be supported with qualitative and quantitative evidence to substantiate claims about the relationship between public intervention and an expected or observed effect.

FIGURE 6. The IA canvas: two examples of instrument-level impact pathways



A - attribution decision/causality mechanism **D** – determinants **F** – feedback

FIGURE 6. The IA canvas: two examples of instrument-level impact pathways (continued)

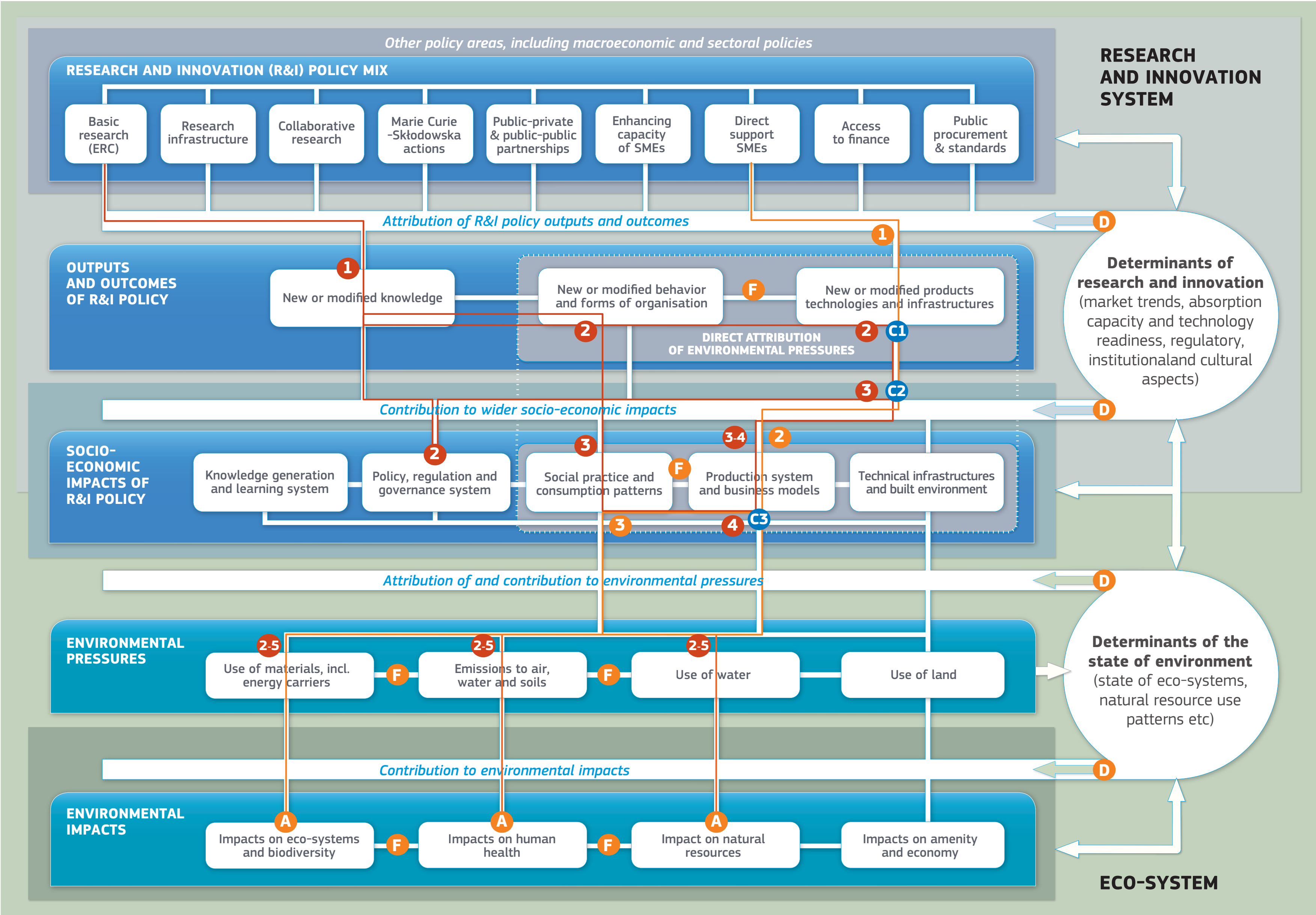


LEGEND:

indicative IA pathway from from direct support to SMEs (product development) to environmental impacts

A - attribution decision/causality mechanism **D** – determinants **F** – feedback

FIGURE 7. The IA canvas: illustrating cumulative R&I impact pathways



LEGEND:

cumulative IA pathway from basic research and direct support to SMEs (product development) to environmental impacts

Numbers on the pathways indicate **the order of effect attribution** (or contribution) to policy intervention (e.g. **1** stands for 1st order or direct effect, **2** for 2nd order effect, **3** for 3rd order effect etc.). The pathways can be analysed by following the order of effect.

Second- and higher-order effects are all indirect effects.

C – **potential cumulative impact (phases in which various impact pathways may create cumulative impact)** **D** – **determinants** **F** – **feedback**

1.3.2 CONSTRUCTING METHODOLOGIES AND SELECTING METHODS OF IA

Constructing IA methodologies to analyse and measure effects of R&I policy is challenging as it requires connecting approaches used by social sciences with environmental assessment methods rooted in natural and physical sciences. The central question is how to make the link between, on the one hand, quantitative and qualitative evidence on effects of R&I and, on the other hand, methodological frameworks focused on environmental pressures and impacts. Creating these connections in practice may require a dedicated research and modelling effort.

In general terms, there are two ways to connect evidence on R&I policy effects and environmental pressures and impacts:

- Direct relationship: evidence on changes in products and behaviours due to R&I policy that can be measured using parameters that are also used by environmental assessment methods (e.g. changing in material requirements of products measured in kilos, water use measured in litres or volumes, emissions measured in kilos etc);
- Indirect relationships: evidence on changes in knowledge (e.g. technical knowledge, social awareness etc) due to R&I policy that may influence products and behaviours which may influence environment. This can be referred to as second- and higher-order effects. This evidence is often qualitative (e.g. changed attitudes towards nature or towards technology in society).

THE AVAILABILITY OF RELEVANT EVIDENCE IN PRACTICE WILL DEPEND ON WHETHER THE INTERVENTION EXPLICITLY AIMS AT REDUCING ENVIRONMENTAL IMPACTS.

Programmes or instruments with environmental objectives are more likely to include relevant indictors in their monitoring and evaluation systems whereas interventions without an evident environmental dimension will focus on gathering evidence of a different nature. The availability and quality of programme data is therefore one of the fundamental factors assuring robustness of IA.

FIGURE 8 illustrates how evidence on outcomes in the areas of knowledge, practices and processes and products and technologies can inform environmental assessment methods and methodological frameworks. The table differentiates between evidence gathered at micro (e.g. product, individual, organisation) and meso-macro (e.g. sector, socio-technical system) levels.

The table can accompany the IA canvas suggesting type of evidence and methods underlying different the IA pathways. Evaluations and IA of research and innovation policy use a wide range of social science methods to capture effects of policies. The table suggests methods, types and nature of evidence relevant for assessing environmental pressures and impacts along with data selection and analytical methods.

