UN SDG Assessment Methodology and Guideline

Version 1.02

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Other reference:

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LIST OF CONTENT

COMPLEMENTARY ELECTRONIC FILES

This guidance document is accompanied by a number of complementary electronic files:

- An ***SDG Assessment Tool*** intended to facilitate the application of a number of methodological steps
  - ➔ Excel file named: "*SDG_Assessment_tool_v.1.02_42750-Jun20-version*"
- A **series of Appendices** (i.e. "Appendices A") documenting the application of the SDG Assessment Tool in each illustrative case, including:
  - ➔ Case 1: Excel file named "*SDG_Assessment_tool_v.1.02_42750-Jun20-version_CASE-1_EV_28052020*"
  - ➔ Case 2: Excel file named "*SDG_Assessment_tool_v.1.02_42750-Jun20-version_CASE-2_NOISE_28052020*"
  - ➔ Case 3: Excel file named "*SDG_Assessment_tool_v.1.02_42750-Jun20-version_CASE-3_Cod_28052020*"
  - ➔ Case 4: Two Excel files named "*SDG_Assessment_tool_v.1.02_42750-Jun20-version_CASE-4_City-BEST-SCEN_28052020*" and "*SDG_Assessment_tool_v.1.02_42750-Jun20-version_CASE-4_City-WORST-SCEN_28052020*"
  - ➔ Case 5: Excel file named "*SDG_Assessment_tool_v.1.02_42750-Jun20-version_CASE-5_PLANET_28052020*"
- A **template for illustrating SDG assessment results**
  - ➔ PowerPoint file named: "*SDG_Assessment_Figure_v.1.01_42750-Jun20-version*"

Chapter 1

INTRODUCTION

The purpose of this methodology and guideline is to **support a <u>semi-quantitative</u> evaluation of the contribution that a research project can have to sustainable development** through the [17 UN Sustainable Development Goals (SDG) and their underlying Targets][1]. The SDGs are indicated in the figure on the front page (Source: www.un.org). Altogether, they address social, economic and environmental dimensions of sustainability.

The developed methodology is inspired by the GHG Protocol's "Project Protocol" standards[2] (also: ISO14064-2:2006 and ISO14064-2:2019[3]) and Life Cycle Assessment standards (ISO14044:2006[4]). Much wider scopes are considered in the methodology as it covers all sustainability dimensions (not just greenhouse gas emissions) and any project that may reach out to systems at a societal level.

The methodology includes a default assessment framework, which is complemented with variants according to specific types of projects. These are specified further down.

Default assessment framework

The default assessment framework comprises 5 main phases, each of which includes a number of steps. Figure 1.1 illustrates those phases and their interactions, which include some iterative loops in order to focus and strengthen the application of specific phases and steps.

- Phase 1: Defining application(s) of the research project at societal level
- Phase 2: Scoping the assessment
- Phase 3: Inventorying effects from project application(s)
- Phase 4: Evaluating the contributions of the application(s) to SDGs
- Phase 5: Interpreting the assessment results

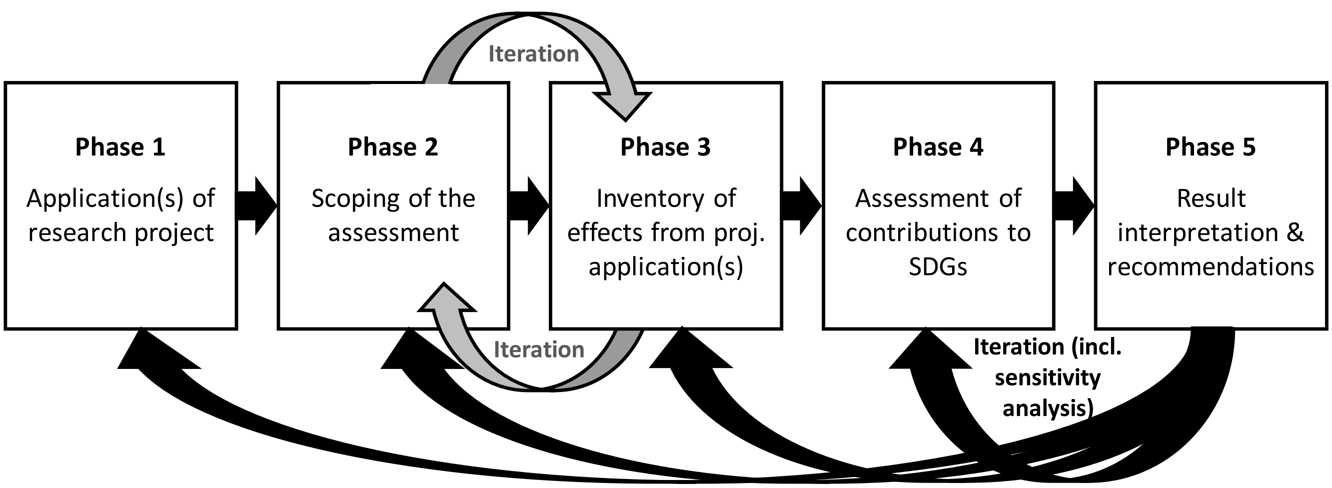

Figure 1.1. Phases and flow of the UN SDG Assessment Methodology.

[1] UN, 2015. Transforming Our World: the 2030 Agenda for Sustainable Development. United Nations Publishing, New York, NY, USA.
[2] The Greenhouse Gas Protocol, 2006. The GHG Protocol for Project Accounting. WRI/WBCSD, Washington, DC, US. ISBN 1-56973-598-0.
[3] ISO, 2019. Greenhouse gases — Part 2: Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements (ISO 14064-2:2019). ISO, Geneva, CH.
[4] ISO, 2006. Environmental management – life cycle assessment - requirements and guidelines (ISO 14044:2006). ISO, Geneva, CH.

Variants of the methodology according to the nature of the project

The default methodology can work well for some project types, but not for all. There may be project types, for which adaptations to the default methodology and its steps illustrated in Figure 1.1 are necessary, thus leading to variants of the methodology to fit each project type.

A categorisation of projects is proposed in Figure 1.2, where each category is defined and then associated with specific variants of the assessment methodology. When determining which project category is relevant to a project under study, it is recommended to first evaluate whether the project can relate to tangible technology development and implementation (Project Type 1 in Figure 1.2), and then, only if it does not, check whether it falls under Project Type 2, and thereafter go to Project Type 3 as a last resort. The decision tree in Figure 1.2 is intended to support this categorisation of the project at hand.

As shown in Figure 1.2, four variants of the assessment methodologies – all derived from the default methodology – can be distinguished, as a result of the project categorisation. For simplicity, these are named "Assessment Methods" A, B, C and D in the guideline. Assessment Method A includes all steps of the default methodology; Assessment Methods B, C and D include adaptations of these steps. The bottom part of Figure 1.2 provides indications as to how each of the Assessment Methods A-D differ from the steps of the default methodology.

In the following Chapter 2 ("Methodology"), the theoretical foundation of the default assessment methodology (= Assessment Method A) is first detailed, before subsequent sections address its implementation into the different Assessment Methods A-D, including the specific adaptations required for Methods B, C and D, respectively. As Assessment Methods B, C and D largely rely on the default assessment methodology, it is important to read its detailed description first. Examples are also provided, along with the methodology to illustrate specific methodological steps.

Following the methodology chapter, Chapter 3 provides a guidance for documenting the application of the assessment methodology in the form of a reporting template. Chapter 4 illustrates the application of the assessment methodologies through a variety of concrete case studies to provide guidance on how to follow the different phases and steps of the methodology under different project situations. A glossary is also available in Chapter 5.

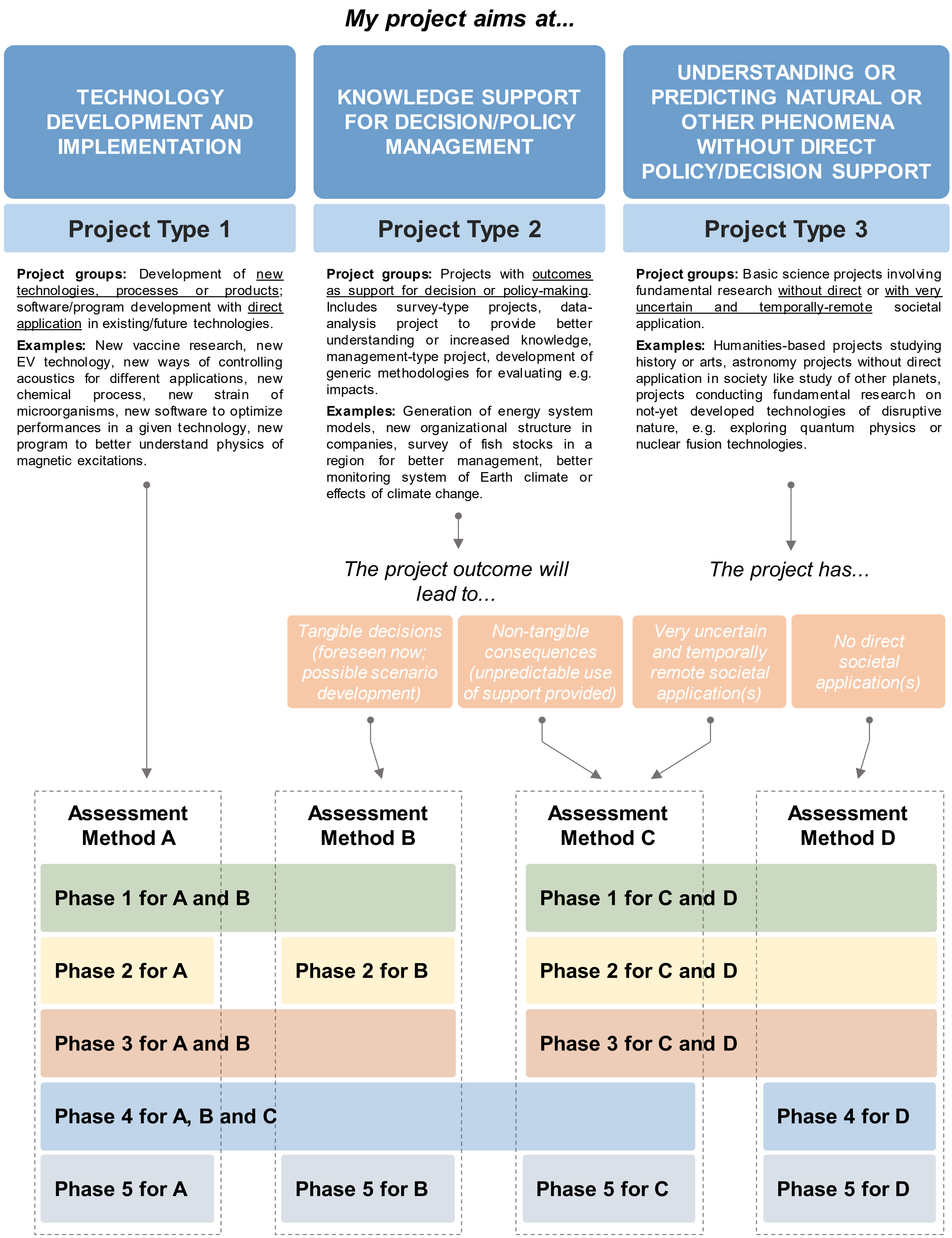

Figure 1.2. Categorization of projects and connections to variants of the assessment methodology. Check first if your project falls as Project Type 1 and then, only if it does not, move to check Project Types 2 and 3 in that order.

Chapter 2
METHODOLOGY

1. Assessment Method A (= default methodology)

In the default methodology, all five methodological phases, as presented in the introduction, are included. Each of them is described and detailed below. Before engaging into the applying the 5 phases, it is recommended to identify to which "Project Type" the research project belongs; Figure 1.2 should be used. This can lead to identifying the relevant Assessment Method (A, B, C or D) to apply in the assessment. Regardless of the selection, the present Section 1 should be read carefully as it provides detailed background for all Assessment Methods B-Dl (see also Section 2).

1.1. PHASE 1: Defining application(s) of the research project at societal level

The aim of the first phase is to clarify the goal of the SDG screening assessment – what is it that you need to assess the sustainability implications of? To this end, you need to take an outside-in view on the research project (termed just "project" in the following for simplicity): what are its potential applications in society? A project can result in a concrete product or technological solution, but may also be a more basic scientific research project that is anticipated to lead to a practical application sometime in the future or just advance scientific knowledge in a specific domain. To judge positive or negative contributions to sustainable development, one needs to think of the expected outcome(s) of the project and translate it into a concrete application in socioeconomic systems.

A project may lead to replacing existing technologies with new ones, but it may also lead to the introduction of technologies, which did not exist before, and some of these may even create new needs in society and new demands in the market. Some projects may have several possible applications and ideally, they should all be considered in order to reflect the potential impacts of the project outcomes on society and environment (i.e. its contributions to meeting the SDGs). Prioritization may be done, however, to simplify the task.

This prioritization can be done at 3 levels:

- **Type of applications**: the primary focus of the assessment should be on the application(s) resulting from the project outcomes that has/have the highest probability/ies to enter the market and/or with the largest potential impact on the SDGs (society or environment).
- **Geographical and/or activity scoping**: to make the assessment more manageable, it may be useful to delimit the scope of the application, for example to a specific country, region or sector. For example, if a new generic organizational structure in companies is developed through the project, the assessment could be limited to studying the impact on a specific sector in a given region. The assessment results obtained with the thus-limited scope can then be scaled up to a global scale at later stage in the assessment (see Phase 4). As for the type of applications, the combination of probability and impact should guide the delimitation to focus on specific sectors/regions.
- **Time horizon**: The temporal range of the application is important to evaluate, as the applications may be associated with immediate vs. delayed implementation (e.g. technology developed today may show potentials much later) or be relevant over a short vs. long period of time in society (e.g. some technologies can become rapidly obsolete, while others can become keystone for future technology development). The evaluation of the contribution of a project to sustainable development should ideally have a long time horizon to avoid ignoring potentially important impacts that occur far into the future. We opt to primarily focus the assessments on effects up to 2030 by default, but possible important effects beyond that time

should also be noted. This choice of a time horizon up to 2030 is motivated by (i) aligning the time horizon of the assessment with the 2030 SDG Agenda, and (ii) keeping the assessment within a reasonable time frame to avoid uncertainties linked to the development of society and central technologies in a longer time.

Our ability to predict which application(s) will actually take place and to what extent they will be effective is, however, limited. Our choice of considered application(s) may be accompanied by large uncertainties and by others regarded as arbitrary; it is therefore important to document them transparently, arguing for the different assumptions made. This can be supplemented by a sensitivity analysis to test some of the alternative applications and examine how differently they may affect the contribution of the project to the SDGs. The sensitivity analysis also supports the iterative approach integrated in the methodology, where it is recommended to revisit and refine the assessment in each of the methodological steps at least once in light of the findings from having gone through all the steps a first time.

Identifying the main application(s) of a research project, along with documenting potential limitations in the geographical, activity and/or temporal scoping, is the main outcome of the goal definition. Examples of projects, potential applications, and selected main application(s) are provided in Table 2.1.

Table 2.1. Examples of goal identification for different projects.

Project	**Potential application(s)**	**Main application(s)**
Project developing new electrolyte characteristics to increase storage capacity in Li-ion battery technologies.	The developed technology could replace existing Li-ion batteries in various products, e.g. electronic products, electric vehicles (EVs), etc.	Application in EVs is selected as the main application due to its large market potential and an increasing shift towards EVs in transportation sector.
Project building new predictive models for material appearance. [a]	The new models for enhanced rendering of material appearance could replace existing models, which are used currently as post-processing / corrective steps in manufacturing (e.g. 3D printing).	Application to 3D printing is considered as it is increasingly relevant and predicted to have increased use in many manufacturing processes.
Project developing a new programme to increase performances of an automatic cutting machine (used in manufacturing industries)	The new programme can replace existing programmes in all cutting machines used in manufacturing industries	The use of the new programme in cutting machines is the main application. To keep it manageable, the scope can be limited to a specific manufacturing company or country (e.g. Germany) at first.
Project developing innovative aquaculture process relying on aquaponics (plant and fish symbiotic ecosystems).	Potential replacement of existing systems for supplying (i) agricultural products, and (ii) fish (other aquaculture systems, fisheries).	Both applications for agriculture and fish production can be considered as main applications (food sector applications). Application to Europe is considered (limit the market scope)
Project developing miniaturized, non-invasive technologies that can track all key health metrics (heart, tensions, organ activities, etc.)	Sensors to take key health measures that can be used by medical sector as well as by individuals (daily use/monitoring).	Application as a smart watch, which can be worn by individuals (hence substituting conventional watches) is considered.

[a] Project topic inspired from a PhD project conducted at DTU Compute by Andrea Luongo

1.2. PHASE 2: Scoping the assessment

The objective of the scoping phase is to identify and map all activities and processes affected by the project application(s), as defined in Phase 1. To do so, two virtual situations are defined: one is the world with the project applications – and their consequences on society and/or environment; the other is the world, where that application would not have occurred (i.e. the project did not exist or did not yield any implementable results). The latter situation is referred to as the "baseline system" while the situation with the application can be referred to as the "new system" (see also Clarifying Box 2.1).

Clarifying Box 2.1. One baseline or several possible baselines?

It is important to understand that, in reality, there is only one baseline and then several possible "new systems" depending on which application(s) is selected in the goal definition. The baseline is the same no matter what applications are considered because it is defined as the world without the project and its applications. In our methodology, the definition of the baseline can be application-dependent, but only because we refine/limit its boundaries to the affected activities/processes, which may be altered depending on the selected applications.

Phase 2 includes two steps, aiming at defining the assessment boundaries of the baseline and new systems, respectively. In general, both the new system and the baseline fulfill the same functions or services to society, albeit with the use of different technologies or approaches (replacement or existing products or technologies with improved ones). In some rare cases, innovations may however lead to creating new needs, rather than just fulfilling existing needs in a new way (e.g. invention of a new cure). In such cases, there is no alternative technology, product or service, which can be replaced, and the baseline and new system fulfil different functions or needs in the society. The identification of the functions or needs of the project applications in the society can provide a starting point to identify the concerned activities (see also Clarifying Box 2.2).

Clarifying Box 2.2. Is there functional equivalence between the baseline and the new systems?

Because the baseline and new systems are broadly defined (up to the entire world) and can be regarded as parallel trajectories of how the world may evolve, there may not be functional equivalence between them. Systems may have different functions responding to different needs. Let us take the example of smartphones, so comparing a world with smartphones and a world without smartphones. Smartphones enable the function of calling/texting someone, like conventional mobile phones, and additionally allow access to advanced features normally provided by a computer (e.g. internet access, etc.). Yet, the deployment of smartphones on the market led to substituting conventional phones but did not lead to any decrease in use of computers. A new need corresponding to the multi-functionalities offered by smartphones (in particular the computer functions now integrated into the phones), and not least the possibility to be 'on-line' 24-7 was created, fostering the development of the social media with very wide-reaching implications for society and other technology development. In the baseline system, conventional phones – with less functionality – could still be in use.

Step 1. Delimiting the assessment boundary of the baseline system

For the baseline, the delimitation of the assessment boundary starts by considering the entire world and then refining the scope boundaries to only include existing products, technologies, activities or services that the project application (from Phase 1) can potentially replace and/or impact. For example, if the defined project application is an improved electric vehicles (EV) technology, the baseline boundary could be scoped to the current transportation systems and its predicted operations without that new technology (with possible geographical and temporal limitations defined in Phase 1, e.g. time horizon up to 2030). Other systems that interact with the transport systems, and may be impacted by them and/or impact on them, should also be included. For example, electricity supply systems are interconnected with transport systems wherever EVs are involved, hence these should be included as part of the baseline. When identifying and defining the assessment boundary of the baseline, one seeks to cover all activities that may be directly or indirectly impacted by the application, and leave out those activities that are not.

To ensure comprehensiveness in the mapping of all activities, it is recommended to adopt a life cycle perspective, and include in the assessment boundary all upstream and downstream processes that may be dependent on the identified activities impacted by the project applications. A definition of the life cycle perspective is provided in Clarifying Box 2.3. Clarifying Box 2.4 additionally defines what processes are in the context of a life cycle perspective.