FIGURE 8. **Linking R&I policy effects and environmental assessment methods**

AREAS OF R&I POLICY OUTCOMES	RELEVANCE OF R&I FOR ENVIRONMENTAL PRESSURES AND IMPACTS	LEVEL OF ENQUIRY	EVIDENCE RELEVANT FOR ASSESSING ENVIRONMENTAL PRESSURES AND IMPACTS	POSSIBLE DATA SELECTION AND ANALYTICAL METHODS	POSSIBLE INPUT TO ENVIRONMENTAL ASSESSMENT METHODS AND FRAMEWORKS
New or modified knowledge	**Is the new or modified knowledge relevant?** **Was / is new or modified knowledge leading to changes in behaviour or products and services?**	**Micro**	Quantitative and qualitative evidence on new knowledge relevant for environment resulting from policy support Qualitative and quantitative evidence on new knowledge contributing to innovative practices and new products	Data collection: Internal programme data Bibliometrics and patent data Survey-based enquiries on R&I structural data (e.g. funding, innovation collaboration) Interviews Data analysis: Counterfactual analysis Case studies Historical tracing Expert-based methods (e.g. expert panels) Foresight (e.g. scenarios) Mixed methods: Experimental methods (e.g. Living Labs)	Input to analysis in the framework of sustainability impact assessments (SIA) or strategic environmental assessments (SEA)
		Meso-macro	Quantitative and qualitative evidence on diffusion of new knowledge and social learning generated with policy support Qualitative and quantitative evidence on new knowledge contributing to diffusion of (new or existing) practices and (mew or existing) products Qualitative and quantitative evidence on new knowledge contributing to new or reviewed policies and regulatory decisions relevant for environment	Data collection: Internal programme data (aggregated) Bibliometrics and patent data Survey-based enquiries on R&I structural data (e.g. funding, innovation collaboration) Interviews Data analysis: Contribution analysis Counterfactual approaches Historical tracing Expert methods (expert panels) Foresight methods (e.g. scenarios)	Input to analysis in the framework of sustainability impact assessments (SIA) or strategic environmental assessments (SEA)

FIGURE 8. **Linking R&I policy effects and environmental assessment methods (continued)**

AREAS OF R&I POLICY OUTCOMES	RELEVANCE OF R&I FOR ENVIRONMENTAL PRESSURES AND IMPACTS	LEVEL OF ENQUIRY	EVIDENCE RELEVANT FOR ASSESSING ENVIRONMENTAL PRESSURES AND IMPACTS	POSSIBLE DATA SELECTION AND ANALYTICAL METHODS	POSSIBLE INPUT TO ENVIRONMENTAL ASSESSMENT METHODS AND FRAMEWORKS
New or modified behaviour, processes and forms of organisation	**What are / will be the changes in environmental pressures and impacts resulting from innovative practices, processes and organisational changes supported by the research and innovation policy?**	**Micro**	Quantitative evidence on changes in resource use and emissions resulting from innovative processes, organisational changes or individual or collective practices (compared to existing alternatives) Qualitative and quantitative evidence on causal mechanisms leading to new practices or processes (e.g. resulting from new knowledge, products or policies)	Data collection: Internal programme data Survey-based enquiries Interviews, focus groups Data analysis: Expert methods (expert panels) Case studies Foresight methods (e.g. scenarios) Mixed methods: Experimental methods (e.g. Living Labs)	Ecological Footprint Material Input per Service Unit (MIPS) CBA/CE Multi Criteria Analysis
		Meso-macro	Quantitative evidence on changes in material, water, land use and emissions due to innovative processes, organisational changes or individual or collective practices (aggregated) Qualitative and quantitative evidence on causal mechanisms leading to diffusion of new practices or processes (including links with products and systemic determinants e.g. institutional lock-ins, social acceptance, regulatory framework etc)	Data collection: Internal programme data (aggregated) Survey-based enquiries on R&I structural data (e.g. funding, innovation collaboration) Interviews Data analysis: Contribution analysis (meso-macro) System dynamics Case studies (e.g. value chains) Foresight methods (e.g. scenarios)	Ecological Footprint Physical accounting (indirect input based on the importance of new practices for changing the material flow) Input-output analysis (indirect) Supply chain analysis CBA/CE Multi Criteria Analysis Adjusting GDP (monetary)

FIGURE 8. **Linking R&I policy effects and environmental assessment methods (continued)**