Clarifying Box 2.3. What is the life cycle of a product or a service system?

The life cycle consists of the entire value chain, including manufacturing, use and end-of-life processing of a product or technology. It comprises all processes that are needed for the system to operate and fulfil its functions. To make the life cycle more legible, these processes in a life cycle are often grouped into four life cycle stages, namely raw materials extraction, production, use and recycling & end-of-life. Note that there could be several cross-cutting or intersecting life cycles depending on the application considered. For example, for electricity from fossil fuels, one can consider the life cycle of the power plant, which interacts with the life cycle of fuels during its operation/use (see Figure 2.1).[5]

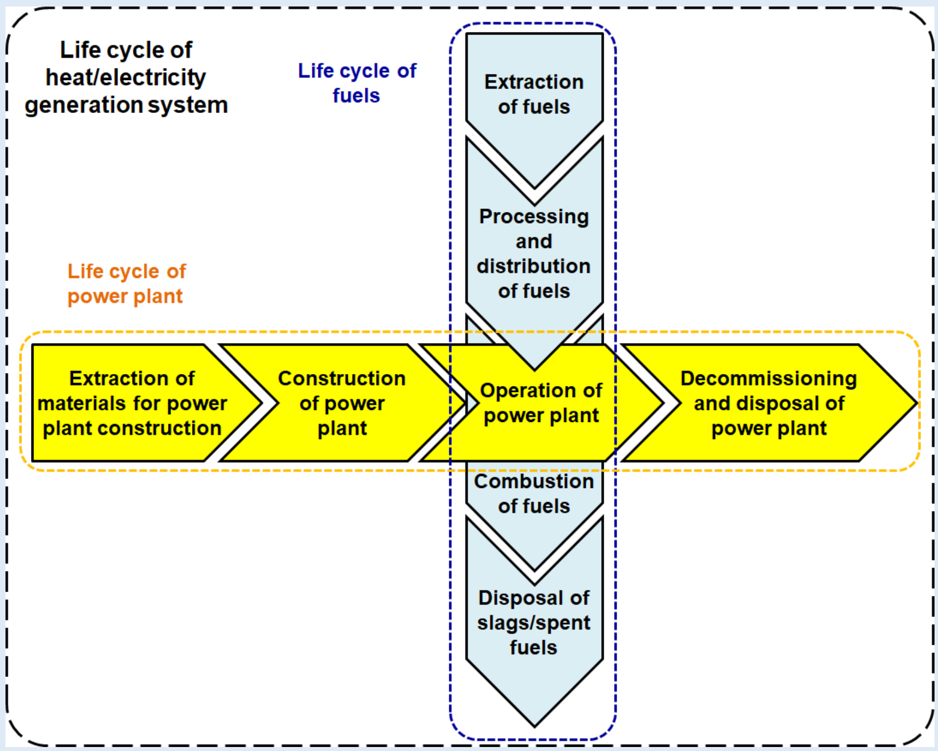

Figure 2.1. Example of life cycle of electricity generation system, with illustration of the four life cycle stages (raw materials extraction, production, use/operation, recycling/disposal). Note that raw materials extraction and production may also be combined in one stage. Source: Laurent et al. (2018)[6].

The life cycle perspective is a way to ensure that a systemic and holistic approach is applied in the assessment, and that no important aspect or relevant processes affected by the application is overlooked. Hence, when mapping the baseline system, differentiation between the four life cycle stages, i.e. raw materials extraction, production, use/operation and end-of-life, should be done. For example, the main processes in the life cycle of transportation systems based on cars are related to the extraction of raw materials (e.g. mining of metals and crude oil), the manufacturing of the car body and power trains, the production and combustion of fuels and lubricants, the waste management processes including recycling of steel, etc.

[5] Laurent A., Espinosa N., Hauschild M.Z. 2018. *LCA of Energy Systems* (Chapter 26, pp. 633-668). In: *Life Cycle Assessment: Theory and Practice* (Eds. Hauschild M.Z., et al.). ISBN 978-3-319-56475-3. Springer, Dordrecht, NL.

Clarifying Box 2.4. What are processes in a life cycle?

A process is a physical activity, a building block, of the life cycle[6]. For example, it can be the refining of crude oil, or the assembly of a smartphone from its different components or the waste management of an amount of municipal waste. In the SDG context, main processes are those processes which contribute most positively or negatively to SDGs of the baseline. For example, the main processes in the life cycle of transportation system based on cars are related to the extraction of raw materials (e.g. metals or crude oil), the manufacturing of car body and power trains the production and combustion of fuels and lubricants, the waste management processes including recycling of steel, etc.

The life cycle of a product, technology or activity can be represented by a few highly-aggregated processes (e.g. 'production of engine') or several hundreds of processes, depending on how detailed and accurate one aims to be. Listing all detailed processes in a life cycle is rarely practical because the number of activities is enormous, even for simple products or systems. To improve precision, it is essential to apply the highest resolution to the modelling of those parts of the life cycle that contribute most to the overall impacts from the life cycle. Some of the identified activities and processes may thus be disregarded if they are shown not to be significantly impacted by the project application (little changes expected).

Identifying and gauging the significance of these effects of the project applications is part of Phase 3 (see below), which is a reason why we recommend that *Phases 2 and 3 be done in iteration* (see Figure 1.1 in Introduction), so the baseline scoping can be iteratively adjusted not to be too broad (= including activities not impacted or insignificantly impacted by the project application) or too narrow (= omitting relevant activities). Eventually, the outcome of Step 1 is a life-cycle-based overview or mapping of the main activities in the baseline, i.e. those anticipated to change from the new system implementation and thereby contribute positively or negatively to the SDGs in a non-negligible way. Figure 2.2 (which is the concrete outcome of Step 1) illustrates a conceptual baseline system life cycle with its main processes. If there is uncertainty as to how important some processes are, it is recommended to include them in a first iteration. Such uncertainty may be alleviated through the iterative conduct of Phases 2 and 3, and lead to some of them being flagged as "main processes" while others could simply be removed.

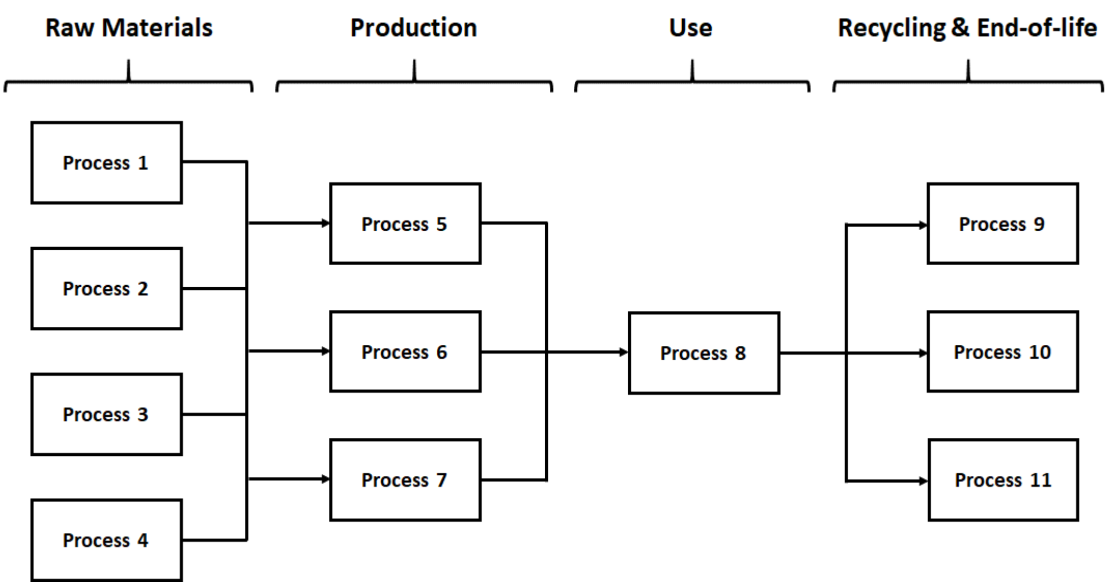

Figure 2.2. Conceptual example of the life cycle of a baseline system, indicating main processes that are needed to fulfill a given function or service, grouped into four life cycle stages.

[6] Bjørn A., Owsianiak M., Laurent A., Olsen S.I., Corona A., Hauschild M.Z. 2018. *Scope definition* (Chapter 8, pp. 75-116). In: *Life Cycle Assessment: Theory and Practice* (Eds. Hauschild M.Z., et al.). ISBN 978-3-319-56475-3. Springer, Dordrecht, NL.

Step 2. Delimiting the assessment boundary of the new system

In situations where the new system fulfils the same functions or needs in the society as the baseline, the assessment boundary of the new system should overall be identical to that of the baseline in the type of activities or sectors included, although specific processes may differ between them (e.g. different manufacturing processes, different synthesis pathways for a chemical, few new specific processes, etc.). Figure 2.3 illustrates how the new system life cycle should be described with indications of the differences compared to the baseline system life cycle. This display of the new system supports the conduct of Phase 3 and should also be iteratively refined after looping the Phases 2 and 3 (representation in Figure 2.3 can be regarded as the final version after iterations of Phases 2 and 3).

In the rare cases, where the two systems fulfil different needs/functions, the baseline (prior to removal of insignificant activities) is simply the whole world without the new application (see also Clarifying Box 2.1), as it evolves from now into the future (e.g. until 2030), while the new system can be delimited as the baseline system complemented with the additional activities triggered by the project application in society. To map the activities within such a new system boundary, we recommend to first identify the main sectors that the new application can impact or interact with (e.g. electronics in the example of smartphones, pharmaceutical sector in the example of new drugs, etc.) and map the key processes or activities in the life cycle of those to add them to the mapping of the baseline (done in Step 1).

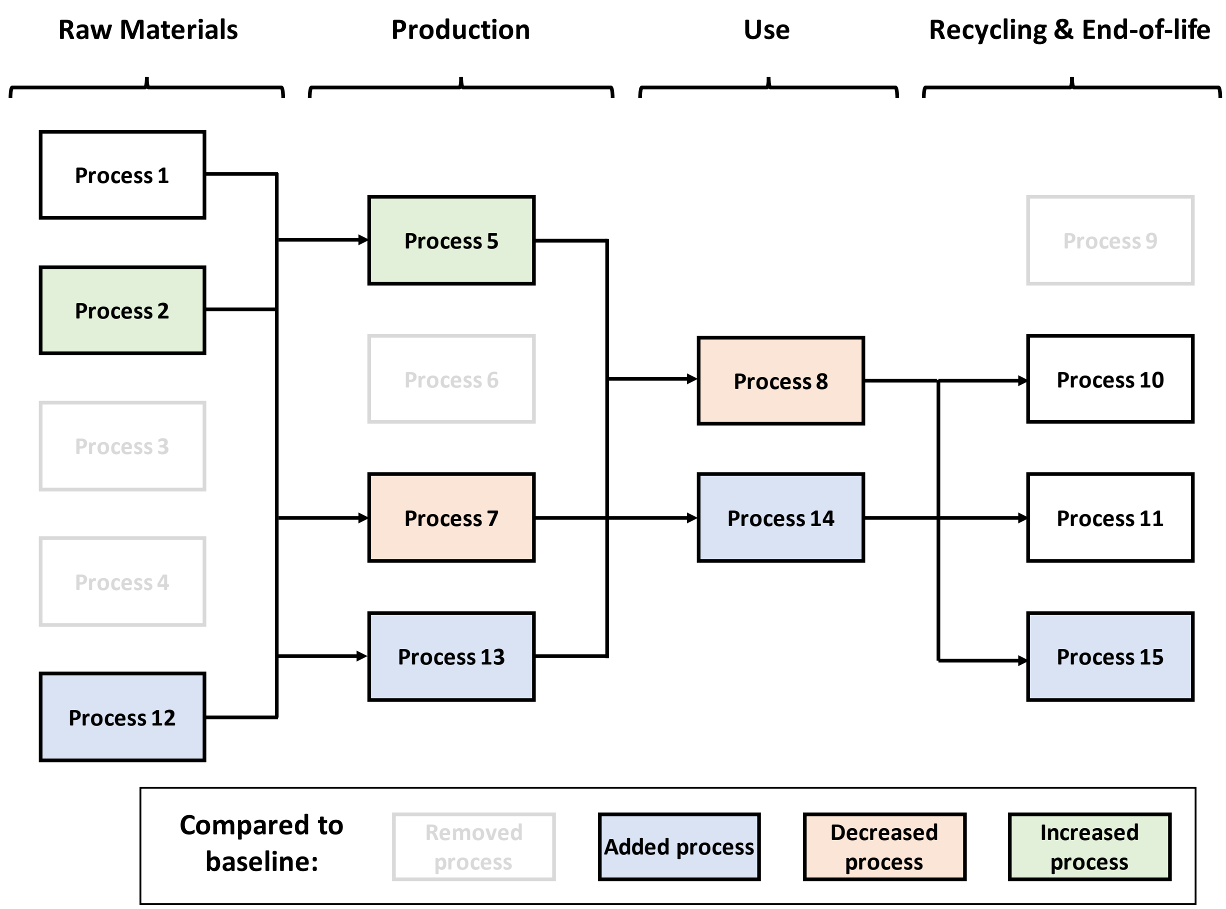

Figure 2.3. Conceptual example of the life cycle of a new system, indicating main processes that are needed to fulfill a given function or service, grouped into four life cycle stages. When possible, removed processes (light grey) and added processes (blue) compared to the baseline system (see Figure 2.2) can be displayed as well as processes with decreased (orange) or increased (green) intensities.

1.3. PHASE 3: Inventorying the effects from project application(s)

The "effects" are changes in activities or processes that the application brings to the baseline (thereby transforming it into the new system). Altogether, the effects therefore express the differences between the baseline and the new system. They can be of very diverse nature: physical or non-physical. Three types of changes in physical processes can exist: (i) introducing new processes to the baseline, (ii) removing some processes from the baseline, and/or (iii) altering existing processes in the baseline to reflect increased or decreased demand for these processes. These physical changes should be visible when comparing the mapping of the baseline (Step 1 in Phase 2) with that of the new system (Step 2 in Phase 2), since they constitute the differences between the two. Non-physical changes can be many-fold: economic (e.g. changes in economic growth), social (e.g. change in consumer behavior), ethical, etc. (Figure 2.4).

Effects may occur in any of the four stages of the system life cycle. The objective of Phase 3 is to identify all these effects and position them across the four life cycle stages, so as to later be able to evaluate their overall contributions to SDGs (in Phase 4).

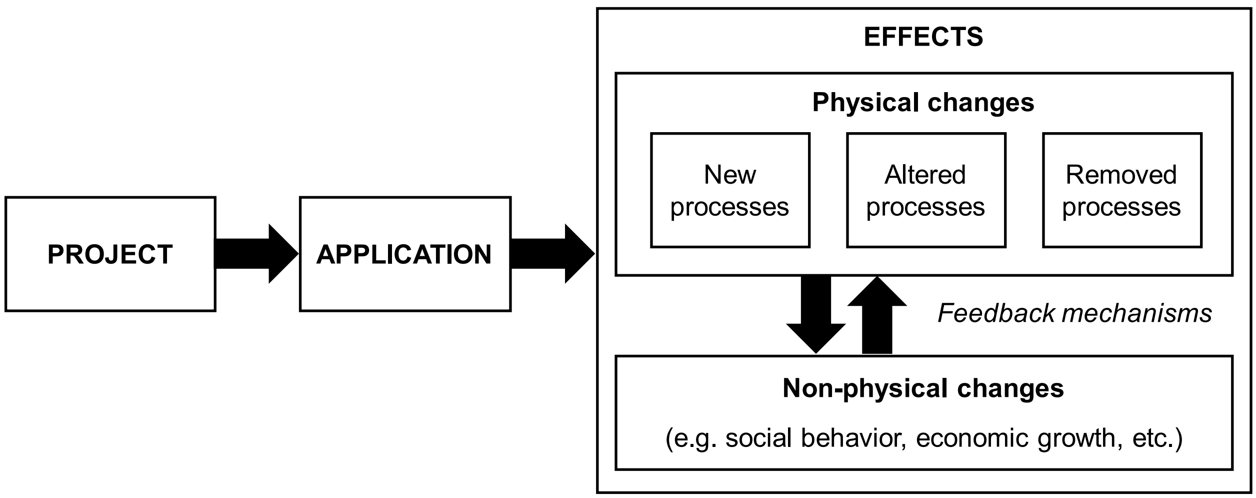

Figure 2.4. Different types of effects of a project application.

Clarifying Box 2.5. Baseline, effects and new system: where to start your thinking?

You typically know two things: the current situation and your project. The former knowledge can help you define the baseline, which is the evolution from the current situation, without any application of the outcomes of your project. Now, your insights into the project and the possible outcomes should enable you to estimate (or guesstimate ☺) what your project application may look like and, more importantly, what it can bring as potential advantages and drawbacks, benefits for and negative impacts on society, economy and/or environment. These potential changes, introduced to the surrounding world, are what we refer to as "effects". They are all changes in the situation described by the baseline that will occur as consequences of the application of your research outcomes. Taking the baseline and accounting for all these changes will result in a new state, which we refer to as the "new system". This is why the methodology requires you to identify and define the baseline system in Phase 2, and thereafter identify the effects in Phase 3 in an iterative manner.

We distinguish between direct and indirect effects to facilitate the identification of all effects. Some effects may however be difficult to flag as direct or indirect and here, we recommend to select one of the two categories and document justifications for it. Since the distinction between direct and indirect effects is not carried over to the evaluation phase (Phase 4), the classification has no further implications on the evaluation results. You should consider it as a way to inspire and structure your identification of the effects.

- ***Direct effects.*** The direct changes from implementing the application in society are defined as "direct effects". In applied science projects, they are typically intended effects, reflecting the purpose of the project and its application. They tend to be limited to the main products, technologies or sectors targeted by the application.
- ***Indirect effects.*** The indirect effects are very often unintended and are the consequences of the application implementation on other products, technologies or systems than the systems targeted by the application.

An example using the introduction of bioethanol as automotive fuel to illustrate the distinction between the two types of effects is provided in Table 2.2. Note that in this example, many processes of the baseline will not change as a consequence of introducing the intended application because they are irrelevant to the application or unchanged by its implementation, and will thus remain the same in the baseline system and the new system. For example, existing gas stations may be used to enable refueling with the new bioethanol blend.

Clarifying Box 2.6. Direct and indirect effects from a project application.

The project application may have a number of effects on environmental, societal or economic spheres, which will differentiate the new system from its baseline. A project with no obvious concrete application will lead to the definition of a new system nearly identical to its baseline: the only effects will be direct and relate to the graduation of the PhD student; they will mainly consist of the individual development of the PhD student him/herself (higher education, well-being, marginal increase in qualified labor on the overall market) and to increased scientific knowledge (see also Section 5). In contrast, a project leading to the discovery of a ground-breaking technology may lead to important differences between the baseline and the new system. For example, if we retrospectively assume that a PhD project led to the discovery of penicillin, its deployment in society for medical use can be identified as its main application. The baseline would be a world evolving without penicillin while the new system would be defined as a world with it. The (intended) direct effect of the project application is to treat infections (now rendered possible in the new system), which will then reduce morbidity and mortality in the population. As part of Phase 2, a number of processes in the biochemical and medical sectors would have been identified: some processes would be newly-created processes (e.g. new synthesis pathway for penicillin at commercial scale), while others would be altered processes (e.g. need for increased production of an already existing agent for the penicillin production; more transportation needs or more specific materials required). Those can still be considered direct effects. A number of indirect effects would also occur: the large demand for the cure calls for important production efforts, which leads to job creation and new business opportunities for the biochemical industry, and increased user support, like more doctors to handle the treatments. At the same time, as a consequence of easy access to the cure and the generally-better health of the population, people start having longer life expectancies and the population tends to increase, leading to more consumption and production with all its associated benefits and impacts for society, economies and environment (e.g. more economic growth, more damage to natural resources, etc.).

Table 2.2. Example of direct and indirect effects from new bioethanol fuel development (non-exhaustive)

Application	Direct effects	Indirect effects
A project developing bioethanol for use as an automotive fuel, with application leading to the replacement of gasoline made from petroleum hydrocarbons with bioethanol to reduce GHG emissions from combustion	**Physical** Additional demand for biomass (i.e. new or altered existing processes), increased industrial production capacity for the fermentation of sugars generated from the biomass and distillation of the resulting bioethanol (i.e. altered existing processes, with increased capacity), development of new logistic pathways in order to enable refueling with the bioethanol (new processes), as well as a reduction in the production and use of petroleum products, if substitution is assumed rather than increasing demand for both fuels as market mechanism (altered processes with decreased capacity). **Non-physical** Better conscience from driving a car that has less impacts on climate change	**Physical** Possible shortage of arable land caused by the biomass production if 1st generation of biofuels is considered (i.e. the crops used for bioethanol production could otherwise be used for food production, creating a gap in food supply meaning that additional arable land is needed to meet the demand), leading to conversion of natural ecosystems to farmland. **Non-physical** Potential changes in transport patterns and demands, as people may be tempted to travel more knowing they drive with low-carbon vehicles.

Once identified (and after the required iterations with Phase 2), the identified effects should be assigned to the different life cycle stages, where they occur or where they have their main influences. This is true for both non-physical and physical changes (on the principle of additions, removals or alterations relative to the baseline).

For effects relating to physical changes, this specification should cover processes, which (i) shall be removed from the baseline life cycle, and/or (ii) shall be added to the baseline life cycle, and/or (iii) shall be altered to reflect increased or decreased demand, and/or (iv) which are likely not to change (but with uncertainty as to whether they might enter in one of the previous three categories (i-iii)). The recommendation to also include processes that carry uncertainty as to their changes (i.e. category (iv)) is intended to ensure that all main processes are scrutinized to decide whether they should be discarded from the assessment. Processes entering this category (iv) should be addressed via iterations with Phase 2 to determine whether they should be kept or removed. In case of persistent doubt, a conservative approach can be adopted to retain them until the evaluation phase (= Phase 4), where the uncertainty may be resolved.

In this identification process, it may be helpful to start from the life cycle stage which is the most obvious for a given application. In the bioethanol example, it could be the production or use stage: the main processes listed in Figure 2.2 and Table 2.2 should serve as starting points and be iteratively completed, where needed. Effects that are non-physical changes should also be allocated to the life cycle stages.

Following the application of the above identification and categorization of the effects, we recommend that they are organized in a table format like Table 2.3: it is an intermediary table, which lists all direct and indirect effects of the application across the different life cycle stages. It still retains processes that are not estimated to change. After the iterations conducted between Phases 2 and 3, the uncertainty of these processes is resolved (i.e. whether they should be considered or not), and a resulting table like Table 2.4 can be derived. Table 2.4 can be regarded as the main output of Phase 3.

Table 2.3. Intermediate table showing direct and indirect effects, highlighting processes and non-physical changes have to be altered (orange: decreased intensity; green: increased intensity), added to (blue) or removed from (grey) the baseline life cycle as a consequence of introducing the new system. Processes with uncertainty as to their alterations/changes are marked in black (still in need of further study).

Raw materials	Production	Use	Recycling & End-of-life
Process 1: possibly no change (uncertainty) Effect 1 (Process 2 to increase) Effect 2 (Process 3 to remove) Effect 3 (Process 4 to remove) Effect 4 (New Process 12 to add)	Process 5: possibly no change (uncertainty) Effect 5 (Process 6 to remove) Effect 6 (Process 7 to decrease) Effect 7 (New Process 13 to add)	Process 8: possibly no change (uncertainty) Effect 8 (New Process 14 to add) Effect 9 (Non-physical change to add)	Effect 10 (Process 9 to remove) Process 10: possibly no change (uncertainty) Process 11: possibly no change (uncertainty) Effect 11(New Process 15 to add)

Table 2.4. Final table showing direct and indirect effects, highlighting processes and non-physical changes which have to be altered (orange: decreased intensity; green: increased intensity), added to (blue) or removed from (grey) the baseline life cycle as a consequence of introducing the new system. Uncertainties in some processes (see Table 2.3) have now been resolved: no changes for processes 1, 10 and 11, but increased intensities for process 5 and decreased intensity for process 8, leading to 2 new effects listed in the table.

Raw materials	Production	Use	Recycling & End-of-life
Effect 1 (Process 2 to increase) Effect 2 (Process 3 to remove) Effect 3 (Process 4 to remove) Effect 4 (New Process 12 to add)	Effect 5 (Process 5 to increase) Effect 6 (Process 6 to remove) Effect 7 (Process 7 to decrease) Effect 8 (New Process 13 to add)	Effect 9 (Process 8 to decrease) Effect 10 (New Process 14 to add) Effect 11 (Non-physical change to add)	Effect 12 (Process 9 to remove) Effect 13 (New Process 15 to add)

1.4. PHASE 4: Evaluating the contributions of the application(s) to SDGs

The effects identified in Phase 3 (Table 2.4) need to be linked to all SDGs, which they can affect positively and/or negatively. This is the objective of Phase 4, which is divided into two steps and aims to (i) identify the SDGs that may be affected by the effects, thus connecting the effects to the impacted goals of the UN SDG framework (Step 1); and (ii) characterize, in a semi-quantitative way, the contributions of each effect to the impacted SDGs (Step 2).

Step 1. Identifying the potential SDGs impacted by the effects

The effects identified in the scoping Phase 3 may lead to positive (e.g. better well-being), or negative (e.g. increase of GHG emissions) contributions to the social, economic and environmental dimensions of sustainability. The framework of the 17 SDGs and their 169 targets offers an authoritative specification of what is meant by sustainable development and can be used for connecting the effects of the new system to positive or negative contributions to sustainable development[7].

Various methods may be used for identifying such connections or linkages, and there is no one-size-fits-all approach. Some effects may have been defined in the scoping Phase 3 with a clear link to SDGs, while others may still require identification of potential consequences for society or environment before it is possible to relate them to the SDGs (see Clarifying Box 2.7). For example, the main effect of a drug like penicillin, to improve human health, would have an obvious direct connection to SDG no. 3 ("Good health and well-being"). In contrast, the indirect effects of the increased life expectancy that results from the development of such a drug would require further analysis of what positive and negative consequences this may induce in the socioeconomic systems and the environment. For such analysis, the causality chain analysis may be useful (see Clarifying Box 2.7). A number of other tools exist that may help link the effects to the different SDGs –see Table 2.5 for a non-exhaustive selection.

Table 2.5. Tools and methods to help link identified effects with their impacts on SDGs (non-exhaustive list).

Tool / Method	Short description	Link (accessed 11/2019)
SDG sector roadmaps	Guidance on how to identify possible actions towards SDG at sectors, including establishing current positions, Identify key impact opportunities and action possibilities.	https://www.wbcsd.org/Programs/People/Sustainable-Development-Goals/SDG-Sector-Roadmaps/Resources/SDG-Sector-Roadmaps
Blueprint for Business Leadership on the SDGs	Examples and inspiration for business actions in support of achievement of SDGs.	https://www.unglobalcompact.org/library/5461
SDG selector	Identify which SDG is relevant for the specific business.	https://dm.pwc.com/SDGSelector/
Ramboll SDG Impact Assessment	Evaluation tools to identify the relevant SDGs to individual companies.	https://www.results.dk/un-goals/
SDG industry matrix	Industry specific actions and ideas towards SDGs.	https://www.unglobalcompact.org/library/3111

In the identification of links between the effects and the potentially-impacted SDGs, you should be careful to look for positive as well as negative contributions; it is important to identify both at this stage. The gauging of these contributions (semi-quantitatively) is performed in Step 2, but at this point it is important that no potentially important links to SDGs are overlooked. Therefore, it is recommended to be conservative in including any potential SDGs (through their related targets, or not) that might be impacted (positively or negatively) by an effect. During the evaluation and interpretation phases (Phases 4 and 5), negligible contributions are identified and could then be removed in an iterative way.

[7] An authoritative and comprehensive introduction to all 17 SDGs and their underlying targets can be found at: https://www.un.org/sustainabledevelopment/sustainable-development-goals/

Clarifying Box 2.7. Effects, consequences, SDG impacts and causality chain

Effects are defined as the physical or non-physical changes in activities or processes that the application brings to the baseline system when introducing the project applications (see Phase 3). These effects can be directly connected to SDGs and/or targets (e.g. increase partnerships in a project application facilitating synergies between industrial players, thus directly connecting to SDG no. 17) or have a chain of consequences on other socioeconomic and/or environmental systems before impacting a specific SDG (See Figure 2.5).

Representing the causality chain as flow charts, as illustrated in Figure 2.6, can offer a visual way to help the user understand the mechanisms by which an effect (i.e. physical or non-physical change) may lead to environmental, social or economic consequences, and eventually to an impact on one or more SDGs.

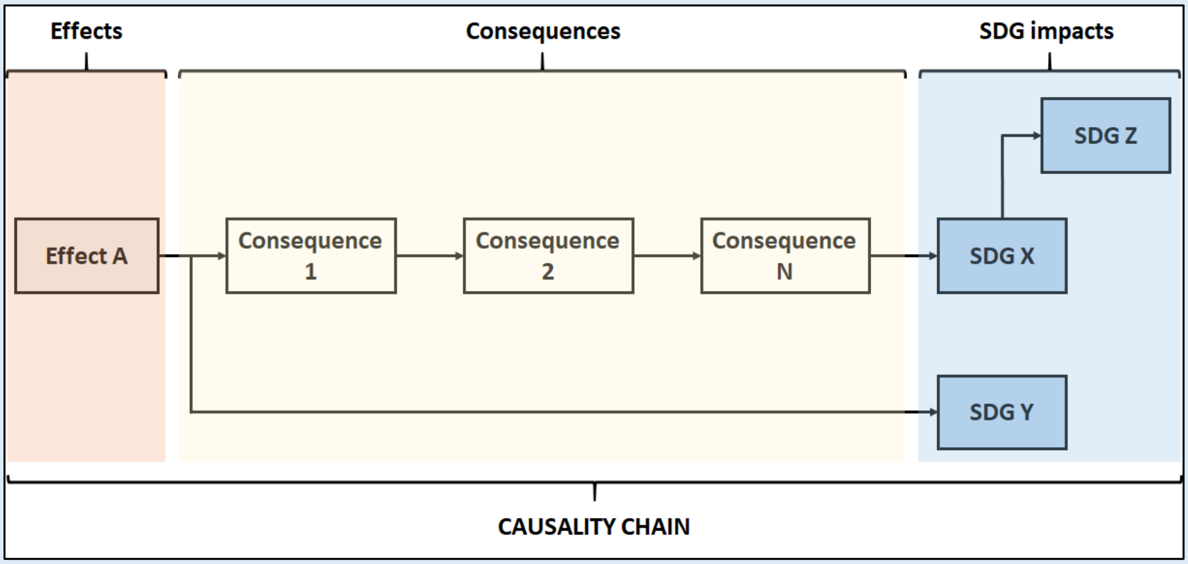

Figure 2.5. Conceptual causality chain linking effects and SDG impacts

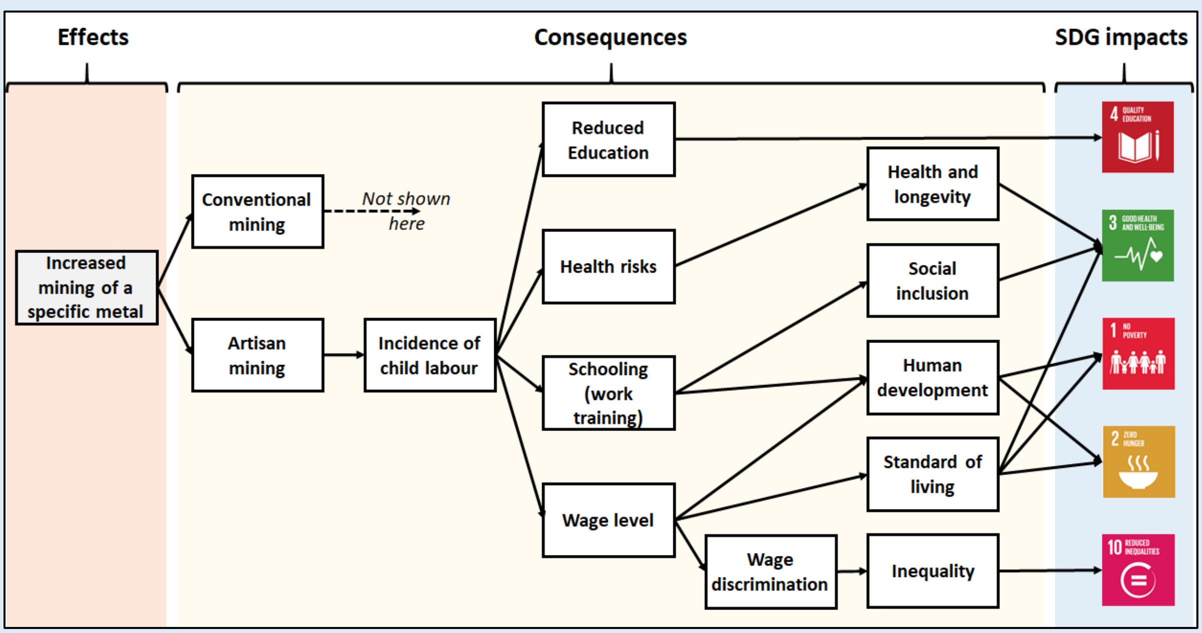

Figure 2.6. Illustrative causality chain linking increased mining of a specific metal (with focus on artisan mining involving child labor) to SDG impacts.

Table 2.6 is the main output of Step 1. It summarizes and documents the connections of each effect to the relevant SDGs. Note that numerous interlinkages exist between the SDGs and between their individual targets, meaning that a negative contribution to an SDG X may induce a negative contribution to another SDG Z (the feedback mechanisms illustrated in Figure 2.4 and illustrated in Figure 2.5) and counterbalance a pre-identified positive contribution to SDG Z. Such interlinkages should be captured as much as possible in the evaluation. This should be indicated in Table 2.6 as well, adding additional rows for each interlinked SDG and providing justifications for each interlinkage in the last column). In Table 2.6, for Effect 1, SDG N_6 is impacted via SDG N_1; likewise for SDG N_8 being impacted via SDG N_2. A number of tools and methods exist to identify these cross-cutting links –some are listed in Table 2.7.

Table 2.6. Template of identification of SDG impacted by each effect, along with justifications

Effect	**SDG**	**Justification for SDG-Targets impacts**	**Justification for interlinked SDG-Targets impacts**
Effect 1	SDG N_1	## *Justifications* ##	Cross-link with SDG N_6
	SDG N_6	Caused by the impacted SDG N_1	## *Justifications* ##
	SDG N_2	## *Justifications* ##	Cross-link with SDG N_8
	SDG N_8	Caused by the impacted SDG N_2	## *Justifications* ##
Effect 2	SDG N_3	## *Justifications* ##	-
…	…	…	…

Table 2.7. Tools and guidance to help identify interlinkages between SDGs and targets (non-exhaustive list).

Tool / Method	**Short description**	**Link (accessed 11/2019)**
SDG Interlinkages Analysis & Visualization Tool	Identify the interlinkage between SDGs and targets.	https://sdginterlinkages.iges.jp/visualisationtool.html
A guide to SDG interactions	Identify SDGs interlinkages across goals and targets	https://council.science/publications/a-guide-to-sdg-interactions-from-science-to-implementation
Nexus approach for the SDGs: Interlinkages between goals and targets	Identify interlinkages between SDGs and targets.	http://sdgtoolkit.org/tool/a-nexus-approach-for-the-sdgs-interlinkages-between-the-goals-and-targets/

Step 2: Semi-quantitative evaluation of the contributions to SDGs

The evaluation of the new system's contribution to the SDGs can be conducted qualitatively or quantitatively. Quantitative assessment can at this point only be performed for a limited number of SDGs (incl. targets) using dedicated tools or methods that have been developed for specific applications (e.g. specific sectors, industry, etc.). This means that a full quantitative evaluation covering all SDGs is currently not possible. In the present methodology, we propose a semi-quantitative assessment to characterize the extent of the contributions of each effect from the application to the SDGs (also termed "SDG impacts" in the following).

The assessment should consider the following three criteria:

1. ***Direction of the SDG impacts:*** Whether the contribution is positive or negative (or negligible/unknown).
2. ***Likelihood of the SDG impacts:*** likelihood that they will occur based on objective evidence to the largest extent possible.
3. ***Magnitude of the SDG impacts:*** expected magnitude of the impact based on objective evidence to the largest extent possible.

Table 2.8 offers rules of thumb for assessing the likelihood, based on definitions for evaluating climate change risks from the IPCC[8]. As the evaluation of the SDG impacts is a forecasting exercise, the likelihood is dependent on the user's subjective judgement, but it should be based on objective evidence to the extent possible. This is why we recommend taking particular care in transparently reporting the assumptions made when assessing the likelihood. In the assessment, the likelihood can be estimated with a numerical value (0-100%) if there is sufficiently robust arguments to back up the estimation, or it can be given as the qualitative statement (i.e. "likely", "possible", "unlikely").

Table 2.8. Guidelines for evaluating the likelihood of SDG impacts

Likelihood	Description	Likelihood
Likely	There is reason to believe that the SDG impact will happen as a consequence of the effect. For example, production of cars will likely to lead to the increase of chemical pollutants during the manufacturing stage, thus increasing the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination (SDG 3).	>67%
Possible	There is some probability that the SDG impact will happen as a consequence of the effect. For example, increased crude oil extraction may lead to pollutants emitted to water bodies, soil and air around the oilfield, thus reduce the water quality (SDG 6). However, whether this consequence will happen depends on how the oilfield is managed. Thus it is categorized as possible to happen.	33%-67%
Unlikely	There is a low probability that the SDG impact will happen as a consequence of the effect. The impacts for which you cannot determine the likelihood should be categorized here. For example, production of extra electricity due to the use of EVs may result in increased consumption of natural resources (SDG 12). However, the extent depends strongly on the type of energy source that is used to produce the affected marginal electricity. While fossil energy sources have extensive use of non-renewable resources during the production stage, this is much more limited when using renewable energy sources, for example in Denmark. Depending on the energy system in the affected region, the contribution of this effect to SDG 12 may be considered unlikely.	<33%

Relating the SDG impacts to a given situation is necessary to enable benchmarking and an appraisal of the magnitude of the SDG impacts. Two situations/levels should be taken: (i) the project application as defined in Phase 1 (with its specific limitations in terms of types of activity, geographical and activity scoping, and time horizon); and (ii) the entire global perspective, for which the SDGs were primarily defined. In the assessment, we recommend first conducting the assessment at the level of the project application, as defined in Phase 1. Then, the results and conclusions should be discussed with respect to how they may be altered when upscaling the considered applications to include all possible types of applications (e.g. sensors taking key health measures as in Table 2.1 considered for smart watch applications, now extended to all applications, incl. medical sector, etc.) and/or the full geographical range of the applications (e.g. from selected countries/regions to entire world) and/or an extended time horizon (e.g. beyond 2030), wherever relevant and applicable. Contributions relative to the total global contributions to the SDG impacts should thus be assessed in this latter case.

[8] Mastrandrea, M.D., C.B. Field, T.F. Stocker, O. Edenhofer, K.L. Ebi, D.J. Frame, H. Held, E. Kriegler, K.J. Mach, P.R. Matschoss, G.-K. Plattner, G.W. Yohe, and F.W. Zwiers, 2010. *Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties*. Intergovernmental Panel on Climate Change (IPCC). Available at <http://www.ipcc.ch>.

Following the above recommendations, the magnitude can first be estimated by gauging the impacts that the project application(s) makes on the SDGs and/or targets (level (i) in above), considering if it affects the entire geographical scope of the application (e.g. affecting population in a specific small part of the region or the entire region) and/or the entire temporal scope of the application (long-lasting vs. short-term impacts). An example is a project developing cures for snake bites. If the project applications (= the serum) enables a significant decrease in the mortality rate from snake bites, then it may be estimated to have a large impacts on SDG 3 ("good health and well-being"). Taken in a global perspective (level (ii) in above), the global number of deaths by snake bites should be related to the total deaths in the world to gauge the global SDG impact contributions.