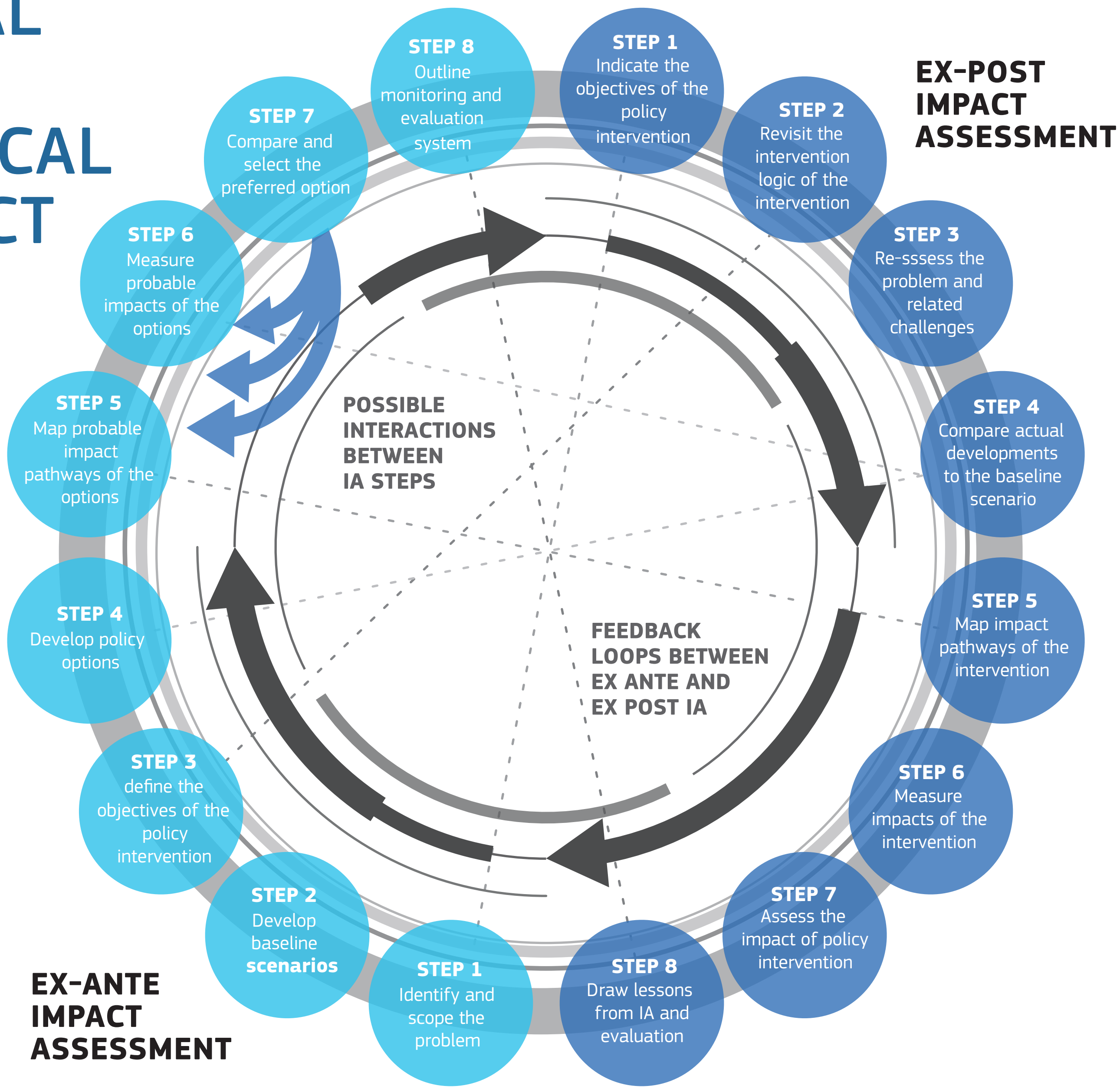
AREAS OF R&I POLICY OUTCOMES	RELEVANCE OF R&I FOR ENVIRONMENTAL PRESSURES AND IMPACTS	LEVEL OF ENQUIRY	EVIDENCE RELEVANT FOR ASSESSING ENVIRONMENTAL PRESSURES AND IMPACTS	POSSIBLE DATA SELECTION AND ANALYTICAL METHODS	POSSIBLE INPUT TO ENVIRONMENTAL ASSESSMENT METHODS AND FRAMEWORKS
New or modified products, technologies	**What are / will be the changes (decrease or increase) in environmental pressures and impacts due to innovative products or technologies supported by research and innovation policy?**	**Micro**	Quantitative evidence on changes in material, water, land use and emissions resulting from new or modified products (pressures and impacts across the life cycle of products compared with alternatives) Qualitative and quantitative evidence on causal mechanisms leading to new products (e.g. resulting from new knowledge, processes or policies)	Data collection: Internal programme data Survey-based enquiries on R&I structural data (e.g. funding, innovation collaboration) Interviews Data analysis: CBA/CE (micro-meso) Case studies Expert-based methods (e.g. expert panels) Foresight methods (e.g. scenarios) Mixed methods: Experimental methods (e.g. Living Labs)	Life Cycle Assessment (direct) Ecological Footprint Material Input per Service Unit (MIPS) CBA/CE Multi Criteria Analysis
		Meso-macro	Quantitative evidence on changes in material, water, land use and emissions due to diffusion of innovative projects and substitution (aggregated information on resource use and emissions) Qualitative and quantitative evidence on causal mechanisms leading to diffusion of new products (including links with practices and systemic determinants e.g. institutional lock-ins, social acceptance, regulatory framework etc)	Data collection: Internal programme data (aggregated) Survey-based enquiries on R&I structural data (e.g. funding, innovation collaboration) Interviews Data analysis: Contribution analysis CBA/CE (meso) Econometric modelling System dynamics Case studies Foresight (e.g. prospective scenarios)	Physical accounting Input-output analysis Ecological Footprint Supply chain analysis CBA/CE Macro LCA Multi Criteria Analysis Adjusting GDP (monetary)

2. ENVIRONMENTAL DIMENSION IN THE ANALYTICAL STEPS OF IMPACT ASSESSMENT

THIS GUIDEBOOK explores how to address environmental pressures and impacts in both ex-ante and ex-post assessments*. Including both ex-ante and ex-post perspectives allows for an integrated approach to IA that considers the IA as a cyclical process.

FIGURE 9 presents the main analytical steps covered in the guidebook emphasising the connections between ex-ante and ex-post assessments. In this approach, the IA is not a one-off exercise, but is part of an ongoing process of policy learning.

FIGURE 9. **Impact assessment cycle**



* This guide complements and extends the European Commission's Impact Assessment Guidelines (EC 2009) by including ex-post IA and focussing on the environmental dimension.

Ex-ante and ex-post IA differ in many respects. They have different purpose, scope and methodology. Whereas ex-ante IA supports the selection and prioritisation of relevant instruments and projects in line with set objectives, ex-post IA assesses the extent to which the selected instruments and projects have achieved the desired impacts. In terms of methodology, ex-ante impact assessments will likely have more qualitative components than ex-post ones. Clearly, explorative or normative prospective methods may include the use of models and data extrapolation as well as narratives, but uncertainty about future developments means that outputs of such quantitative methods are more open to interpretation than the results of most ex-post assessments or evaluations

Ex-ante IA by definition involves more risk and uncertainty. It deals with future that cannot be "known". This is particularly true for ex-ante IA of "blue sky" research and support to radical innovation. This means that IA has to rely on a range of assumptions about probable applications of research, its distance to market, scale and time of diffusion as well as substitution effects of the innovation. In the design phase of an intervention or projects of explorative nature, policy makers and stakeholders have a limited view on possible impacts over time. Expected effects, especially long-term impacts, are therefore likely to be inaccurate or to lack detail. Ex-ante IAs tend to overestimate positive impacts of policy intervention, hence the need to involve a range of experts and stakeholders in the IA process in order to ensure "future-proofing".

A degree of uncertainty influences also ex-post assessments and evaluations. Ex-post IA does not have full information and knowledge on impact mechanisms, especially in relation to complex processes on the level of societies and economics. Ex-post IA may suffer from difficulties

Despite evident differences, both ex-ante and ex-post assessments are based on a similar conceptual understanding of causality, attribution and contribution, and impact pathways. What differs is the amount of information and knowledge available for determining causalities and tracing, often complex, impact pathways. Establishing a learning loop between two perspectives could improve quality of public intervention at all levels by offering a reality check for "cost optimism" in policy and project assumptions alike.