To assist in characterizing the magnitude of the SDG impacts of the considered project applications (level (i)), we propose the use of the thresholds described in Table 2.9 and inspired from Cohen (1989)[9]. As for the likelihood, it is possible to estimate the magnitude with a specific value (0-100%) or use the qualitative statements (large-moderate-small-negligible).

Table 2.9. Guidelines for evaluating the magnitude of SDG impacts (for project applications; level (i)).

Magnitude	**Description**
Large 50-100%	The effect will have a major impact contribution to the SDGs. For example, if the use of EV increases dramatically in a country with a renewables-based electricity grid mix, this may significantly improve the sustainability of transport system in the city, thus contributing positively to SDG 3 (good health and well-being) or SDG 11 (sustainable cities) with a large contribution.
Moderate 20-50%	The effect will have a moderate impact contribution to the SDGs. For example, SDG 9 is to build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation. Consumers' behavior change or willingness to use EV will promote the development of the EV sector, which is considered as a sustainable industrialization with clean and environmentally sound technology. However, the consumer's behavior change may not be the main driving force for the SDG impacts, but may still have a large contribution to the SDG, thus the magnitude is considered moderate.
Small 5-20%	The effect will have a minor impact contribution to the SDGs. For example, the production of EV-specific parts will increase the emission of chemical pollutants, of which a fraction will be emitted to marine waters, thus contributing negatively to the prevention and reduction of marine pollution (SDG 14). However, the share of marine pollution coming from the EV-specific parts is not expected to be significant in comparison with all other industries that emit marine pollution. Thus the contribution of this effect to SDG 14 is considered small.
Negligible 0-5%	The effect will have no or little impacts on the SDGs.

The combination of the information from the three criteria is the basis of a semi-quantitative evaluation of the contribution of an effect to a specific SDG impact. **An Excel-based tool has been developed to make the evaluation – and its documentation – easier to carry out (see complementary file; list p.3).** It uses the correspondence Table 2.10. The likelihood and magnitude can be indicated either quantitatively (numerical values) or qualitatively (e.g. "large", "likely", etc.). Documentation to justify the likelihood and magnitude estimates should also be indicated therein. The resulting table resembles Table 2.11 (see Excel-based tool).

[9] Cohen J., 1988. Statistical Power Analysis for the Behavioral Sciences. Second edition. ISBN 0-8058-0283-5. Lawrence Erlbaum Associates, New York, US.

Table 2.10. Scoring system for evaluation of an effect contribution to SDG

Magnitude/Likelihood	Likely	Possible	Unlikely
Large	+++/---	++/--	+/-
Moderate	++/--	+/-	0
Small	+/-	0	0
Negligible	0	0	0

Table 2.11. Illustration of SDG impacts evaluation scores of the effects (as in Excel-based tool)

Effects	**SDG**	**Direction**	**Likelihood**	**Magnitude**	**Evaluation score**	**Justifications for likelihood**	**Justifications for magnitude**
Effect 1	SDG N_1	positive	likely	large	+++	xxxxx	xxxxx
Effect 2	SDG N_2	negative	possible	small	0	xxxxxx	xxxxx
…	…	…	…	…	…	…	…

Using the information from Table 2.4 from Phase 3, which categorizes all effects according to the life cycle stages that they primarily relate to, Table 2.11 should then be translated into Figure 2.7, offering a graphical representation of the detailed evaluation of SDG impacts for communication and use in the interpretation (Phase 5). Figure 2.7 is the main output of the Phase 4.

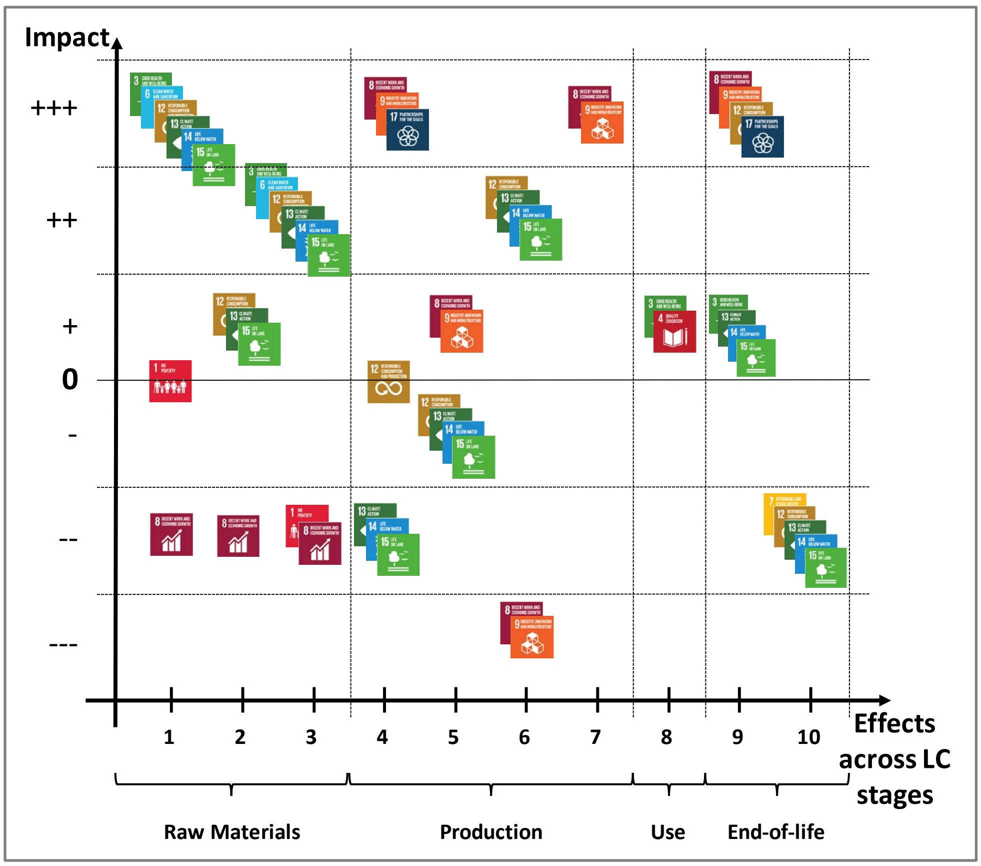

Figure 2.7. Illustration of a sustainability assessment profile showing the contribution of a project application to the different SDGs (based on Laurent et al. 2020[10])

[10] Laurent A., Owsianiak M., Dong Y., Kravchenko M., Molin C., Hauschild M.Z., 2019. Assessing the Sustainability Implications of Research Projects against the 17 UN Sustainable Development Goals. Procedia CIRP (In Press), 1-6. DOI: 10.1016/j.procir.2020.01.077

1.5. PHASE 5: Interpreting the assessment results

Through Phases 1-4, the contribution of a project and its considered application(s) to the SDGs have been identified, categorized in a life cycle perspective and semi-quantitatively assessed. The detailed results of this evaluation, which are represented in the form of Figure 2.7 enables the user to identify possible hotspots for improvement (i.e. parts in the system life cycle, where large negative contributions to the SDGs are caused) and also reveal trade-offs between SDGs (when the application leads to positive contributions for some SDGs and negative for others). This information can be used in an overall characterization of the contribution of the project to sustainable development (as represented by the SDGs). It is also very useful for identification of improvement needs that may be further analyzed and potentially integrated into the research project.

In interpretation of the results, the following questions should therefore be addressed:

- What are the main sustainability impacts of the implementation of the outcomes of the research project?
- Which SDGs are most relevant for the project, identified as the ones that receive the largest contributions across the life cycle, both positive and negative? Where do they occur, i.e. in which life cycle stage(s) and what causes them?
- Are there tradeoffs between life cycle stages when all positive and negative contributions to SDGs are considered?
- For an individual SDG, are there tradeoffs between effects or life cycle stages so that a positive contribution from one may be outweighed by a negative contribution from another to the same SDG?
- Are there tradeoffs between social (SDG 1-6, 16-17), economic (SDG 7-11) and environmental (SDG 12-15) dimensions of sustainability?

Answering the questions above provides a useful starting point to interpret the results further in terms of potential changes that can be made with regard to the project and its resulting application. Depending on the obtained results, there may be a need for performing a sensitivity analysis, where other applications are tested, where a different scoping is considered, or where the analyses of the baseline and the new system defined in Phases 1 and 2 are revisited and refined to improve the certainty for some of the central assumptions that were made. Such iterations, as illustrated in Figure 1.1 (in the Introduction section), are fundamental for the effective use of the methodology.

Often relevant is also the exploration of scalability of the results. If the application has been limited in its scoping in Phase 1, it is relevant to study how the scale or extent of the contributions to SDGs (in terms of direction, magnitude and likelihood) can vary in different settings and/or when extrapolated to a regional or global context. This can be done qualitatively or quantitatively. Illustrative Case 4 (Chapter 4), corresponding to Assessment Method C, presents an attempt at studying the scaling impacts on SDG contributions with best and worst case scenarios. Although performed as part of Assessment Method C, such an investigation (or sensitivity analysis) is applicable to all Assessment Methods and should be considered in any Phase 5.

In general, the interpretation phase is project-specific as both the nature of the analysis and its outcome depend on the assumed project application. This analysis should also lead to possible recommendations on how to improve the SDG performances of a specific project application. These recommendations can be divided between *short-term recommendations to stakeholders conducting the project* (PhD students and supervisors to take measures within the PhD project to prevent negative contributions to SDGs during future implementation of the project application) and *long-term recommendations to stakeholders in charge of implementing the project results into the society* (translating the output of the project into concrete applications). To facilitate reaching such conclusions, the following questions may be addressed:

- Where in the life cycle of the application can changes be made so that some of the negative SDG impacts are mitigated?
- What could those specific changes be? Characterize them from a technological or economic point of view (also assessing their feasibility).
- Can any of these changes be anticipated in the PhD project itself so the negative SDG impacts are prevented from happening when the application is implemented?

2. Introduction to the different Assessment Method variants

As explained in Chapter 1, the different variants are all derived from the default assessment methodology. Assessment Method A is in fact a default replica of the methodology described in Section 1 (in present Chapter 2). Necessary adaptations in some steps of the assessment methodology to comply with the specificities of each Project Types led to the elicitation of three additional Assessment Methods, i.e. Method B, C and D. Figure 2.8 provides a systematic overview of the specific conditions in each phase for the four Assessment Methods A-D.

Method A is fully described throughout Section 1 (default assessment methodology). Assessment Methods B, C and D are briefly described in Sections 3-5, respectively. Differences between the default assessment methodology and method variants are emphasized, so the reader should therefore refer to Section 1 for more details. In other words, Sections 3-5 are not stand-alone sections for documenting Assessment Methods B-D.

	Assessment Method A	**Assessment Method B**	**Assessment Method C**	**Assessment Method D**
Phase 1	Focus on project application	Focus on project application	Focus on project itself	Focus on project itself
Phase 2	Scope: project application	Scope: project activities + project application	Scope: project activities	Scope: project activities
Phase 3	Inventory changes from scoped systems	Inventory changes from scoped systems	Inventory changes from scoped systems + increased knowledge	Inventory changes from scoped systems + increased knowledge
Phase 4	Contribution to SDGs	Contribution to SDGs	Contribution to SDGs	Contribution to SDGs and beyond (other sustainability dimensions)
Phase 5	Interpretation & recommendations	Interpretation & recommendations, incl. sensitivity to different implications of decision support (scenarios)	Interpretation & recommendations, incl. sensitivity to different utilization of increased knowledge	Interpretation & recommendations, incl. discussion on impacts on sustainability at large (beyond SDGs)

Figure 2.8. Overview of the specificities of each phase for the different Assessment Methods

3. Assessment Method B

This method should be used for projects, which have a purpose of providing enhanced knowledge support, and therefore do not have a strict technological objective. Tangible results from enabling or implementing that knowledge support can be foreseen, although with uncertainty depending on if/how the targeted stakeholders of the project outcomes will use the support provided. In these cases, applications of the project outcomes can therefore be defined, for example by developing scenarios.

Clarifying box 2.8 synthesizes the main adaptations to consider in each phase of the default methodology for Assessment Method B. Further explanations are briefly given in the following sections. The Method B application is illustrated through a case study in Chapter 4 (in Section 3).

Clarifying Box 2.8. Main adaptations to consider in Assessment Method B relative to default methodology (A).

- *Phase 1*: No major changes; need to define an application or a scenario resulting from the project outcomes.
- *Phase 2:* Reasoning of Phase 2 is the same, but additional need to expand the systemic perspective to include the project activities leading to the enhanced knowledge support.
- *Phase 3*: Aligning with Phases 1 and 2, the effects should be identified and distinguished between those resulting from the project activities (knowledge support) and those from the application/scenario defined (resulting from utilization/implementation of knowledge support).
- *Phase 4*: Same as in the default methodology.
- *Phase 5*: Same as in the default methodology, but requirement to discuss uncertainties and the sensitivities to different implications resulting from the decision support uptake (e.g. assuming other applications or scenarios than the one defined in Phase 1) (= sensitivity of results to explore).

3.1. Adaptations to default Phase 1

Phase 1 in Method B is similar to Phase 1 in the default methodology because the decision/management support provided by the project will lead to tangible and identifiable results. As part of Phase 1, it is therefore suggested that you provide an overview of the different alternatives that may result from the different use or implementation of the decision support. If relevant, one or more can then be selected based on likelihood (most likely scenario) or relevance (e.g. best vs. worst case).

Sensitivity analysis could also be planned in this phase (it may also be done in later Phases, e.g. Phases 2-4), accounting for possible scenarios to run in the assessment. If relevant to the case, a limitation of the geographical or temporal scopes may be necessary (see Section 1.1 in Chapter 2); these may be subject to sensitivity analyses.

3.2. Adaptations to default Phase 2

Compared to Phase 2 in the default methodology, it is recommended that you first adopt a systemic perspective, starting from the project activities up to the use of the generated knowledge support at societal level. In most cases, the project activities will be burden-free and be one-time events compared to the use of the knowledge support in society, which itself may lead to lasting changes. For example, a project focusing on data analysis may create low impacts during the project time compared to the use of the data by stakeholders, who may make decisions, which significantly alter activities in specific sector(s). In those cases, the project activities may thus be disregarded from the scope. There may be rare cases, where the project activities are associated with non-negligible contributions (positive or negative) to sustainability compared to the use of the knowledge support; this may be the case for projects requiring heavy use of experimental equipment/materials. In those situations, the project activities could then be integrated as part of the scoping.

Because of the nature of the projects focused on knowledge support for policy/industry management purposes, the project outcomes and their potential use(s) may not be particularly compatible with a strict life cycle perspective, as advocated in the default Phase 2 application (see Section 1.2 in present Chapter 2). It is therefore recommended that you first use a causality chain approach to map the different activities and processes, starting from the provision of the enhanced knowledge support through to their possible use(s), as defined in Phase 1. The baseline system is the business as usual (BAU) scenario, whereas the new system accounts for the enhanced support, which may lead to changes compared to the BAU scenario. The life cycle perspective should then be integrated into this mapping to further specify the activities, which may be significantly impacted by the new system, compared to the baseline –see Clarifying Box 2.9.

In the example of Figure 2.9, which is taken from Illustrative Case 3 (see Chapter 4), the increased knowledge in the fish stock assessment models is expected to lead to more accurate predictions of the stocks for the following year. This is expected to cause possible modifications in the regulations of the fisheries in that following year, and eventually leading to physical changes in the fisheries activities. While a life cycle perspective may be applied to each activity along that causality chain, it is mainly relevant for the actual changes in the fisheries activities, e.g. with less/more fuel being consumed, less/more vessels operating, etc. Studying the legislation activities in a life cycle perspective would be of little relevance and should be dismissed.

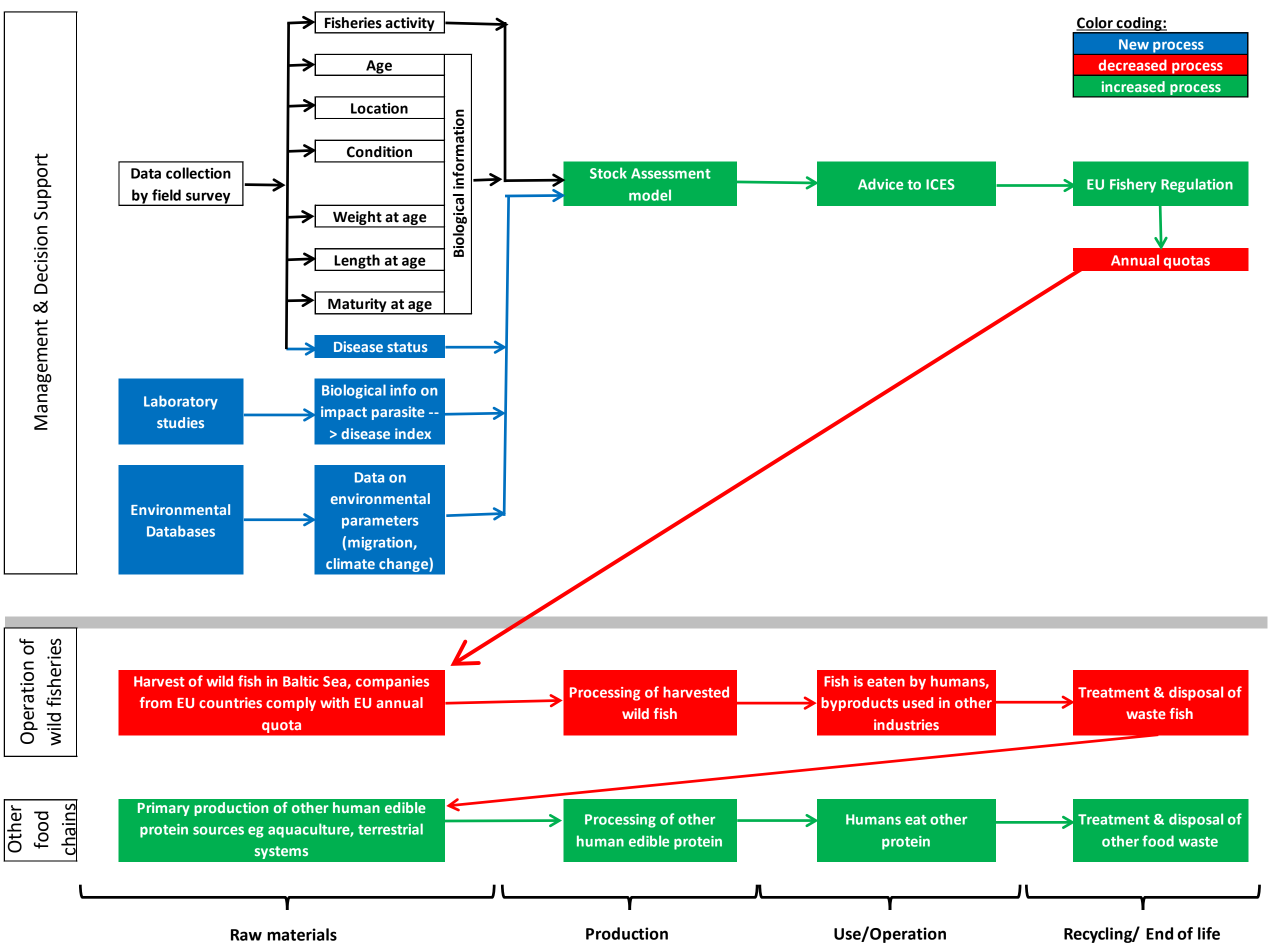

Figure 2.9. Scope of the new system for the Eastern Baltic Cod case (color coding indicated in top right corner of the figure). Figure extracted from Illustrative Case 3 (Figure 4.10 from Section 3 in Chapter 4).

Clarifying Box 2.9. Systemic perspective and life cycle perspective in the scoping for Method B.
In Project Type 2 (relevant for Assessment Method B), the system scoping can be illustrated by taking an overarching systemic perspective (instead of a direct application of a life cycle perspective, as done for Project Type 1 and Assessment Method A). This means that the scoping can first be illustrated by a chain of events, typically capturing the activities associated with the knowledge creation and leading to the decision or policy support (top part of Figure 2.9). It is then complemented by the application of the decision/policy support, which translates into actual changes in physical systems: these systems need to be represented by a life cycle perspective, wherever relevant, as they are the ones, which will mainly drive the negative and positive contributions to the SDGs.

3.3. Adaptations to default Phase 3

Phase 3 is the same as in the default methodology (Section 1.3 in present Chapter 2), with the difference that the life cycle categorization used by default in Phase 3 could be adapted to accommodate the decision/management support creation and its systemic perspective, as defined in above Phase 2 (see also Clarifying Box 2.9). A slightly adapted inventory table, with one added column to include this perspective, is considered more appropriate, compared to Table 2.4 –see template in Table 2.12.

Table 2.12. Example/template of inventory outcome from Phase 3 for Assessment Method B.

Management/decisions/policy support	**Implementation of the decision/policy management support**			
	Raw materials	**Production**	**Use**	**Recycling & End-of-life**
Physical changes				
Effect 1 (Process 2 to increase) Effect 2 (Process 3 to remove)	Effect 3 (Process 4 to remove) Effect 4 (New Process 12 to add)	Effect 5 (Process 5 to increase) Effect 6 (Process 6 to remove) Effect 7 (Process 7 to decrease) Effect 8 (New Process 13 to add)	Effect 9 (Process 8 to decrease) Effect 10 (New Process 14 to add)	Effect 12 (Process 9 to remove) Effect 13 (New Process 15 to add)
Non-physical change (social, economic, ethical etc.)				
			Effect 11 (Non-physical change to add)	

3.4. Adaptations to default Phase 4

Phase 4 in Assessment Method B is identical to the default methodology (see Section 1.4 in present Chapter 2). It should be applied to all changes inventoried in Phase 3.

3.5. Adaptations to default Phase 5

Phase 5 in Assessment Method B is identical to the default methodology (see Section 1.5 in present Chapter 2), with the additional recommendation that a sensitivity to different implications of the decision support in the assessment should also be considered. Following the selection of Assessment Method B, tangible consequences are expected from the implementation of the decision/policy management support. However, there is some degree of uncertainty associated with these consequences, which may then lead you to consider several probable consequences in the assessment as part of a sensitivity analysis. This can be done in the structured form of defining and assessing scenarios, or in the form of a combined overview of different consequences (the latter option was followed in Illustrative Case 3 in Chapter 4 for short and longer-term effects).

Phases 1-4 are affected by this sensitivity analysis and the results should be discussed in Phase 5, for example evaluating qualitatively how the results and conclusions of the SDG assessment may change under different scenarios or situations resulting from different utilizations and/or effects of the decision/policy management support.

4. Assessment Method C

Assessment Method C is applicable to projects falling under Project Type 2, where the project outcomes does not yield tangible consequences (unpredictable use of decision/policy management support), or under Project Type 3, where the project focuses on fundamental research with very remote and very uncertain societal applications (e.g. projects on fusion reactor technologies, quantum physics, etc.). The adaptation of the methodology is intended to account for the high degree of uncertainty in the identification and characterization of the project applications. To facilitate this, Assessment Method C also encompasses the project activities instead of just the project applications (in contrast to Assessment Method A, where the project activities are disregarded). Clarifying Box 2.10 describes the main adaptations to consider in each phase, relative to the default assessment methodology A. Further explanations are given in the following sections.

Clarifying Box 2.10. Main adaptations to consider in Assessment Method C relative to default methodology (A).

- *Phase 1*: Focus is shifted to the project itself, where the application/actions results from the project outcomes should be outlined, together with justifications for their uncertainties.
- *Phase 2:* System scoping should be limited to the project activities, ending with a “black box” for increased knowledge support.
- *Phase 3*: Identify all relevant effects from the project activities themselves, and add one effect to capture the provision of the enhanced knowledge support or recommendations.
- *Phase 4*: same as in the default methodology, with the exception that the effect of providing enhanced knowledge should be linked to positive and negative contributions to SDGs under different possible scenarios.
- *Phase 5*: same as in the default methodology, but with a requirement to discuss the sensitivity of the assessment to different utilizations and/or consequences of the created knowledge.

4.1. Adaptations to default Phase 1

Phase 1 is similar to the default assessment methodology. The main focus should however be on describing the project activities, justifying the uncertainties which are too large to identify and define one or more project applications, and discussing the possible consequences and/or utilization of the knowledge generated by the project (preparing the ground for Phase 4).

4.2. Adaptations to default Phase 2

Phase 2 in Assessment Method C focuses on the project activities themselves, up to the generation of the knowledge from the project, which can be decision or management support (e.g. Project Type 2) or fundamental knowledge on specific technologies (e.g. Project Type 3).

The utilization of this knowledge and the subsequent implications for society, which is where most of the uncertainties lie, are investigated using scenarios which should be included as part of a sensitivity analysis. That sensitivity analysis should be introduced and specified in Phase 4.

As a result of the above, the scoping figure(s) under Phase 2 can end with a "black box", reflecting the knowledge creation from the project, without further specifying the use and implications of that knowledge. Figure 2.10 provides an example extracted from the Illustrative Case 4 (Section 4 in Chapter 4).

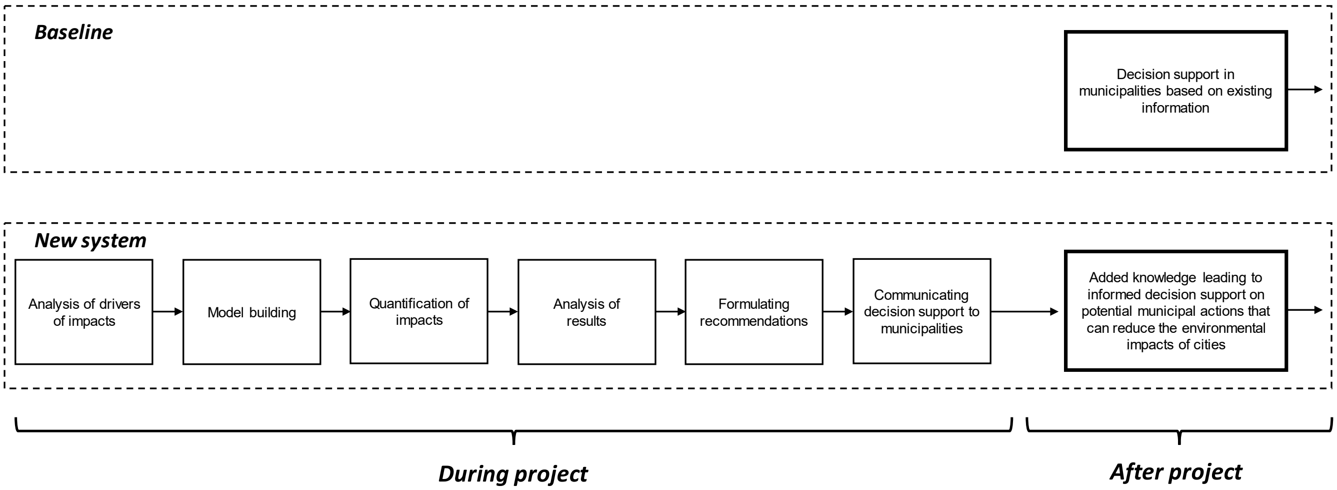

Figure 2.10. Scope of the baseline and new systems for a project on the development of an environmental sustainability assessment methodology for cities, from which the decision support provided carries large uncertainties (extracted from Illustrative Case 4; see Chapter 4).

4.3. Adaptations to default Phase 3

Phase 3 inventorizes all effects associated with the project activities (during the life of the project), which can have relevance in terms of the magnitude of impacts on SDGs (e.g. specific large equipment, etc.). As a minimum, these should include the effect of added knowledge/scientific advances during the project. In addition, where relevant, it should also include one effect linked to the overall provision of increased knowledge from the project. An example taken from Illustrative Case 4 is provided in Table 2.13.

Table 2.13. Effects of the new system compared to the baseline system, illustrating the added knowledge, extracted from Illustrative Case 4 on developing an environmental sustainability assessment methodology for cities.

During project work	**After project work**
Effect 1: Added knowledge/scientific advances on assessments of environmental sustainability of cities.	Effect 2: Added knowledge leading to informed decision support on potential municipal actions that can reduce the environmental impacts of cities.

4.4. Adaptations to default Phase 4

Phase 4 differs from the default assessment methodology by addressing the effects from the generated knowledge or decision/policy management support. The assessment of effects during project work follows the same approach as the default methodology. However, the added knowledge and its implications at the end of the project should be assessed via the use of a sensitivity analysis to evaluate their different possible implications/utilizations at societal level.

For example, in Illustrative Case 4 (see Chapter 4), best and worst case scenarios were developed and tested to estimate the impacts of the generated decision support on SDGs depending on the level of actions taken (i.e. the uptake). Other explorative scenarios could also have been made to assess the SDG contributions from different possible outcomes (targeting a specific system within the city, e.g. energy supply or food supply systems).

4.5. Adaptations to default Phase 5

Phase 5 follows the same approach to performing Phase 5 used in Assessment Method B, where the level of uncertainties and its consequences on the results are explored through a sensitivity analysis. In the discussion, the sensitivity analysis – and the discussion – should cover the extent to which the enhanced knowledge may lead to different results. Different options can thus be considered in case of successful (or less successful) uptake, e.g. decision-makers implementing the added knowledge to various extents (cf. example in Illustrative Case 4; Chapter 4), unlocking the potential of new technologies, etc.

5. Assessment Method D

Assessment Method D addresses projects with no direct societal applications. These projects belong to Project Type 3 (see Figure 1.2). They have an exclusive focus on fundamental research that does not impact society or the environment in a concrete, physical way. Examples are projects within humanities (e.g. history, arts, etc.) or fundamental science projects in some fields of physics or mathematics (e.g. cosmology). For those project types, adaptations to the default assessment methodology are particularly needed for Phases 4 and 5 (relative to the other Assessment Methods). Clarifying Box 2.11 summarizes the main adaptations to consider in each phase. Further explanations are briefly given in the following sections.

Clarifying Box 2.11. Main adaptations to consider in Assessment Method D relative to default methodology (A).

- *Phase 1*: Focus exclusively on the project activities. Complement with descriptions of the potential implications at a societal level, if any.
- *Phase 2:* System scoping should be limited to the project activities.
- *Phase 3*: Identify all effects of the project activities themselves, and add one effect to capture the provision of the enhanced knowledge.
- *Phase 4:* same as in the default methodology for the project activities, with additional linkages of the generated, enhanced knowledge to sustainability as a whole (beyond the scope of the SDGs, if relevant). This last part can also be integrated in Phase 5 if qualitatively addressed.
- *Phase 5:* discuss the contribution of the project activities and compare to their contribution to sustainability at large through knowledge creation.

5.1. Adaptations to default Phases 1-2

The conduct of Phases 1-2 follows that of Assessment Method C, to which the reader is referred. The main focus is on the project activities alone. Any potential implications anticipated at a societal level should be discussed qualitatively as part of Phase 1. If some concrete implications can be identified during that discussion process, it means that an application of Assessment Method A, B or C would be more appropriate, and hence that Assessment Method D is not to be used.

5.2. Adaptations to default Phase 3

In Assessment Method D (like in Method C), Phase 3 will often be limited to inventorizing only one effect that may not be negligible: the knowledge increase or creation resulting from the project research. Because there is only one effect, it may not be necessary to report it in a table, as shown in Table 4.5 (Illustrative Case 5 in Chapter 4). Instead, a short justification/description of the effect in text can be sufficient.

5.3. Adaptations to default Phase 4

In Phase 4, the linkage to SDGs should be made, wherever possible. It shall be mentioned that unless the research directly involves (with clear causality) heavy equipment having particular contributions to some of the SDGs in a regional or global context, the project activities are likely to lead to negligible impacts (e.g. use of one laptop during the project). It means that the potential links of the increased knowledge to SDGs and, in a broader sense, to sustainability aspects, should be prioritized. The latter perspective (beyond the SDGs) can be qualitatively addressed either in Phase 4 or in Phase 5 (in Chapter 4, in Illustrative Case 5, the latter approach was adopted).

5.4. Adaptations to default Phase 5

Phase 5 interprets the results from Phase 4 and attempts to link the increased knowledge from the project to sustainability aspects, including the SDG impact assessment from Phase 4, as well as a qualitative discussion relating to a broader definition of sustainability or sustainable development. In this discussion, literature sources should be sought to document the different arguments.

Chapter 3
REPORTING TEMPLATE

The following is a template to report your SDG assessment and document its methodological application and results. The report should be concise with an extent of approx. 5 pages plus appendices. Use the appendices to transparently document the assumptions you make on the different methodological steps and the detailed tables to support your results.

The template below can be regarded as a default template. It is best suited to Assessment Methods A and B, and slight adaptations may be made when reporting cases resulting from Assessment Methods C and D (see Chapters 2 for methodological guidance, which may facilitate understanding and meeting below requirements). You should also refer to the five illustrative case studies in Chapter 4 that can provide inspiration and guidance on reporting expectations for all Assessment Methods (see Chapter 4).

1. Phase 1: Considered application(s) of the research project *(ca. 0.5 page)*

- Describe briefly the research project
- Describe potential societal or technological application(s) of the research project and justify the selection of the application chosen for the assessment, including types of activities, geographical/activity scoping and time horizon.
- State which Assessment Method (A, B, C or D) has been applied and provide justifications for the choice

2. Phase 2: Scope of the assessment *(ca. 1.5 page)*

2.1. Delimitation of the baseline system

- Describe and justify products, technologies or services which are replaced by the main application or, in rare cases, describe which new needs in society the main application fulfills
- Present the life cycle of the baseline in a figure, in the form of a flow diagram, indicating the main processes (see Figure 2.2 in the methodology that should be used as a template)

2.2. Delimitation of the new system

- Describe and justify products, technologies or services of the new system and/or, in rare cases, describe which new needs in society the main application fulfills, including specifying the main processes of the sectors that the new application can impact or interact with
- Present the life cycle of the new system in a figure, in the form of a flow diagram, indicating the main processes (see Figure 2.3 in the methodology that should be used as a template)

Recommendation:

- *In both Sections 2.1. and 2.2, report the final mapping of the life cycle of the baseline and new systems, after having gone through the iterations between Phases 2 and 3, so the system life cycle should only include the main activities affected by the project applications (see Methodology).*

- *In some cases, a single figure, instead of two separate figures to represent the scope of the baseline and new systems, may be used (see illustrative cases for inspiration). Graphical highlights (e.g. color coding) shall however be used to make a clear distinction between the baseline and new systems.*

3. Phase 3: Inventory of effects from the applications *(ca. 1 page)*

Present the main direct and indirect effects of the project application(s) in a table, indicating processes that are either new to the baseline, removed from the baseline, or altered in the baseline (increased or decreased). Also identify and position effects that are non-physical changes (social, economic, ethical, etc.). Justify the effects, potentially using a separate section in Appendix A. Position the effects across the four life cycle stages of the baseline. Table 2.4 from Chapter 2 should be used as a template.

4. Phase 4: Evaluation of the application contributions to SDGs *(ca. 1 page)*

- Justify the impacts on SDGs for each effect, and the cross-SDG links (Step 1 from Phase 4 in Chapter 2) in a table that you document in Appendix A. Table 2.6 in Chapter 2 should be used as a template.
- Justify the likelihoods and the magnitudes of the SDG impacts, and report the evaluation results of the assessment (Step 2 from Phase 4 in Chapter 2) in a table that you document in Appendix A. Table 2.11 in Chapter 2 should be used as a template.

Recommendation: To facilitate the reporting of both above points, submit the filled-in tables from the Excel-based tool separately to the report (PDF document), as they already integrate Table 2.6 and Table 2.11 (in separate worksheets). The filled-in Excel file is Appendix A (submit as a separate electronic file), hence there is no need to copy/paste the tables in your report.

- Present the evaluation results in a figure, using Figure 2.7 in Chapter 2 as a template.

5. Phase 5: Interpretation of the assessment results *(ca. 0.5 page)*

- Describe, as a minimum, the most important positive and the most important negative SDG impacts of the implementation of the considered project application(s)
- Describe possible hotspots for improvements, potential tradeoffs between SDGs and between life cycle stages and/or components of the new system, and potential tradeoffs between social, economic and environmental dimensions of sustainability
- Provide short-term recommendations to stakeholders conducting the project and long-term recommendations to stakeholders in charge of implementing the project results into the society (See Methodology)

6. References *(no page limit)*

Lists references used in the report.

7. Appendices *(no page limit)*

Appendix A (separate Excel file, template provided, i.e. electronic Excel-based tool)

Excel file with (i) justification of SDG impacts and the cross-SDG links (Table 2.6 as template), and (ii) detailed SDG impact evaluation, incl. evaluation scores and justifications of likelihoods and magnitudes of the SDG impacts (Table 2.11 as template).

Appendix B

Detailed documentation behind the identification of effects (Phase 3), if relevant

Other necessary documentation for transparent reporting

Chapter 4

ILLUSTRATIVE APPLICATIONS OF THE METHODOLOGY

(ASSESSMENT METHODS A, B, C & D)

This chapter illustrates the application of the SDG assessment methodology to a number of illustrative cases, with reporting in compliance with the reporting template provided above. Each of the cases illustrates the application of a specific assessment method (A, B, C & D). Two very different cases illustrate Assessment Method A.

For pedagogical purposes, some aspects and reporting tips/tricks are provided as part of Clarifying Boxes (which explains why some cases currently take up more than 5-6 pages). For that reason and for gaining additional insights into the methodology application, it is therefore recommended that you browse through all illustrative cases regardless of the Assessment Method relevant to the assessment under study (hence not limiting the focus to the case fitting the selected Assessment Method).

A detailed decision tree was provided in Figure 4.1 and can be used to identify which Assessment Method is relevant for a given project under study. It additionally provides a synthetic view of the specificities of Phases 1-5 in each.