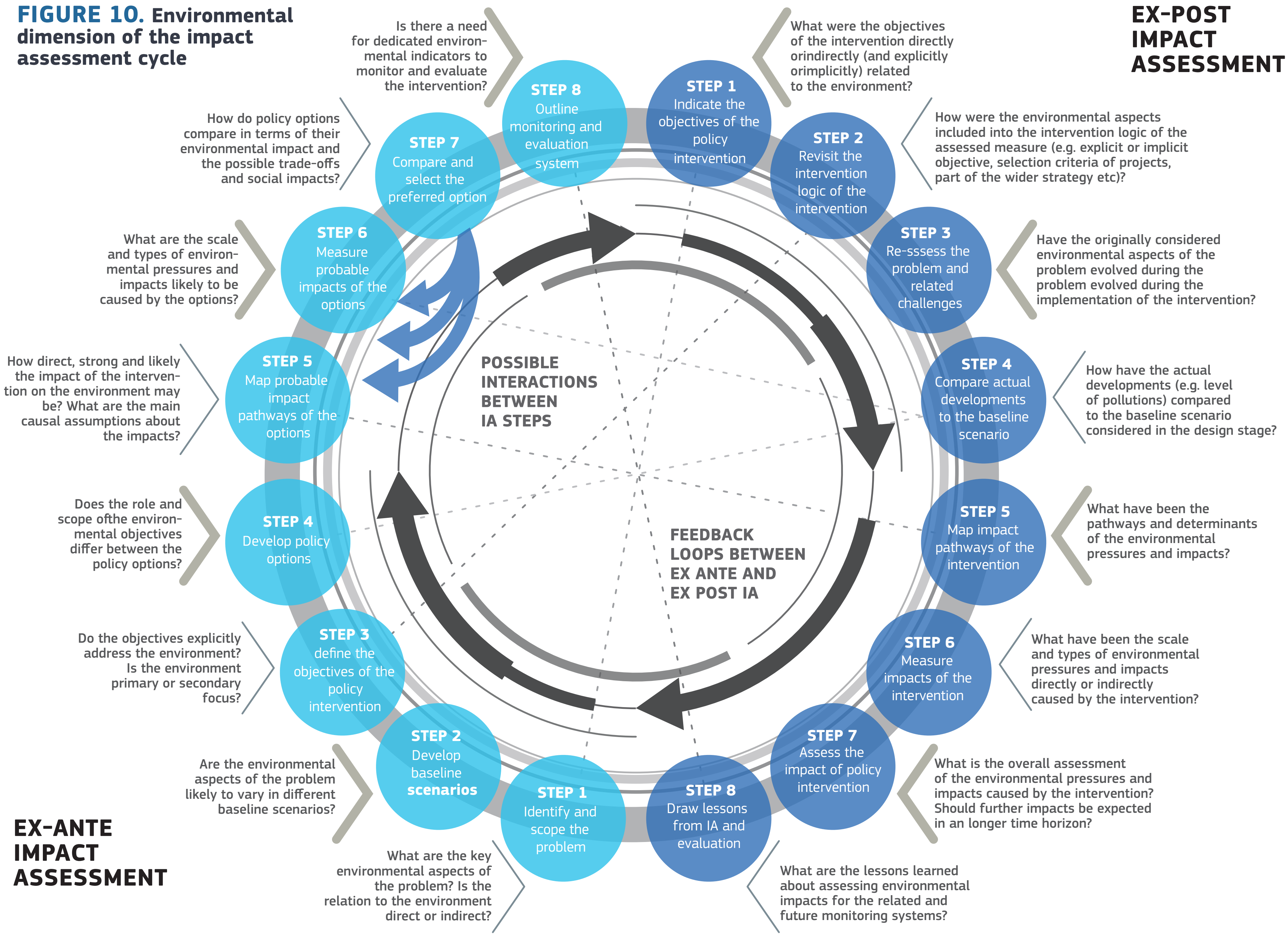
The following sections provide guidance on how to address the environmental dimension when tackling analytical steps of IA. The sections provide key questions and recommendations on the scope of the assessments.

FIGURE 10 presents examples of questions to be asked when pondering the environmental pressures and impacts of the assessed intervention.

In both ex-ante and ex-post exercises consulting external experts as well as other stakeholders can contribute to the robustness and transparency of assessments. Depending on the needs and the nature of the problem addressed by the policy intervention, stakeholders can be consulted about any step of the IA.

For more detailed material, including descriptions of methods, concrete examples of IA and reflections on how to conduct IA on different levels (programme, instrument, project), the readers are invited to consult an extended version of this publication.

FIGURE 10. Environmental dimension of the impact assessment cycle



2.1.1 EX-ANTE IMPACT ASSESSMENTS

STEP 1. IDENTIFY AND SCOPE THE PROBLEM

The ex-ante IA starts by describing the problem and related challenges that are to be subject to policy intervention. In order to include an environmental dimension the first step of any IA should aim to:

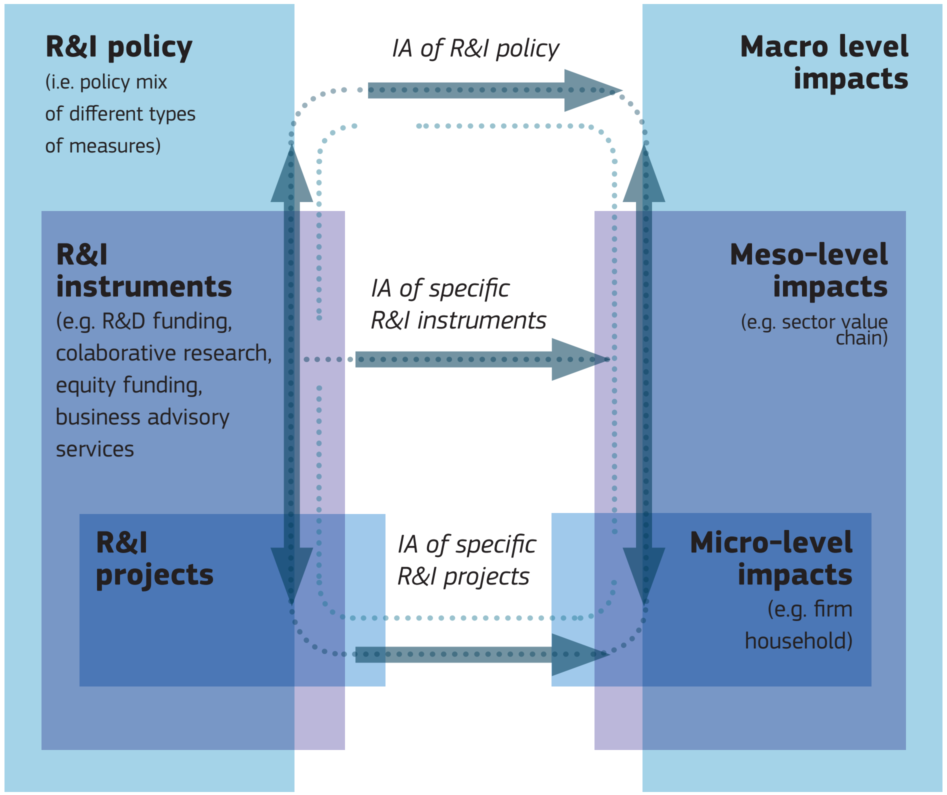
- Identify and describe key environmental aspects of the problem (note that environmental aspects may be directly or indirectly linked to the problem and related challenges);
- Establish main drivers and underlying causes of possible environmental pressures and impacts related to the problem and the future intervention;
- Identify any "wild cards" which could disrupt the expected impacts (positively or negatively) (this could include cross-impacts with other measures being implemented or discontinued as well as "surprise factors");
- Based on the available studies, data and expertise, verify whether (positive or negative) environmental pressures and impacts are likely to be significant or whether they are uncertain;
- Decide if IA requires a dedicated IA component focused on environment;
- Add environmental indicators to the baseline of the intervention (depending on the nature of the problem these may be core or secondary baseline indicators).

In case of significant evidence and knowledge gaps it is recommended that the decision whether to include a stronger emphasis on environmental dimension is taken based on expert consultations.

In order to find a meaningful approach to assessing environmental impacts (and, in fact, any other impacts), any systemic IA framework has to consider that policy is intervening in an open dynamic system, where many factors are at play and influence the outcome of the intervention.

Finding a meaningful level and scope of impact assessment is one of the key decisions determining the robustness of the overall exercise.

FIGURE 11. Policy intervention and levels of IA



STEP 2. DEVELOP BASELINE SCENARIOS

The fuller account of possible future developments requires explicit consideration of alternative scenarios of how a baseline will develop. The IA exercises including a stronger emphasis on a prospective dimension should:

- Take into account the baseline, develop a prospective scenario or several scenarios of possible;
- Take into account the baseline and develop a prospective scenario or several scenarios of possible developments and trends related to the problem, explicitly concidering relevant environmental trends;
- Include sensitivity analysis and risk assessment in the scenario development taking into account the dimension of natural environment;
- Select the most plausible scenario to be a main basis for the design of the policy options.

Developing scenarios makes the baseline more robust and allows for a better view on resilience of proposed policy options.

STEP 3. DEFINE THE OBJECTIVES OF POLICY INTERVENTION

Depending on the problem definition and the wider policy context, environmental aspects may be a primary or secondary focus of policy intervention:

- If the problem and its root causes are linked to the natural environment, make sure to explicitly include it in the objectives of policy intervention;
- If the problem is indirectly linked to the environment, ensure that the objectives of policy intervention are coherent with existing and upcoming EU regulations, policies and strategies targeting the natural environment.

Note that the full realisation of possible (negative or positive) impacts on the environment may be revealed in steps 5 and 6. The IA process should be flexible enough to allow for iteration between the steps. If new significant insights are gained from the qualitative and quantitative analysis of the impact pathways, the objectives and options should be revisited and adjusted accordingly.

FIGURE 12. Methodology of impact assessment applied by the Green Investment Bank (GIB), UK

The Department of Business Innovation and Skills prepared the ex-ante Impact Assessment (IA) of the GIB in May 2012, to be reviewed around April 2015. This IA applies to the £3bn committed by the Government to fund the GIB over the period to 2015, not addressing the potential costs and benefits thereafter.

The IA considers the following different policy options:
1. Do nothing;
2. Create a fund or consolidate existing ones;
3. Increasing the application of existing Government policies;
4. Create the Green Investment Bank, addressing the market failures and barriers present in the financial markets (recommended option).

Key assumptions in this IA had to be made in order to estimate a range of portfolios for the bank. The net present value (NPV) was used to assess the value for money of the different options, describing the difference between the present value of a stream of costs and a stream of benefits over time.
The monetised costs considered the different NPVs of different technologies that were to be included in the portfolio of the GIB and included monetised capital and operating expenditure costs. For the benefits the savings from CO2 emissions avoided and the financial returns of the investments were taken into account. The different NPVs for different technologies had been estimated by prior work from BIS and Vivid Economics.

The bank is an independent institution that tries to maximise green impact and profitability, depending on market conditions and the available investments. As a result, its portfolio of projects cannot be determined beforehand, as it is not a matter of policy. The results of this IA are usually given considering a range of illustrative portfolios or through a Monte Carlo analysis considering 90% of the funds committed.

Finally, the results of the IA take into account a level of variation in certain parameters, such as the level of additionality, the default rate and the mobilisation rate of private capital.

Source: Case study of the UK Green Investment Bank

STEP 4. DEVELOP POLICY OPTIONS

Explicit inclusion of environmental aspects in policy options will depend on the problem and on the objectives of the policy intervention. In the case of interventions with high impact on environment, the criteria should explicitly include environmental pressures and impacts and reflection on possible synergies and trade-offs between them and other impacts, notably social and economic impacts.

Policy options should be developed taking into account baseline scenarios and their differences in terms of environment trends.

STEP 5. ANALYSE THE IMPACTS: QUALITATIVE MAPPING OF PROBABLE IMPACT PATHWAYS

Qualitative mapping of impact pathways allows for better realisation of possible direct and indirect impacts of policy intervention on the economy, society and environment.

The mapping aims to:

- Identify (direct and indirect, positive and negative) environmental pressures and impacts of policy options and how they relate to economic and social impacts of the intervention (causal mechanisms);
- Use narratives and visualisations to describe the possible direct and indirect causal pathways leading to environmental pressures and impacts;
- Assess the environmental impacts against the baseline in qualitative terms (check the proportionality principle);
- Consider the risks and uncertainties of the option in relation to environmental impacts;
- Decide if IA requires a dedicated quantitative IA component focused on the environment.

The IA canvas introduced in this guidebook can serve as a “drawing board” supporting thediscussion on the pathways. Qualitative mapping should be supported by readily available quantitative data. The mapping will allow for a better understanding of the scale and time when public intervention may contribute to environmental pressures. Along with the problem definition and baseline it is a sufficient basis for taking a decision on whether a dedicated quantitative estimate is need for IA. The decision should take into account the proportionality principle.

STEP 6. ANALYSE THE IMPACTS: QUANTITATIVE ESTIMATES OF ENVIRONMENTAL IMPACTS

Estimating possible impacts should be based on both qualitative and quantitative evidence. Quantitative IA of R&I should be performed when previous steps suggest a possibly high impact of policy on the environment. The quantitative assessment of tangible pressures and impacts should focus on collecting data on R&I effects that may influence parameters of environmental assessment methods (e.g. physical accounting, CBA).

The step aims to:

- Analyse available data to verify causality claims and assess possible environmental impacts of policy options;
- If possible and feasible (e.g. depending on the budget, timing as well as type of data needed), collect primary data to complement existing evidence; focus on R&I effects that can directly or indirectly influence parameters that can be linked to environmental assessment methods (e.g. tonnes of CO2 emissions or materials, etc.);
- Assess the impacts against the baseline in quantitative and monetary terms.

The step can also focus on indirect effects of R&I on the environment (e.g. new knowledge to be generated by a research activity). The assumptions on future causalities should be based on both quantitative and qualitative evidence; the causal claims of future impacts are subject to many caveats and uncertainties. The latter should be made transparent in IA reports.

FIGURE 13. Assessment criteria used in (ex-ante) IA using RIAM method

THE ENVIRONMENTAL IMPACT ASSESSMENT METHODOLOGY

offers the tool "rapid impact assessment matrix" (RIAM) that allows scoring based on multiple criteria. RIAM is quite flexible, transparent and leaves a permanent record, which can be independently checked, validated or updated. The simple, structured form of RIAM allows re-analysis and in-depth analysis of selected components in a rapid and accurate manner. This flexibility makes the method a powerful tool for both executing and evaluating IAs. The scales in RIAM allow both quantitative and qualitative data to be assessed. Being an EIA tool RIAM is applied to infrastructure projects and can be adopted with some adjustments in the ex-ante (but also in ex-post) environmental impact assessment of research infrastructure support projects and programmes. The matrix can be extended by including several dimensions.