Illustrative cases:

- **Case 1.** Project on new battery electrolyte development (Assessment Method A)
- **Case 2.** Project on algorithm development for noise control system (Assessment Method A)
- **Case 3.** Project on parasitic nematode and its influence on cod migration (Assessment Method B)
- **Case 4.** Project on development of an environmental sustainability assessment methodology for cities (Assessment Method C)
- **Case 5.** Project on study of exoplanetary atmospheres (Assessment Method D)

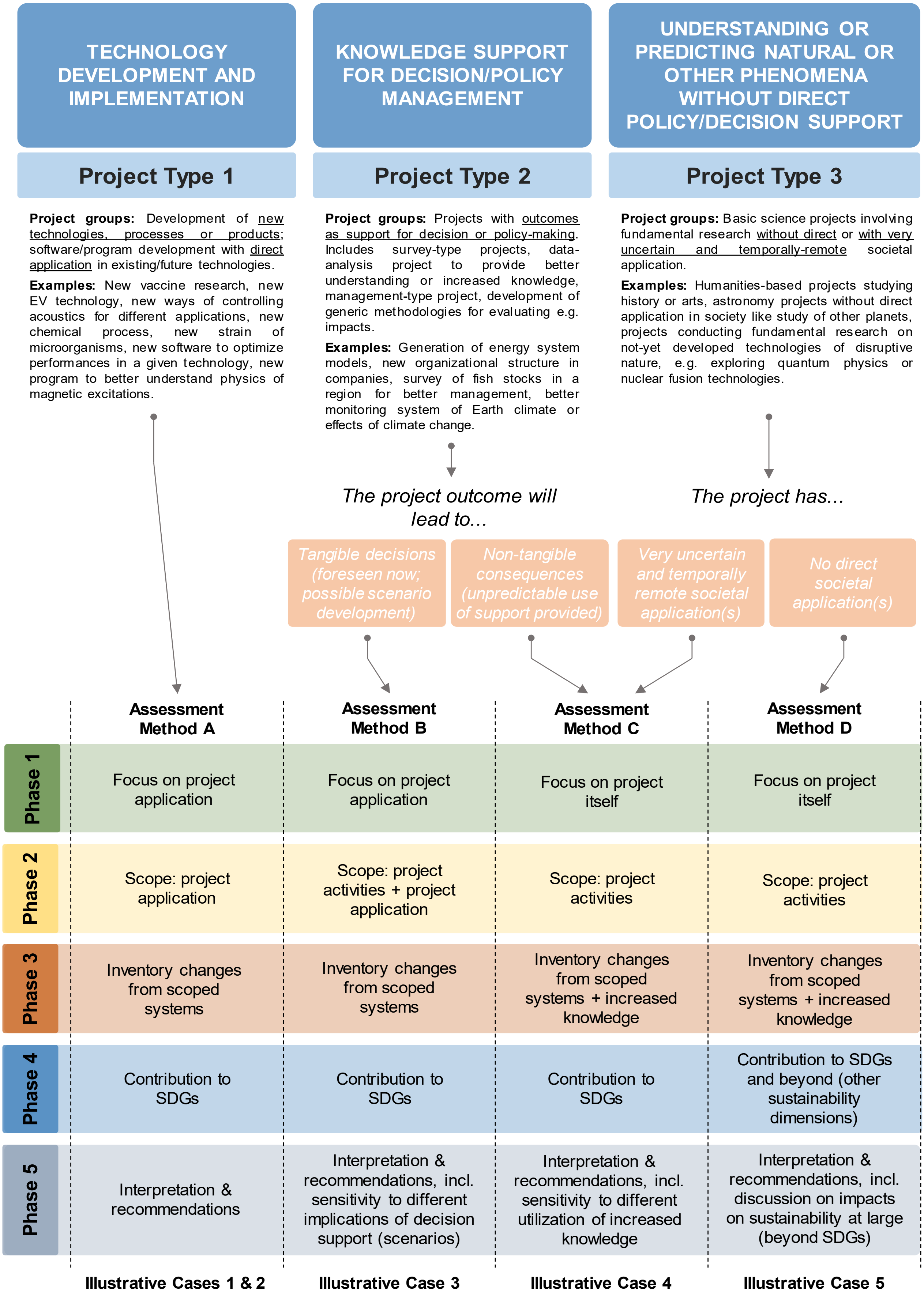

Figure 4.1. Decision tree for the methodology application with all 4 Assessment Methods.

1. PROJECT ON NEW BATTERY ELECTROLYTE DEVELOPMENT (Assessment Method A)

1.1. Phase 1: Considered application(s) of the research project

The project used as a virtual case is taken from one of the examples from Table 1.1 in the methodology. It focuses on the development of new electrolyte characteristics to increase storage capacity in Li-ion battery technologies. The developed technology could replace existing Li-ion batteries that are in use in many different applications, e.g. electronic products, electric vehicles (EVs), etc.

For the assessment, the application in EVs for car transportation is selected as main application due to its large market potential and the increasing shift towards EVs in the transportation sector in Europe (which is assumed the primary geographic zone of interest for the study). To keep the scope of the study manageable in this example, only the Danish market for use of EVs as passenger cars is considered in the assessment. Sensitivity analyses or further study may be conducted later to expand that scope to the entire European market (or wider) and to also include other types of applications (e.g. electric trucks for freight transport, other transport modes, other applications than transport like electronics, etc.). The time horizon in the assessment is taken as default up to 2030. Considering the project focus on technology development (Project Type 1, see Figure 4.1), Assessment Method A is used for the SDG assessment.

Clarifying Box 4.1. Alternative way of reporting Phase 1 (example)

- **Research project** – New electrolyte which increases the storage capacity of Lithium ion (Li-ion) batteries
- **Potential applications** – replace existing uses of Lithium ion batteries, such as electronic vehicles (EVs) and products.
- **Chosen application** - the main application is EVs for passenger cars, and the scope will be limited to implementation in the greater Copenhagen area over the period 2016 – 2030.
- **Justification for selected application** – (1) increasing shift towards EVs in Europe, (2) scope limited to passenger cars, which is the current and short-term main use of EVs, (3) time frame limited to 2030, to align with Paris agreement greenhouse priorities and medium term focus, (4) geographical scope limited to Denmark to make analysis manageable, but sensitivity cases could be envisaged to look at European/global market and other applications (electric trucks, public transport, other transport modes and non-transport applications)
- **Appropriate Assessment Method**: Assessment Method A due to the project focus on technology development (Project Type 1)

1.2. Phase 2: Scope of the assessment

1.2.1. Delimitation of the baseline system

EVs are already in use in several European countries to move away from petroleum-based conventional vehicles, which constitute the bulk of the vehicle fleet today and are associated with large emissions of greenhouse gases and air pollutants. Therefore, the baseline can be identified as the passenger car transport systems in Denmark with current projections as to the distribution of power train technologies (Internal Combustion Engines (ICE) vehicles, battery EVs, hybrid EVs, etc.) and fuels (e.g. petroleum-based, biomass, electricity). An illustration of possible baseline system is given in Figure 4.2[11].

[11] Bohnes F., Gregg J. S., Laurent A., 2017. Environmental impacts of future urban deployment of electric vehicles: a case study of Copenhagen for 2016-2030. *Environ. Sci. Technol.* 51, 13995–14005.

Determination of the life cycle of the baseline essentially comes down to mapping the life cycle of the passenger car fleet system, including all its components; this is illustrated in Figure 4.4 (disregarding color coding; see also Clarifying Box 4.3 about Phase 2 reporting).

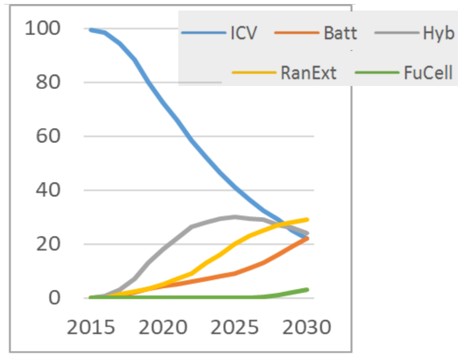

Figure 4.2. Baseline system evolution up to 2030, with relative decrease of ICE vehicles (ICV) and increase of EVs, i.e. battery (Batt), Hybrid (Hyb), Range-extended (RanExt) and Fuel-cells (FuCell) vehicles (Source: Bohnes et al.[11])

In the life cycle of the baseline system, the raw material extraction stage includes: a) fossil fuel extraction for mining, processing, electricity generation and transport fuels; b) common metal ore extraction for producing capital equipment; and c) rare earth elements for producing Li-ion batteries, and wind and solar energy generation equipment. The production/processes life cycle stage in the baseline system include: the manufacture of car components and their assembly into passenger vehicles, including existing EV battery production; the manufacture and installation of electricity generation infrastructure and car charging stations; the production and distribution of transport fuels for ICE engines; and the construction of road infrastructure. The use life cycle stage in the baseline system includes the use of fossil transport fuels in ICEs and electricity in EVs, as well as the maintenance of all associated infrastructure (cars, charging stations, refueling stations, roads). The recycling or end-of-life life cycle stage for the baseline system includes the disassembly and reuse of cars, car components and all associated infrastructure (roads, charging stations), the recycling of metal and battery components, the treatment and disposal of wastes (e.g. liquids) and the landfilling of any residual wastes e.g. slags from coal fired power generation.

1.2.2. Delimitation of the new system

The project application (= new EVs with improved battery storage, also referred to as "new battery EVs" in the following) could make EVs more attractive to customers (e.g. because of extended range enabled by the new battery technology) and speed up the penetration of EVs on the market, thus leading to a faster deployment of EVs to replace conventional internal combustion engines (ICE) vehicles. This entails different projection scenarios, which are illustrated in Figure 4.3. The exact performances of the new battery EV is likely unknown or at least uncertain at the time of the project, hence a best guess should be made and documented based on available literature or data found on the application (e.g. market studies, projections, etc.). It is advisable to define ranges of key values or scenarios that can be used later as sensitivity analysis.

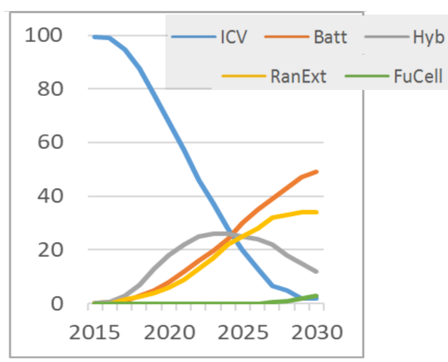

Figure 4.3. New system evolution up to 2030, with, compared to baseline steeper decrease of ICE vehicles (ICV) and increase of battery EVs (Batt). Hyb: Hybrid, RanExt: Range-extended; FuCell: Fuel-cells vehicles (Source: Bohnes et al.[13])

Several parameters can be influential on the penetration rate of the new EVs with improved battery storage, including production costs, national regulations or incentives (e.g. bans or subsidies to limit or encourage specific technologies), driving habits, adapted infrastructure availability (e.g. charging stations), etc. Many of these parameters are region- or country-specific, meaning that the extent of substituting conventional vehicles with EVs may differ from one country to another. In countries, where substitution will be rendered more difficult because of national conditions, the new system will be closer to the baseline (= little difference since little penetration of new EVs). In contrast, in countries with government incentives and measures facilitating EVs deployment, the difference between the baseline and the new system will be more important. In a potential sensitivity analysis focusing on other countries or entire regions like Europe, these differences between countries should be accounted for.

The life cycle of the new system is similar to the baseline system, and Figure 4.4 overall still applies, although a number of processes are altered compared to the baseline system –see color coding in Figure 4.4. Clarifying Box 4.2 also describes a more synthetic way of reporting the new system scoping.

Clarifying Box 4.2. Alternative way of reporting the new system scoping

For the new system, the reporting can be limited to highlighting the differences between the baseline and the new systems, as follows in bullet points.

- The new battery will allow longer travel distances and it is assumed that this will lead to an accelerated transition from ICEs to EVs. This will lead to an increased rate of uptake of EVs, leading to a reduce market share of ICEs. However, the exact performance of the new battery is not currently known, and other market factors, such as costs, subsidies and availability of charging infrastructure, may also influence the rate of enhanced EV uptake.
- In the raw material extraction life cycle stage, changes will include increased extraction of rare earth elements for producing, increased extraction of fossil fuels for mining and electricity generation, and a decreased in fossil fuel extraction for ICEs. In the production life cycle stage, a completely new process will be required for the new battery manufacturing, while there will be increased production of infrastructure for electricity production, EV batteries and support systems, EV charging stations, increased electricity production and decreased ICE and fossil fuel production. During the use life cycle stage, the main difference will be the increase in electricity consumption and the corresponding decrease in fossil transport fuels. In the end of life/recycling stage, there will be more EV batteries requiring disposal, more waste from fossil fuel electricity generation and fewer ICEs requiring disposal.

Clarifying Box 4.3. Use of figures in Phase 2 reporting

To illustrate Phase 2 outcomes, two options can be considered: (i) reporting the baseline system and the new system scoping on two separate figures, (ii) reporting the two systems on a same figure, with use of color coding. In cases, where there is only few added/deleted processes or activities (which is by far the majority of cases), the latter option should be preferred. The distinction between the two systems can be clearly reflected/identified using the color coding as done in Figure 4.4.

Note that Figures 4.2-4.3 could be considered as background and that they can therefore be reported and argued in an Appendix. Furthermore, in some cases, such detailed forecast scenarios may not be available, in which case the text should provide – preferably referenced – arguments and documentation to describe the considered scenarios.

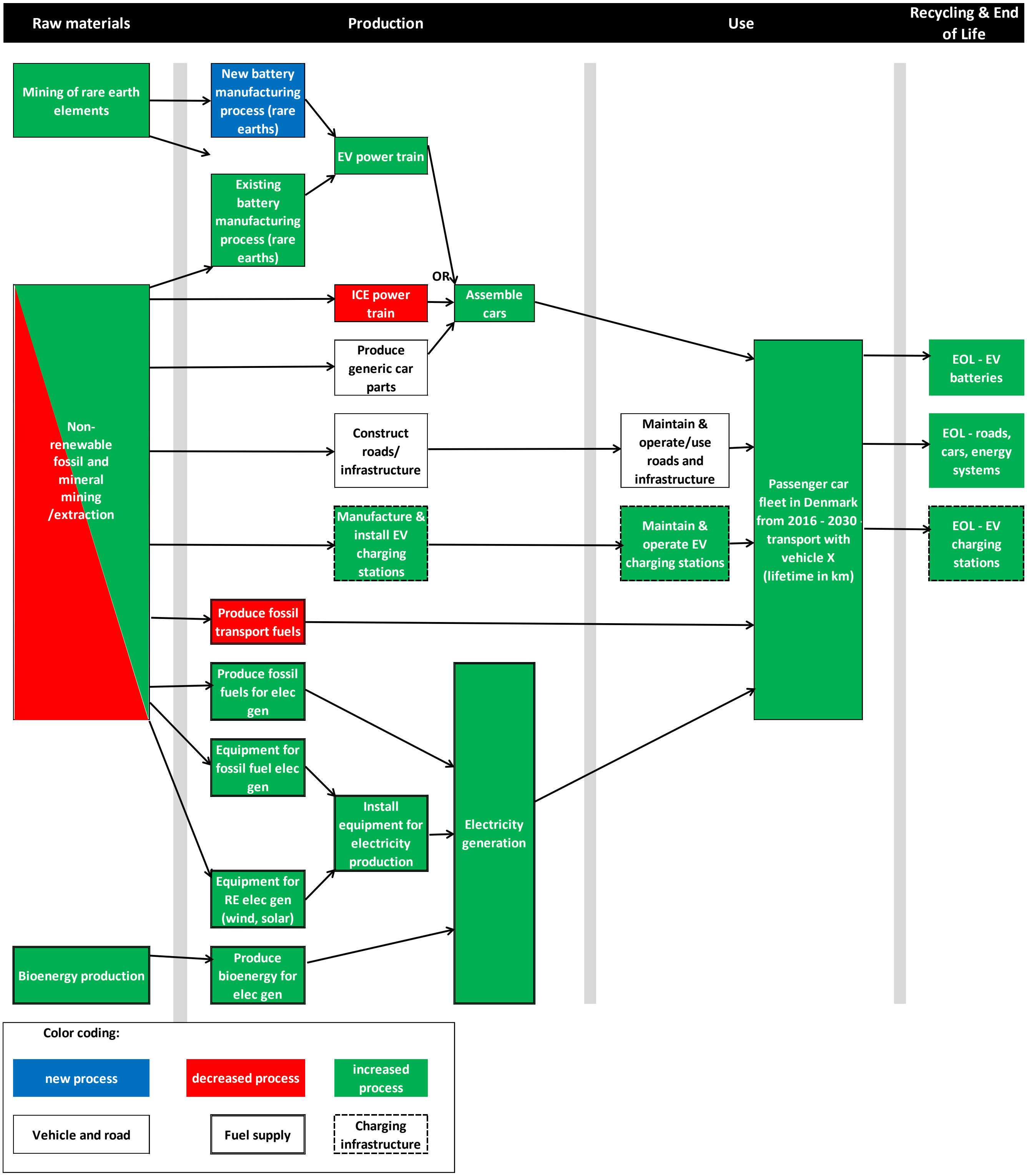

Figure 4.4. Simplified overview of the life cycle of passenger car fleet in Denmark. Color coding indicates changes from the new system compared to baseline (as in Figure 2.3 of Methodology); blue: added processes, orange: processes with decreased intensities; green: processes with increased intensities (processes with gradients are affected by both increasing/decreasing intensities depending on specific embedded activities).

1.3. Phase 3: Inventory of effects from the applications

Table 4.1 – in the same format as Table 2.4 in Methodology – reports all direct and indirect effects of the considered project application (increased deployment of EVs) on the baseline life cycle, identifying processes that shall be added, removed and/or altered. Detailed justifications behind the identifications of the effects are provided in Appendix A.

Table 4.1. Direct and indirect effects of the new system, including non-physical changes, highlighting added (blue) or removed (grey) processes as well as processes with increased (green) and decreased (orange) intensities, compared to the baseline system.

Raw materials	Production	Use	Recycling & End-of-life
Physical changes			
Effect 1: Increased extraction of rare earth elements needed for production of electric drive motors of EVs **Effect 2:** Increased extraction of fossil fuels and production of bioenergy for mining operations of rare earth elements	**Effect 5:** Increased production of capital goods and equipment to support increased electricity demand from passenger car transport (was 3) **Effect 6:** Increased production and installation of EV charging stations (incl. at households) (was 4) **Effect 7:** Decreased production of ICE engines and their supporting equipment (turbines, intercoolers, etc.) (was 5) **Effect 8:** Added process of new electrolyte production (was 6)		Effect 16: Increased treatment and landfilling of slags from power plants as more slags will be generated during production of electricity from coal Effect 17: increased waste management of EV batteries Effect 18: Decreased waste management of ICE engines
Effect 3: Decreased extraction of fossil fuels for production of transport fuels for ICEs (was 8)	**Effect 9:** Increased production of EV batteries and supporting systems (was 7) **Effect 10:** Decreased production of fossil and bioenergy fuels for use in ICEs	Effect 13: Decreased consumption of fossil and bioenergy fuels in ICEs (was 12)	
Effect 4: Increased extraction of fossil fuels and production of bioenergy to generate electricity for charging EVs (was 11)	Effect 11: Increased production of electricity from fossil fuels Effect 12: Increased production of electricity from renewable fuels (wind, solar, bioenergy)	Effect 14: Increased electricity consumption in EVs	
Non-physical changes			
		Effect 15: Increased driving (km per person) due to extended range capacity of EVs, driving EVs becoming cheaper in use, being perceived as environmentally friendly (e.g. "zero -emissions") by users	

1.4. Phase 4: Evaluating the contributions of the application to SDGs

Table A1 in electronic Appendix A reports the links between the effects and the SDGs and their associated targets, together with justifications.

Table A2 in electronic Appendix A documents the estimations of likelihood and magnitude of the potential impacts of the identified effects on the SDGs, along with their justifications and the quantification of the resulting evaluation score. A brief example if also provided in Clarifying Box 4.4.

Clarifying Box 4.4. Examples of background reasoning for Steps 2 of Phase 4

The judgement of likelihood, it is an expert judgement, which should be based on science-based evidence as much as possible. For example, the decreased fuel combustion in the car engine will very likely reduce the chemicals releases to the environment (SDG 12, target 12.4), as the direct impacts arising from this effect. Chemicals may further transport to and affect terrestrial ecosystems (SDG 15). It is an indirect impact from target 12. The likelihood depends on how far the pollutants may transport and how much may land on terrestrial ecosystem thus causing biodiversity loss there. Thus the impact of this effect on SDG 15 is possible.

The judgement of magnitude should use the potential maximum achievement of a specific SDG target as reference. For example, target 11.6 is to reduce the adverse per capital environmental impacts of cities. As the air pollution from transport is one of the major contributors to this target, the achievement of reducing fuel combustion may be considered as major in magnitude.

The SDG evaluation scores obtained in Table A2 (using the Excel-based tool) is translated graphically into Figure 4.5.