The figure presents an overview of the assessment criteria used by RIAM

CRITERIA	DESCRIPTION	SCALE
Importance of the impact	Important to national interest Important regionaly Importent to areas outside the lokal context: areas of coverege can be defined as a part of region Important only in the local context No geografical or other recognised importance	4 3 2 1 0
Magnitude of change	Major positive benefit Sagnificant improvement in status quo Improvement in status quo No change in status quo Negative change to status quo Sagnificant negative disadvantage or change Major disadvantage or change	+3 +2 +1 0 -1 -2 -3
Permanence of the impact causing activity	Permanent or long-term Temporary and medium-term Temporary and short-term No change/ not applicable	4 3 2 1
Reversibility of impact	Irreversible impact Slowly reversible impact Reversible impact No change/ not applicable	4 3 2 1
Cumulative synergizm	Obviouse cumulative/ synergic effects with other projects and activities Cumulative/ synergic impact exists, but not uncertain Non-cumulative/ single impact No change/ not applicable	4 3 2 1
The sucestibiity of the target environment	The target area is extremly sensitive to environmental changes The target area is sensitive to environmental changes The area is stable for the environmental changes caused by the project No change/ not applicable	4 3 2 1

Source: overview of criteria from Ijäs et al (2010); more information on RIAM method can be also found on the website of DHI Group (http://www.dhigroup.com/MIKECUSTOMISEDbyDHI/RIAM.aspx)

STEP 7. COMPARE THE POLICY OPTIONS

In case of policy problems or policy interventions with significant anticipated environmental impacts it is suggested to:

- Compare the positive and negative environmental pressures and impacts for each policy option;
- Present comparisons between policy options by categories of impacts (e.g. economic, social, environmental) and affected stakeholder groups;
- Identify, where possible and appropriate, a preferred option in terms of environmental pressures and impacts taking into account different time horizons of impacts and (possible) trade-offs or synergies with socio-economic impacts.

STEP 8. OUTLINE MONITORING AND EVALUATION

The monitoring and evaluation system of the policy intervention with anticipated positive or negative impacts on the environment should include dedicated environmental indicators allowing for measuring the intervention's environmental performance, at the very least in terms of achieving the formal environmental objectives or targets. The indicators should inform later evaluations and assessments of both direct and indirect impacts of policy. They should be tailored so they can inform established methods of assessing environmental pressures and impacts.

FIGURE 14 presents an example of the monitoring and evaluation indicator system giving a significant consideration to measuring environmental performance of R&D projects.

FIGURE 14. Indicators collected for monitoring and IA of the Dutch EET programme

The Dutch Economy, Ecology, Technology committed subsidies to R&D projects from consortia of universities, knowledge institutes and companies, focusing on building knowledge for realising major improvements in sustainability and realising both large environmental improvements as well as good economic results.
The monitoring system adopted by the programme assumed the collection of wide range of output and impact indicators for the economic, ecological and cooperation impact. Every two years a monitoring report was produced by the Programme Office to estimate possible programme impacts. The approach was based on determining effects for each project and adding these up. Four information sources are used for the monitoring report:

- the EET database with project outputs based on the original applications and the project reports;
- an annual survey on the "Standard Outcome Indicators" (SOI). All project coordinators had to submit their expectations on effects of all projects on economy, ecology, technology and cooperation, as defined by a standard set of indicators;
- discussion with the project consortium on their assessment of the SOI;
- final reports (from projects that were finished).

The following indicators were asked from each project participant (for quantitative indicators a most likely estimate, a minimum estimate and a maximum estimate were asked)

ECONOMY	ECOLOGY	TECHNOLOGY	COOPERATION
• description of the way how the project results will be exploited • additional costs until market introduction • expected moment of market introduction (year) • expected moment of maximum turnover • newness of the market (existing and known market, existing and unknown market, new niche, new large market) • geographical area (NL, Europe, world) • competitive position against alternatives/competitors • expected market share • expected additional turnover (€) • expected year when investments in the development will be earned backmarket persistence of the project result • expected cost savings in the company because of the project results (and description of cost savings) • economic effects with customers (outside the consortium) because of the project • economic effects with spin-off companies • possible barriers for market acceptance • expected chance that the project will be a commercial success for respondent	• describe mechanism how environmental effect is obtained • define unit for relating the environmental effect to (e.g. kg of product, power installed in watt) • indicate indicate environmental effect: CO2 emission reduction (tonne CO2/j); amount of sustainable energy (TJ/y); energy savings (TJ/y); savings in raw materials (T/y); substitution by renewable resources (tonne/y); reduction of waste (tonne/y; for each waste stream); decrease in use of groundwater (m3/y); decrease in use of drinking water (m3/y); decrease in emission of waste water (m3/y); additional production of drinking water (m3/y); decrease CO2 combustion (tonne/y); decrease non-combustion CO2 (tonne/y); decrease CH4 emission (tonne/y); decrease N2O emission (ton/y); decrease CF6, HFC, PFC (tonne/y); decrease NOx emission (ton/y); decrease SOx emission (tonne/y); decrease NH3 emission (tonne/y); decrease VOC emission (tonne/y); decrease fine dust emission (ton/y); decrease N (nitrogen) emission (ton/y); decrease P (phosphorus) emission (ton/y); decrease in noise (number of affected persons); decrease in odour (number of affected persons); decrease in use of land space	• Number of inventions for which a patent application has been submitted • Number of EU/ US / worldwide patent applications • Number of patents granted • Number of expected patent applications still to come • Number of delivered PhDs • Number of PhDs still to defend their thesis • Number of publications in refereed journals • Number of publications in professional papers • Likelihood of technical success for the project • Dependency of commercial success on technical success	• History of earlier cooperation with other partners • Changes in partners during project execution • New projects with EET partners • Will the cooperation be continued after the EET project? If yes, with which partners? • To what extent do you think the consortium capable ofbringing the project to the market? • Could you describe the quality of the cooperation in theconsortium (Likert scale, 1-5)

Source: Case study on the Dutch EET programme

2.1.2 EX-POST IMPACT ASSESSMENTS

STEP 1. INDICATE THE OBJECTIVES OF THE ANALYSED POLICY INTERVENTION

The ex-post IA commences with identifying and revisiting the objectives of the assessed policy intervention. In the context of environmental assessments it is recommended to:

- Review the objectives of the analysed intervention indicating objectives (directly and indirectly, explicitly and implicitly) related to the environment;
- In case of IA of interventions that did not address environmental issues directly (and in case of thematic assessments), identify strategies and policies with relevant environmental objectives and targets that framed the policy context of the intervention;

Identification of explicit or explicit objectives allows for scoping the assessment as well as to differentiate between intended and unintended effects.

STEP 2. REVISIT THE INTERVENTION LOGIC OF THE ANALYSED INTERVENTION

Identification of objectives is followed by re-constructing the intervention logic of the analysed intervention of mix of interventions. The step aims to:

- Develop intervention logic of the intervention including objectives, specific actions as well asintended outputs, outcomes and impacts;
- Indicate elements of the intervention directly or indirectly linked to environment;
- In case of IA of interventions that did not address environmental issues directly and thematic assessments, establish the implicit intervention logic taking into account external environmental objectives and targets.

Logic models are normally used to visualise the interventions intended (overall, strategic and operational) objectives, inputs, outputs, outcomes and wider impacts.

STEP 3. RE-ASSESS THE PROBLEM AND RELATED CHALLENGES

In case of impact assessments of major interventions that have been implemented over long periods, it is recommended to revisit the environmental aspects of the problem originally addressed by the intervention in order to analyse whether and how these aspects (and their determinants) have changed since the intervention was designed.

STEP 4. COMPARE ACTUAL DEVELOPMENTS TO THE BASELINE SCENARIO

The analysis in Step 3 allows to compare the relevant developments related to the environment with the assumptions made in baseline scenarios performed for ex-ante IA or evaluation. The step can be performed only if explicit baseline scenarios were developed at the design stages of the assessed intervention:

- If only one baseline scenario was considered, relate the collected evidence on environmental pressures and impacts to the original baseline scenario (whenever possible include quantitative indicators) and assess how the actual developments compare to the initial assumptions;
- If different scenarios were considered, assess whether and how the actual developments relate to the scenarios developed at the time of ex-ante IA.

Steps 3 and 4 are especially relevant for assessments involving contribution analysis and counterfactual approaches, as it allows to better map the evolving context of the public intervention.These steps will also provide relevant information for decision whether an in-depth dedicated environmental assessment is required. An environmentally relevant trend emerging during the implementation of the of the intervention, for example, could influence the relevance and uptake of the effects of R&I policy.

STEP 5. ANALYSE THE IMPACTS: QUALITATIVE MAPPING OF IMPACT PATHWAYS

This step aims at identifying environmental pressures and impacts to which the assessed intervention contributed. The main activities are to:

- Identify (direct and indirect as well as intended and unintended) environmental impacts and how they occurred (causal mechanisms);
- Assess the impacts against the baseline in qualitative terms;
- Use visualisation tools (such as the IA canvas introduced by this guidebook) and narratives to describe the direct and indirect causal pathways;
- Consider environmental impacts inside and outside the EU;
- Collect and analyse qualitative evidence to verify causality claims in the intervention logic (if feasible combine qualitative and quantitative methods).

Qualitative assessment should allow to gather enough evidence to decide whether the environmental impacts of the analysed intervention were significant and whether there is significant uncertainty about environmental pressures and impacts caused by the intervention. This step should screen existing monitoring data and involve leading experts in analysis and decision-making. Based on the analysis and taking into account proportionality principle, the decision can be taken to perform a dedicated ex-post quantitative assessment.

STEP 6. ANALYSE THE IMPACTS: MEASURING ENVIRONMENTAL IMPACTS

This step aims at measuring environmental pressures and impacts to which the assessed intervention contributed. The main activities are to:

- Based on the identified pathways collect available internal and external data and select appropriate methods to assess environment-related outcomes and impacts;
- If feasible, collect primary data to complement existing monitoring and evaluation data (see examples presented in FIGURE 14 and 15);
- Assess the impacts against the baseline in quantitative and monetary terms (consider using counterfactual approaches if feasible).

Measuring impacts should be based on both quantitative and qualitative evidence.

Qualitative evidence will be especially relevant in analysing the nature of causation mechanisms that contributed to wider socio-economic impacts. Ex-post assessments on R&I effects, especially those involving the notion of socio-economic impacts, should be based on both quantitative and qualitative evidence. The causal claims on impacts may be subject to many caveats and uncertainties, although in most cases not as severe as in ex-ante assessments. Assumptions on causal mechanisms (and their rationale) should be made transparent in IA reports.

STEP 7. OVERALL ASSESSMENT OF THE IMPLEMENTED POLICY OPTION

The overall assessment of the policy intervention should bring together various qualitative and quantitative methods to:

- Assess the (positive and negative; intended and unintended) environmental pressures and impacts of the implemented intervention compared with the objectives and targets;
- Taking into account time lag and other determinants, assess whether further environmental impacts of the intervention can be expected (including further diffusion, substitution effects, rebound, displacement etc.);
- Assess the relevance of framework conditions for impacts.

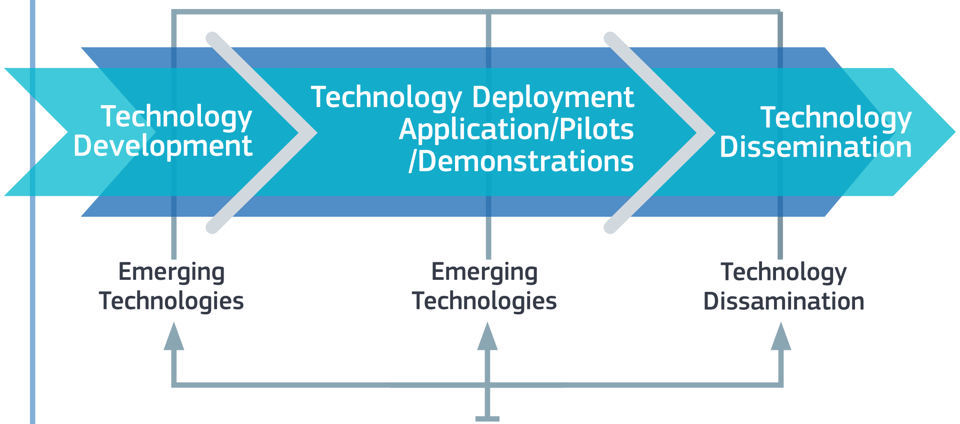
At this stage the results of Steps 5-6 should be analysed against findings on the evolving baseline and the role of various determinants, including framework conditions.

STEP 8. LESSONS FROM MONITORING AND EVALUATION

The IA should conclude on the robustness and usefulness of data gathered in monitoring and evaluation of assessed intervention in order to suggest concrete recommendations for the design of future policy interventions as well as on the environment-related indicators to be used in monitoring and evaluation systems.

FIGURE 15. "Technology tracking" system of the AMO

The Advanced Manufacturing Office (AMO) is part of the Energy Efficiency and Renewable Energy (EERE) programme of the U.S. Department of Energy. AMO aims to foster the production and use of advanced manufacturing technologies with the overarching goal to reduce by 50% in 10 years the life cycle energy consumption of manufactured goods. It supports technological R&D projects undertaken by universities, research sector and manufacturers and technology deployment projects for manufacturers (SMEs or large companies). AMO has worked with the Pacific Northwestern National Laboratory to develop a "technology tracking" system that monitors the progress of the funded R&D projects towards achieving energy and cost savings.



Impact Tracing System — Database

KEY IMPACT CATEGORIES TRACKED:

- Cumulative energy savings, current energy savings, type of fuel saved, units operating
- Cumulative and anual pollution reductions
  (particulates, nitrogen oxides, volatile organic compounds, sulfur dioxide, carbon dioxide)

The monitoring system also records the success of the funding in terms of accelerating the road to market of the technologies supported. The tracking system has been in place for around 30 years, and can be characterised as a conservative, highly quantitative benefits measurement system. The technology monitoring process starts with recording the technologies developed with AMO support into an "active tracking list" (or database) as soon as they are classified as commercially successful. At this stage, the respective technology has a full-scale operational unit. They are then tracked for their contributions to energy and cost savings for 10 years. Indicators are selected with a view to collecting evidence on the success of the programme's support to innovation diffusion processes. The information is collected through direct contact with vendors or end-users of the technology, which allows for calculating unit energy savings associated with each technology, as each technology has a characteristic amount of unit energy savings. The funded projects are obliged to provide information and be monitored by the Pacific Northwest National Lab (PNNL) as part of the technology tracking system. PNNL is in contact with the project Contact Points or the Principal Investigators. Once the projects report the technology as commercialised, the PNNL collects data on the technologies by email from the companies that are producers or users of the technology. For rarely used technologies, all users are contacted. The data are collected for a period of ten years for the commercialised technology.