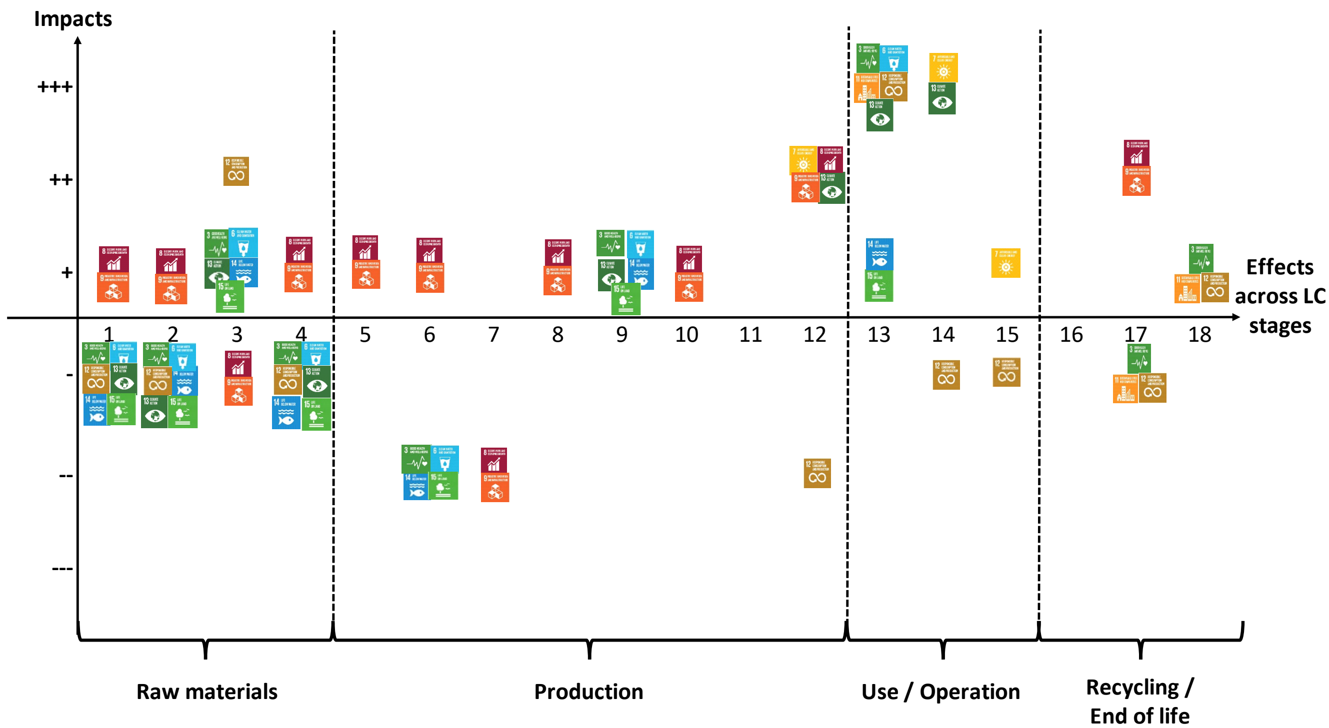

Figure 4.5. Visual representation of SDG impact assessment for the project of new battery technology development. To make the figure legible, impacts evaluated with negligible contributions are not displayed (hence no SDGs flags for some effects); background scoring of all SDGs and targets is documented for each effect in Table A2 (Appendix A).

1.5. Phase 5: Interpretation

Results of the evaluation support the following major observations: (i) slightly more SDGs are impacted positively than negatively, (ii) the number of SDG impacts resulting from cross-SDG links is relatively large (Appendix A1), (iii) the SDG impacts span the entire range of likelihood (from unlikely to likely) and magnitude (from negligible to large, with relatively large representation of negligible and small severity scores), (iv) most of the affected SDGs experience both positive and negative impacts. Relatively large representation of small and negligible severity scores explains why ca. 50% of all impacts are seen as not contributing substantially (that is, impact assimilated/scored as negligible) to their linked targets. These non-contributing impacts are listed in Appendix A2, but are not shown in Figure 4.5 to make it more legible (and to focus on those effects which matter the most).

Screening results presented in Table A2 and Figure 4.5 may suggest that the overall contribution of the project to SDG is neither positive nor negative. There are numerous tradeoffs between SDG impacts, and conclusions regarding the overall sustainability contribution of the project depends on the relative importance of the SDGs and their targets, which is not considered in this evaluation.

Tradeoffs between the different life cycle stages are also apparent, and sometimes positive SDG impacts occurring in one stage are countered by negative SDG impacts in another, or even in the same life cycle stage. The project is expected to have positive SDG impact on SDGs 8 and 9 (in the production stage), 3, 6, 7, 11, 12, 14 and 15 (in the use stage) and 8 and 9 (in the end-of life stage). These positive impacts are caused by less demand in fossils-based fuels during car operations, leading to reduction of emissions from car exhaust pipes and reduced extraction of crude oil for production of petroleum fuels; the entire petroleum fuel supply chain is affected. On the other hand, the project is expected to have negative impact on SDGs 12 (raw materials) or 8 and 9, but also 3, 6, 13, 14, 15 (production stage). These impacts are mainly caused by e.g. increased need for battery production efforts and associated impacts (metals resource use and possible emissions). The results also show tradeoffs between effects for specific SDGs. This is most apparent for the environmental SDGs related to human health (SDG 3), climate (SDG 13), life below water (SDG 14) and life on land (SDG 15).

It is seen that negative contribution to some SDGs is caused by the need for production of electricity for charging the EV batteries, which can therefore be considered as a hotspot. Note that the magnitude of this contribution will naturally depend on the nature of the electricity grid mix in the considered geographic location, and which energy sources will become relevant in the future. In the application context of Denmark, this is deemed of less importance as the electricity grid mix is increasingly composed of renewables. When studying potential upscaling of the effects of the project applications (not done here), these should however be considered. The changes in the electricity grid mix are outside the sphere of influence of battery technology developers and the inventor of the new electrolyte. However, the battery developers could focus on optimizing charging conditions to minimize energy losses during charging (particularly when electricity comes from fossils-based sources).

An alternative, more concise way of reporting the result analysis and conclusions of the assessment is provided in Clarifying Box 4.5.

Clarifying Box 4.5. Alternative way of reporting Phase 5

A more synthetic way may also be done:

- Major observation: i) net impact across all effects is largest for climate change and renewable energy, but is positive for all other SDGs assessed, so overall sustainability will depend on relative weighting of SDGs ii) large number of cross linkages iii) most SDGs were impacted positively and negatively in different effects iv) SDG impacts ranged across all likelihood and magnitude categories v) several effects with small or negligible magnitude of impacts (1, 5, 6, 11, 16, 17 and 18)

- The most important positive SDG impacts relate to climate change and affordable clean energy (SDGs 13 and 7), as a result of replacing transport fuel use, particularly fossil fuels, with electricity from renewable sources. This provided benefits for SDGs relating to health, water and sustainable cities (SDGs 3, 6 and 11).
- The most important negative SDG impacts relate to the potential impact of increased fossil fuel use for electricity generation for EV charging (SDGs 3, 6, 13, 14 and 15), the adverse economic impacts on the ICEs industry sector (SDGs 8 and 9)
- Hotspots and trade-offs between SDGs, life cycle stages, processes and SDG sustainability dimensions – the raw materials stage was a trade-off between increased and decreased fossil fuel extraction, the exact extent of which will depend on the amount of electricity sourced from renewables. The production life cycle stage had a balance of positive and negative effects, but the use/operation phase was predominantly positive. The net effect for all sustainability dimensions was positive, with economic and environmental SDGs the most positively affected.
- Short-term recommendations to stakeholders conducting the project – the current and projected electricity generation mix in EV deployment areas should be a focus of the project when assessing any environmental benefits of the technology, and focus on optimising the efficiency of the charging process to minimise the consumption of electricity.
- Long-term recommendations to stakeholders in charge of implementing the project results into the society – contributions of EV to SDGs, particularly to SDG 13 climate action, are heavily dependent on the underlying electricity generation mix for EV recharging.

1.6. Appendices

1.6.1. List of content

Appendix A (Electronic Excel file)

- Table A1. Documentation of linkage between identified effects and SDGs-targets (Step 1 of Phase 4)
  Contains justification of SDG impact and the cross-SDG links (Table 6 as template)
- Table A2. Documentation of evaluation of SDGs-targets impacts (Step 2 of Phase 4)
  Contains detailed SDG impact evaluation, incl. evaluation scores and justifications of likelihoods and magnitudes of the SDG impacts (Table 11 as template)

Both Tables A1 and A2 are documented within the Excel-based tool used for the case study, which constitutes Appendix A (provided as is).

Appendix B

- Detailed justification for effect identification (Phase 3 support)

1.6.2. Appendix B - Detailed justifications for effect identification (Phase 3)

As identified in Phase 2, the main consequence of the new system is to substitute the use of ICE vehicles with EVs (see Figures 4.2 and 4.3). Direct effects in the life cycle stages of the new system ensue from this substitution: (i) increase in production of car components specific to EVs (e.g. battery technology, electric drive motors requiring significantly larger amounts of rare earth elements like neodymium and dysprosium, etc.), (ii) decrease in production of car components specific to the ICE vehicles (note that some of this technology is still valid for hybrid vehicles and some of the range-extended EVs), (iii) additional infrastructures to build (e.g. charging stations), (iv) increased electricity demand (and hence of entire value chain of electricity generation in Denmark, which may be supplied by fossil-fuel sources and renewable energy sources like wind power, and may require additional capacity installation), (v) decreased need for gasoline and diesel (hence of entire value chain of petroleum and/or biomass fuels, e.g. decreased need for biodiesel and bioethanol, currently blended in small quantities (<10%) into petroleum fuels), and (vi) increased management of hazardous waste (batteries) and decreased management of conventional engines. Some of those direct effects could also be regarded as indirect when they are consequences that the new battery EV deployment has on other sectors than the transportation sector. As indicated in the methodology, the distinction between direct and indirect effects is not important as long as all effects are identified.

Indirect effects can also be identified as unintended changes caused by introducing EVs. An example is the higher energy requirements for EVs than for ICE vehicles (to heat the inside of the car in cold weather in Denmark: with ICE vehicles this heating comes from waste heat from the engine). That increases the energy demand needed to support EV transport above the requirements for propelling the car. This may put additional pressure on the electricity grid, which in turn may have implications for the electricity supply for transportation and other sectors (safety or stability, e.g. shortage, disruption, etc.). Another example of an indirect effect could be that several EVs drivers will install a charging station at home, which may require to adapt or change the electric installation of their houses.

In addition to these physical changes, non-physical changes are also relevant to consider. The new battery EVs and their extended range may influence user behavior in several ways. The increased attractiveness of EVs with extended range capacity (and lower operation costs that compensate the higher investment costs, compared to ICE vehicles) may lead to more driving, and this should be reflected in the projections defining the new system; this is what explains most of the differences between the baseline and the new system. Other behavioral changes, which could potentially be influential, are that customers may drive more (e.g. to seek charging stations with lowest costs or better service, because it is cheaper than driving with ICE vehicles) or differently (more or less acceleration/deceleration resulting in different energy needs, more comfortable driving). Government incentives or regulations could also influence such behavior changes in the population. In the specific case study of EVs, market studies could include evolutions of transportation patterns under different conditions or scenarios. This information could then support the definition of projections for the new system. Such projections can be fine-tuned iteratively between Phases 2 and 3 based on the identification of the effects to arrive at the projections displayed in Figure 4.3.

Finally, other non-physical effects could be considered, including the new business opportunities generated by the development of the new battery technology, like economic growth in the electronics sector or EV sector, and the likely recession of the sectors dependent on the ICE technology.

A number of processes identified in Table 4.1 can be classified as likely not to change, albeit there can be some uncertainty about the actual effect. These processes include: i) extraction of metal ores Cu, Al, Fe, with some uncertainty about material needs of additional infrastructures for charging; ii) manufacturing of different power trains, with some uncertainty about manufacturing of electric drive motors; iii) manufacturing of common car parts, as many parts of ICE and EVs are similar and are provided by the same suppliers; iv) assembly of a car, as assembly of both ICE car and an EV are expected to be similar; v) maintenance of an EV car, although there is uncertainty about functional long-term performance of new battery which may require replacement; vi) dismantling of system/capital goods and cars, with effect to uncertain to include as dismantling of charging station is not currently done; vii) reuse of some car parts, where no change is expected as many car components, be it an ICE car or EV, are the same and can be reused; viii) shredding, where no change is expected because EVs are currently disposed of in the same way as ICE cars are; ix) recycling of metals, where again no change is expected; and x) landfilling of post-shredding residue, where again no change is expected.

2. PROJECT ON ALGORITHM DEVELOPMENT FOR NOISE CONTROL SYSTEMS (Assessment Method A)

2.1. Phase 1: Considered application of the research project

Noise from construction sites are a serious challenge in building and infrastructure projects, especially in cities, where people live close together. Low frequencies caused by the machinery can generate considerable noise pollution, which can propagate over large distances and cause buildings to vibrate. This can lead to discomfort, hypertension, cardiac problems and other noise related pathologies, to citizens exposed to them. Often, the problem is handled by the municipality by regulating the hours within which the construction activities can take place. In extreme cases residents may have to be relocated while construction takes place and/or financially compensated. An example is the city of Copenhagen, where citizens have experienced severe noise problems related to the construction of a new metro line, which eventually led the municipality to compensate affected citizens with a total of 400 million DKK.

In that context, the goal of the research project is to develop an algorithm, which is planned to be implemented later into existing signal processing unit (e.g. loudspeakers) to actively cancel out the noise generated by construction sites. This project outcome (= algorithm) will enable the realisation of a noise control system designed to create quiet areas in cities close to a construction site. The system will include loudspeakers in strategic positions and electrical signals that can actively reduce the sound pressure level in the designed regions. The main application for the project is therefore the realisation and implementation of such systems for construction sites in cities with residential areas close by.

The scope of the assessment is limited to construction sites in the city of Copenhagen up to 2030 (assuming systematic implementation of the new system). In construction sites, several industries are involved, incl. the construction workers and the stakeholders mainly affected by the noise, namely the nearby residents and the municipality dealing with the consequences – i.e. medical treatment and financial compensation. The focus will be on the latter group, although occupational health damages from noise exposure could also be integrated into such assessment. Wider implementation of the developed algorithm could also be considered (other uses than for construction sites, scalability of the system to the world, etc.).

The project is not about technology development (algorithm development), but it can be linked to a direct technology implementation. Hence it is categorised under Project Type 1 (see Figure 4.1). Aligned with this classification, Assessment Method A is therefore used for the SDG assessment (see Figure 4.1).

2.2. Phase 2: Scope of the assessment

2.2.1. Delimitation of the baseline system

The baseline system is the construction sites without the new system of active noise cancellation. The use of equipment thus leads to noise pollution (and all its consequences). This can be represented by Figure 4.6 (see also Clarifying Box 4.6).

2.2.2. Delimitation of the new system

In the new system, the developed algorithm will be part of a noise cancellation system.

The technologies needed for that system already exist, although their demand may therefore increase, e.g. more loudspeakers and associated electrical sound components (in which the algorithm will be implemented) needed. For the system to work, it will require a large number of speakers. The life cycle of the construction site itself will not be changed, as the noise control system will work as an add-up system, allowing the construction activities to take place (but without disturbing nearby residents). The new system can therefore be scoped as the life cycle of the loudspeakers (and associated sound equipment) –see Figure 4.7 (see also Clarifying Box 4.6).

It includes the raw materials extraction, with mining of metals such as copper, iron and aluminium and fossil fuels (mainly crude oil) for plastics parts in the systems. Producing the speakers will require electricity, of which a share will likely be from fossil fuels (oil, coal, natural gas). During use at the construction site, the new system will mitigate noise pollution in the surroundings. The use of the speakers will require large amounts of electricity, probably supplied by diesel generators or the grid. When the construction project is finalised, the speakers may be reused again on another site or if they have lost functionality and are at the end of their lifetimes, they will likely be dismantled, recycled and/or disposed of.

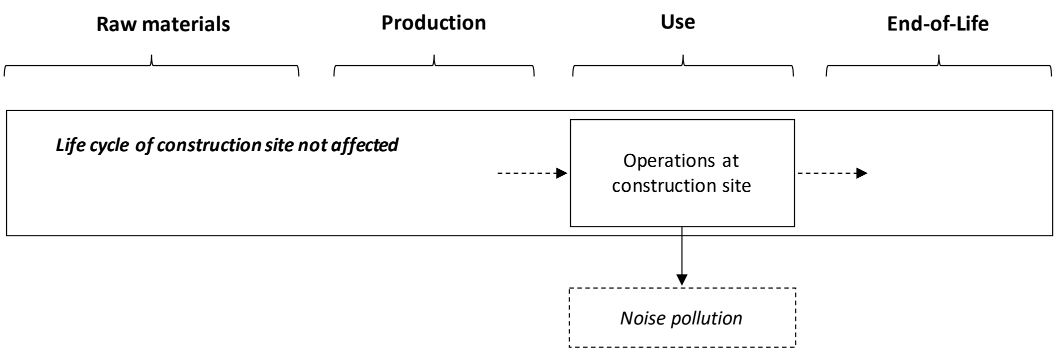

Figure 4.6. Scope of the baseline system.

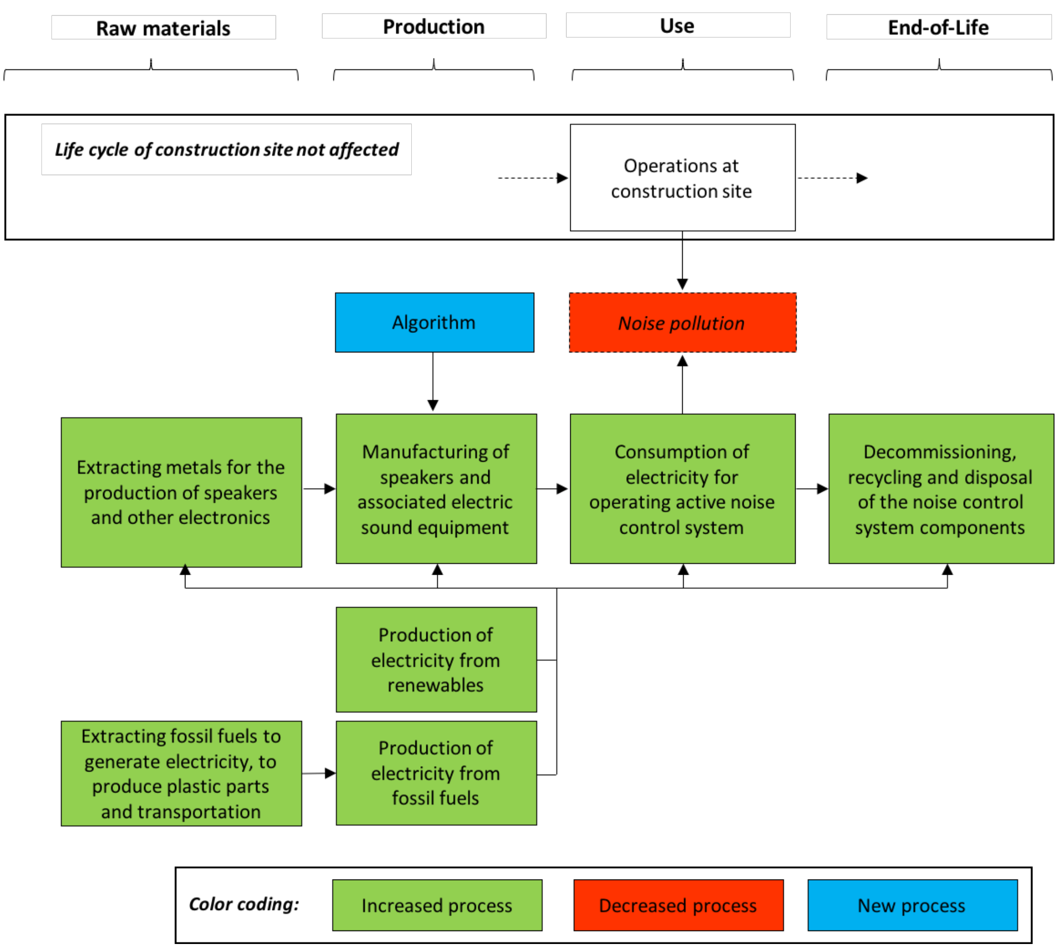

Figure 4.7. Scope of the new system.

Clarifying Box 4.6. Use of figures in Phase 2 reporting
To illustrate Phase 2 outcomes, two options can be considered: (i) reporting the baseline system and the new system scoping on two separate figures (= showing Figures 4.6 and 4.7), (ii) reporting the two systems on a same figure, with use of color coding (= only Figure 4.7). In cases, where there is only few added/deleted processes or activities (which is by far the majority of cases), the latter option should be preferred. The distinction between the two systems can be clearly reflected/identified using the color coding as done in Figure 4.7.

2.3. Phase 3: Inventory of effects from the applications

In Table 4.2 the effects of the new application of the technology are presented, building upon the scoped system in Figure 4.7. Note that the developed algorithm itself is not reflected in the table as it is not a change in itself, but rather trigger changes (i.e. all changes listed in Table 4.2 are effects from the new availability of this algorithm).