The main indicators monitored for the technologies supported by AMO include:

- Number of units sold, installed and operating in the US and abroad (incl. size and location);
- Units decommissioned since the previous year;
- Energy saved;
- Environmental benefits;
- Improvements in quality and productivity achieved;
- Other impacts, such as employment and effects on health and safety;
- Marketing issues and barriers.

GENERAL MESSAGES

R&I give rise to a range of effects in all three areas of sustainable development: the environmental, economic and social. The central assumption in the overall methodological framework developed for this guide is that **any integrated assessment seeking to identify and measure environmental impacts of R&I needs to be based on a robust understanding of the socio-economic effects of public intervention.** Without evidence on how fast innovative products or services diffuse in society and how they are used, for example, we cannot estimate their environmental impact.

This publication is a modest step in establishing an integrated IA framework and methodological advice on how to identify, scope and assess the environmental pressures and impacts of research and innovation policy. The central element of the guide is the notion of impact pathways that allow for the scoping of challenging IA assignments in which the link to the environment may seem remote at the first sight.

We have noted in this guide that outcomes and impacts of R&I policy are of diverse nature, depend on a number of determinants and unveil to a different extent in the short, medium and long term. There are likely to be spillovers, substitutions and rebounds, so that R&I in one area can have effects on activity in a related or completely different area. It is often challenging to anticipate ex-ante or attribute ex-post the main lines of such consequences, especially at the meso and macro levels of analysis. There is no one-size-fits-all approach to capture this complexity.

Impact assessment practice focused on sustainability should ensure access to **diverse evidence, interdisciplinary expertise and sufficient time for reflection and exploration.**

If relevant, the process should allow for revisiting initial assumptions. While simple answers based on undisputable quantitative data may not be a routine result, especially of complex ex-ante assessments, qualitative impact assessment based on impact pathway mapping and system thinking can offer a valuable contribution to the knowledge base assisting the design and implementation of the current and future R&I policies.

As guidance to IAs including a significant environmental dimension it will be useful to bear in mind the following issues:

- **Level of impact assessment:** It is more straightforward to measure environmental pressures and impacts at the product, user or household level than to measure it at the industry or national level. The most meaningful, and at the same time the most challenging levels of impact assessment are the meso (e.g. product-service systems) or macro level (socio-technical system). Meso and macro level IA need to take account of more factors than the product level measures. This should be recognised when interpreting outcomes and impacts of public intervention;
- **Level of uncertainty and risk:** The estimates, notably performed in ex-ante IA, of meso and macro level pressures will be more uncertain. In this context, IAs should be based on a systemic qualitative reflection on probable impact pathways. Ex-post impact assessments will typically include further quantification. In general, the more "upstream" R&I policy measure is or the further it is removed from the market or final application, the more difficult it is to provide an exact estimate of its impact;
- **Trade-offs between different impacts:** Integrated impact assessments may point to possible rebound effects and trade-offs between the economic and environmental impacts. The environmental assessment has to place these impacts in context: how do environmental impacts stack up against the social and economic benefits of the activity?If the environmental impacts of new technology, good or service were deemed to be small, the appropriate action would be to find a way to mitigate them, possibly from the benefits of the innovation. The trade-off could also be the other way: R&I activity may generate significant environmental benefits but at some cost in economic terms. An example could be a material efficient product that raises the cost of an appliance. In this case the real value of the innovation has to take both the environmental, social economic dimensions into account. It would recognise, for example, that the prohibiting cost considerations might influence the rate of adoption of the innovation and the associated environmental benefits. In this context, whenever possible the IA of R&I should account for possible rebound effects, trade effects and other systemic feedbacks.

- **Precautionary principle:** When operating under the fog of risk and uncertainty that surrounds more radical R&I it helps to have a few "lights" that can guide our assessments and actions in order to achieve a shared "directional certainty" about the desired course of action. One such light is provided by the precautionary principle (PP). The result of an R&I programme may be a new product or service, for example, of which the life cycle impacts cannot be evaluated with a full confidence and precision, but there may be reservations shared by key experts and stakeholders that its use or disposal may have serious impacts on ecosystems. Recognising the principle of proportionality, the IA is a process in which the level of uncertainty and risk should be assessed pragmatically.

In cases where uncertainty about impacts is considered relatively low or where risks of impacts can be assessed, the precautionary principle would dictate that the ex-ante IA includes strict criteria for ways in which the product or service is designed, produced, used and disposed while the ex-post IA devotes significant resources to collecting information on the impacts observed. In cases where uncertainty of impact is considered high, impact assessments could put forward more radical recommendations delaying or stopping planned R&I activities.

REFERENCES

EEA (1999) Environmental indicators: Typology and overview. Technical Report No. 25, European Environment Agency, Copenhagen

EEA (2010) The European Environment. State and outlook 2010. Material resources and waste. European Environment Agency, Copenhagen

European Commission (2009) Impact Assessment Guidelines, SEC(2009) 92

Giljum, S., Behrens, A., Hinterberger, F., Lutz, C., Meyer, B. (2008) Modelling scenarios towards a sustainable use of natural resources in Europe. Environmental Science and Policy 11(3), 204-216

Hoekstra, A.Y., Mekonnen, M.M. (2012) The water footprint of humanity. Proceedings of the National Academy of Sciences 109(9), 3232-3237.

Hyder (1999) Guidelines for the Assessment of Indirect and Cumulative Impacts as well as Impact Interactions, European Commission

Ijäs A., Kuitunen M, Jalava K. (2010) Developing the RIAM method (rapid impact assessment matrix) in the context of impact significance assessment Environmental Impact Assessment Review, 30, pp. 82–89

Markandya, A. (ed.) (2010) The Social Costs of Electricity: Scenarios and Policy Implications. Edward Elgar Publishing

Markandya, A., Dale, N. (2001) Measuring environmental degradation: developing pressure indicators for Europe. Edward Elgar Publishing.

Sala, S., Pant, R., Hauschild, M., Pennington, D. 2012. Research Needs and Challenges from Science to Decision Support. Lesson Learnt from the Development of the International Reference Life Cycle Data System (ILCD) Recommendations for Life Cycle Impact Assessment. Sustainability 4, 1412-1425

FURTHER READING

An extended version of the guide can be downloaded from **http://europa.eu/!Xm84ND**.

The full texts of 12 policy case studies developed for this report are available on **http://europa.eu/!Tj97Qn**.

The synthesis report comparing the policy case studies is available on **http://europa.eu/!JC47Qf**.

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