Table 4.2. Inventory of effects of the new system compared to the baseline system, highlighting increased (green) and decreased (red) process intensities.

Raw materials	Production	Use	Disposal
Physical effects			
Effect 1: Increased extraction of metals for the production of speakers and other electronics Effect 2: Increased extraction of fossil fuels to generate electricity, produce plastic parts, and transportation in the speakers' life cycle	Effect 3: Increased manufacturing of speakers and associated electric sound equipment Effect 4: Increased production of electricity from fossil fuels Effect 5: Increased production of electricity from renewable sources	Effect 6: Increased consumption of electricity for operating active noise control system	Effect 8: Increased decommissioning, recycling and disposal of the noise control system components
Non-physical effects			
		Effect 7: Decreased or removed noise pollution near construction sites (leading to decreased/ removed financial compensation and health-related issues)	

2.4. Phase 4: Evaluating the contributions of the application to SDGs

In Appendix A, the links between the effects and the SDGs is presented with a detailed justification (Table A1). Table A2 (in Appendix A) reports and justifies the estimations of likelihood and magnitude of the potential impacts of the identified effects on the SDGs. The resulting SDG evaluation scores are translated into Figure 4.8. In the figure, some effects are not related to any SDGs. This is due to negligible influence or unlikelihood that the impact will occur. Justification for this is provided in Table A2 (Appendix A).

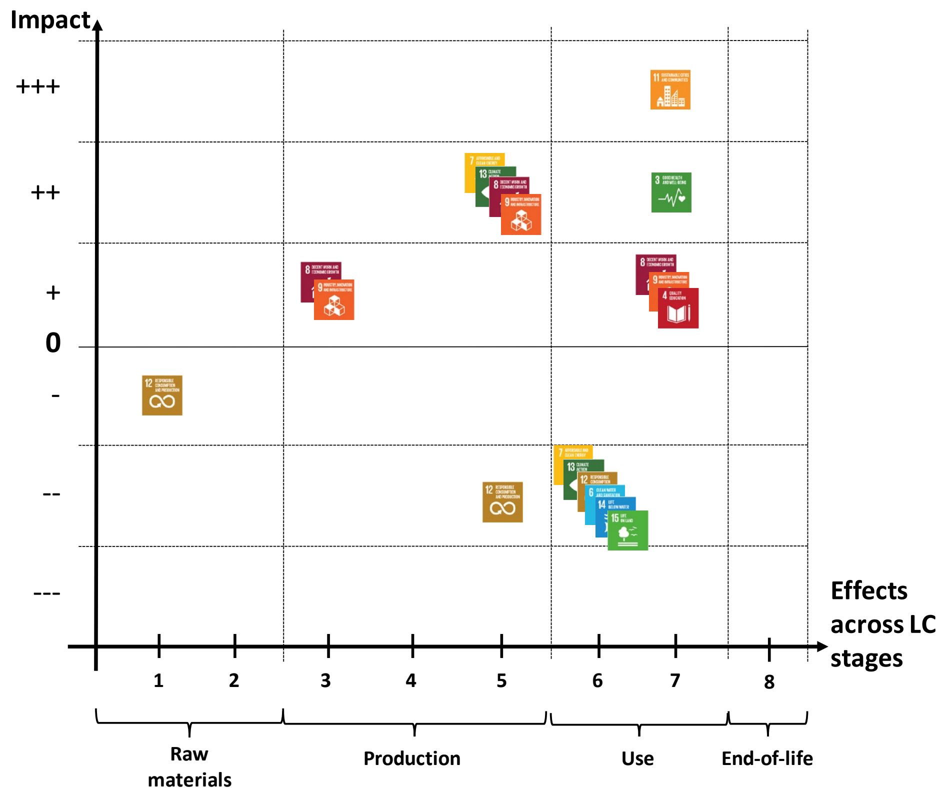

Figure 4.8. Visual representation of SDG impact assessment for the project of implementing active noise control at construction sites. Background scoring of all SDGs and targets is documented for each effect in Table A2 (Appendix A). To make the figure legible, impacts evaluated with negligible contributions are not displayed (hence no SDG flags for some effects); background scoring of all SDGs and targets is documented for each effect in Table A2 (Appendix A).

2.5. Phase 5: Interpretation

The most important positive impacts will be to SDG 11 and will occur during the use stage of the system. Introducing active noise control at construction sites in cities will create more liveable spaces and allow municipalities to invest funds, which would otherwise have been spent on compensations for affected citizens, in initiatives that further improve urban living, e.g. more accessible public transport. The economic gains from avoided compensations may thus lead to investments in public schools, hence benefitting SDG 4 and contribute to quality education for all. On the other hand, the gains may be compensated by the additional expenses from the implementation of the technology, which might be large considering the large number of devices needed to create quiet zones around a construction site. Removing or decreasing noise from construction sites will reduce the risk of chronic diseases for nearby residents, such as stress and cardiac diseases, thus reducing the weight on the health care system, thereby contributing positively to SDG 3. Another aspect, not treated in the assessment due to uncertainty, is the possibility of decreasing the duration of construction processes, if more hours during the mornings and evenings (due to less noise) can be spent as work hours. Today, construction sites have framed working hours to allow the nearby residents quietness. This could lead to further economic benefits.

The most important negative impacts are also located in the use stage of the speakers. Having speakers in use at multiple locations during the entire time of the constructions will require large amounts of energy (likely from a diesel generator or the grid). Extraction the crude oil for the diesel fuel or the important share of fossils fuels in most electricity grid mixes will impact a number of SDGs related to the environment (including human health), e.g. SDG 3, 6, 13, 14 and 15. Furthermore, the extraction of metals for the production of speakers, and their potential recycling at their end-of-life will have some impact on SDG 12.

Therefore, we can anticipate a trade-off between the gains from reducing noise pollution and the added materials and energy needed to reduce it. Reducing noise pollution will increase liveability and quality of life for nearby citizens and have a positive impact on the financial side. The social and economic aspects of sustainability may therefore benefit from the introduction of active noise control, while the environment may experience the negative consequences.

From these observations, recommendations could therefore be made to use recycled materials to produce the speakers and subsequently recycle as many parts as possible at the end of life. It appears that the consumption of electricity, especially related to the use of the speakers will be a hotspot and it will therefore be a priority to develop the algorithm to be a little power intensive as possible. The sound system should furthermore be chosen based on efficiency in terms of energy consumption (low wattage) and finally, the system should be sought to be supplied with renewable energy sources.

2.6. Appendices

2.6.1. List of content

Appendix A (Electronic Excel file)

- Table A1. Documentation of linkage between identified effects and SDGs-targets (Step 1 of Phase 4)

  Contains justification of SDG impact and the cross-SDG links (Table 2.6 as template)

- Table A2. Documentation of evaluation of SDGs-targets impacts (Step 2 of Phase 4)

  Contains detailed SDG impact evaluation, incl. evaluation scores and justifications of likelihoods and magnitudes of the SDG impacts (Table 2.11 as template)

Both Tables A1 and A2 are documented within the Excel-based tool used for the case study, which constitutes Appendix A (provided as is).

3. PROJECT ON PARASITIC NEMATODE AND ITS INFLUENCE ON COD MIGRATION (Assessment Method B)

3.1. Phase 1: Considered application of the research project

- **Research project** – The project has two main components: (1) identify and quantify how the liver worm, a parasitic nematode, is affecting the physiological condition, and therefore the performances, of the Atlantic Cod in the Baltic Sea using laboratory studies, and (2) map migration patterns of Baltic Cod in the Baltic Sea, identify subpopulations and determine which environmental factors affect the migration patterns and populations. This information will then be used to modify the existing stock assessment model (SAM), and is expected to reflect reduced performance/ increased mortality of the Baltic Cod species. The Eastern Baltic Cod fishery (EBC) was closed from July-December 2019, and the 2020 quota reduced the allowed catch by 92% compared to the original 2019 quota (European Commission, 2019), as the species is in distress and on the verge of collapse.
- **Selected applications** – The project is geographically limited to the Baltic Sea and uses data on existing fish stocks obtained from international surveys of fish populations and fisheries activities. The time horizon for the project is from the current day up until 2030, as part of an ongoing annual process that uses annual survey information to predict population for the next year. Therefore, the project will lead to the provision of decision support, which can help frame regulation of wild fish stocks of EBC by the European Commission. These regulations are likely to lead to reduced fishing of EBC in the short term. The adaptive stock assessment method developed in the project could also be applied to other wild fish stocks and in other locations. Assessment Method B is therefore used (see Clarifying Box 4.7).

Clarifying Box 4.7. Use of decision tree and selection of the Assessment Method.

The project is directed to knowledge creation to support policy making. The project outcome is indeed the provision of a revised stock assessment model, which can better help policy-makers responsible for managing fish stocks in the Baltic Sea. So the project falls under "Project Type 2" (see Figure 4.1). With the likely outcome of the following regulations, we can estimate that it will lead to tangible results. Hence, following the decision tree in Figure 4.1, the project is to be assessed using Assessment Method B.

3.2. Phase 2: Scope of the assessment

3.2.1. Delimitation of the baseline system

The baseline system uses biological information from international surveys (such as age, weight, length, maturity, location and condition for each species), parameters estimated from the survey data (such as total mortality (sum of fishing and natural mortality), spawning stock biomass, recruitment (number of individuals recruited to the adult population), length distribution, stock biomass and stock numbers) and data on fisheries activities to produce a SAM which reflects the dynamics of the whole population of a species and then predicts the stock levels for the following year. The project therefore engages mainly in modelling activities. The results from the SAM and relevant observations and recommendations are provided to the International Council for the Exploration of the Seas (ICES), who then provide scientific advice to member nations and international regulatory commissions. The European Commission (EC) uses this information to regulate fishing quotas in the following year. The result of these regulations imply physical changes on different systems, e.g on fishing activities, which should be considered in their life cycle -see Figure 4.9 of the baseline system (see also Clarifying Box 4.8).

3.2.2. Definition of the new system

In comparison to the baseline system, the new system will: (1) use additional biological information on parasitic infections to assess their negative affect on parameters such as fish mortality and condition; and (2) use environmental and fisheries operational data from existing databases to assess migration patterns, subpopulations and the impact of climate change. These two new sources of information will be used to modify the SAM, and the results from the SAM may therefore change, possibly leading to different advice from the ICES to the EU, and the EU subsequently changing fishing quotas. The application is limited to EBC in the Baltic Sea, due to the critical status of the stock at present. The provision of better knowledge support is expected to lead to recommended decrease in wild EBC fishing in the Baltic Sea in the short term, with reopening of the fishery once stocks recover to sustainable levels.

Figure 4.10 provides the scope of the new system (see Clarifying Boxes 4.8 & 4.9).

Clarifying Box 4.8. Systemic perspective and life cycle perspective in the scoping.

In Project Type 2 (relevant for Assessment Method B), like the case here, the system scoping can be illustrated by taking an overarching systemic perspective (instead of a direct application of a life cycle perspective, as done for Project Type 1). This means that the scoping can first be illustrated by a chain of events, typically capturing the activities associated with the knowledge creation and leading to the decision or policy support (top part of Figures 4.9 and 4.10). It is then complemented by the application of the decision/policy support, which translates into actual changes on physical systems: these systems need to be represented by a life cycle perspective, wherever relevant, as they are the ones, which will mainly drive the negative and positive contributions to the SDGs.

Clarifying Box 4.9. Illustration choice for scoping of the baseline and new systems

As mentioned in the guideline, one or two figures can be made to represent the scoping of both baseline and new systems. Here two separate figures are shown (Figures 4.9 and 4.10), but Figure 4.10 could be sufficient with an appropriate use of colour coding.

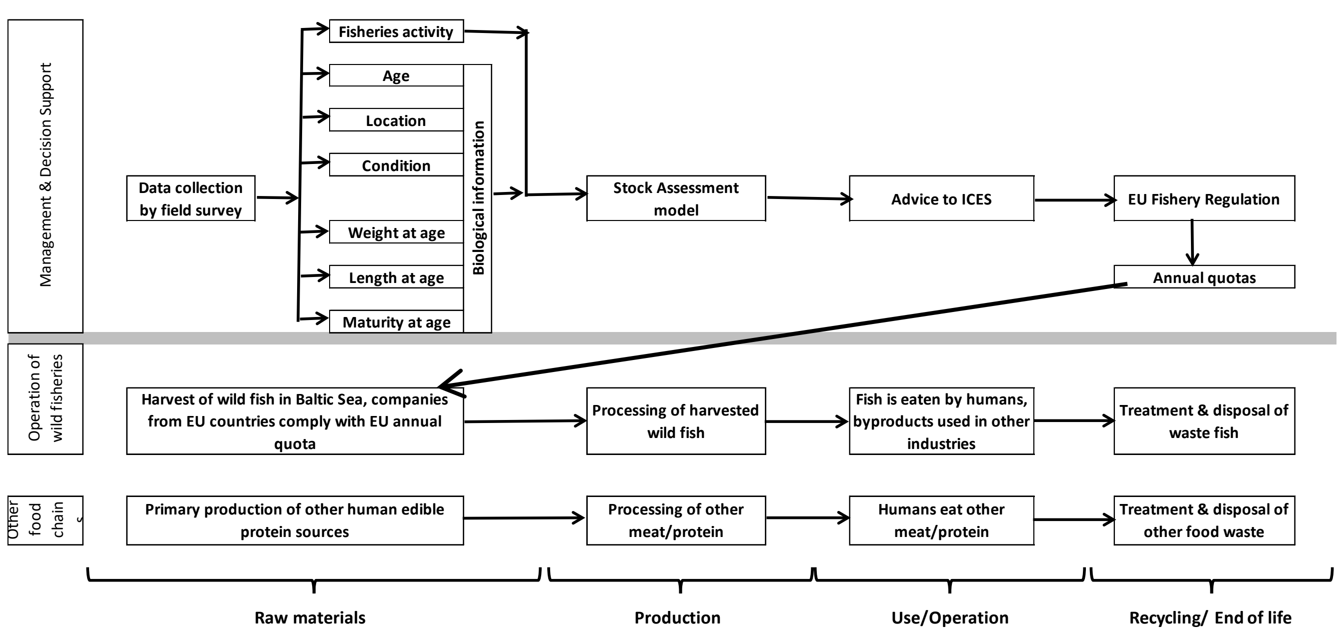

Figure 4.9. Scope of the baseline system for the Eastern Baltic Cod case

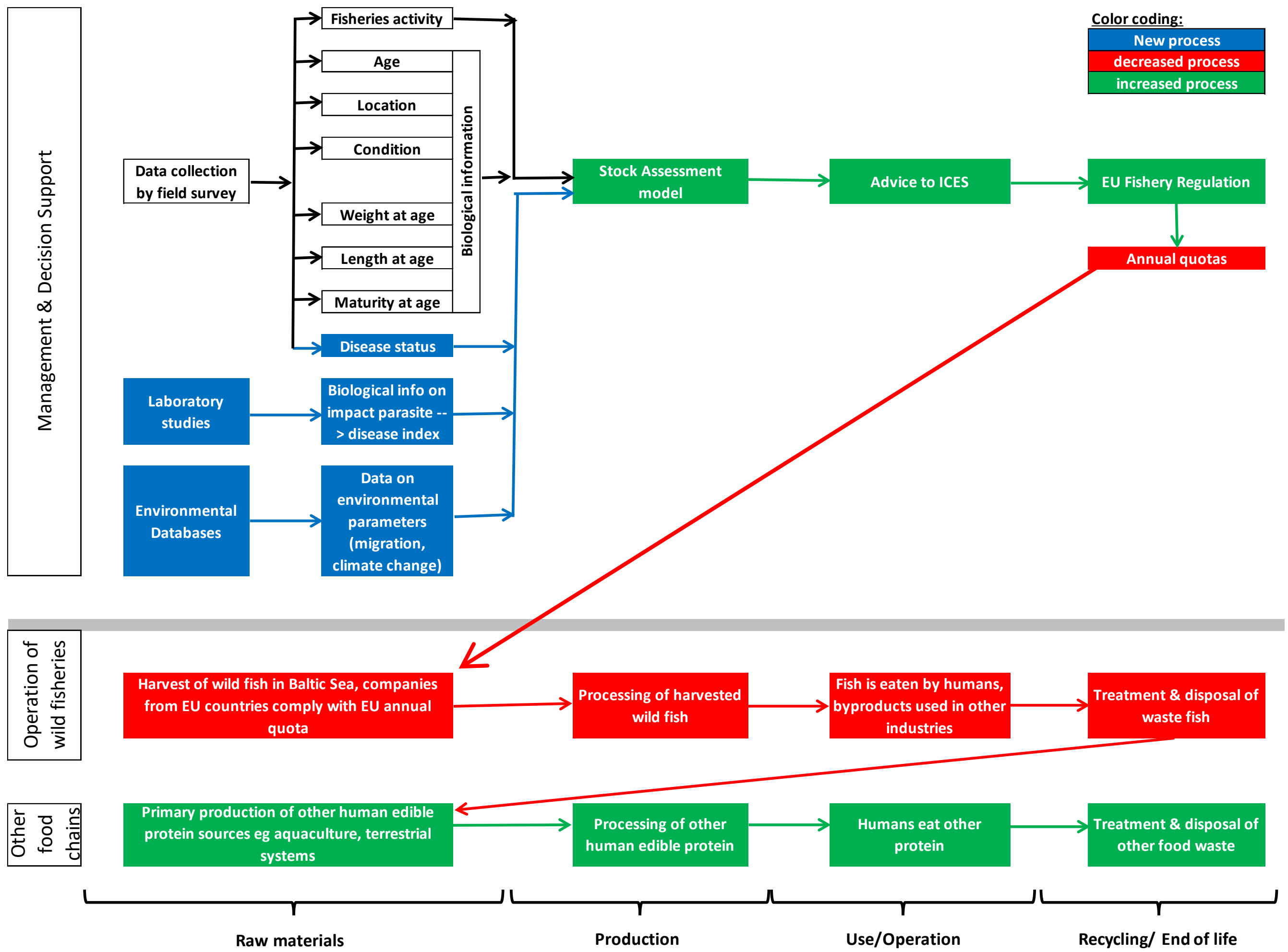

Figure 4.10. Scope of the new system for the Eastern Baltic Cod case (color coding indicated in top right corner of the figure)

3.3. Phase 3: Inventory of effects from the applications

Table 4.3 highlights the main direct and indirect effects of the project applications. Some of the effects relate to the management and decision support system currently used to manage harvesting from wild fisheries in the EU, while other effects relate to the impact that these management decisions, such as continuing fisheries restrictions, will have on the underlying supply chains and inter-related supply chains. As EBC quotas have been reduced by 92% for the 2020 year compared to the original 2019 quota and the EBC fishery was closed from July-December 2019, EBC products entering food markets have already decreased, so it is assumed that the existing shortfall and any possible further shortfall as a results of this project will be made up by other human edible protein (HEP) sources, such as cod from other locations, fish from aquaculture or HEP from terrestrial-based food production systems, such as animal production systems (ruminants such as cattle and sheep and monogastrics such as chicken and pigs) and non-animal systems (peas, beans). Although it is considered beyond the scope of this analysis to determine what specific alternative HEP sources would make up the shortfall of HEP from EBC, almost all other terrestrial HEP production supply chains have higher environmental impacts and aquaculture may have higher eutrophication and toxicity impacts, but lower climate change impacts (Ellingsen and Aanondsen, 2006; Stucki and Jungbluth, 2012). Separate effects are used for the short term implications of the continued closure of the EBC fishery, and the longer term implications of reopening the fishery, albeit at lower quota levels once the increased knowledge on disease status and environmental impacts is included in the SAM.

Table 4.3. Main direct and indirect effects of the project application. Color coding: blue text indicates new effects, red text indicates effects which have decreased and green text indicates effects which have increased.

Management & Decision Support	Raw materials	Production/ Processing	Use/ Operation	Recycling/ End-of-life
Physical changes				
Effect 1 - new biological information on impact of parasite & environmental impacts/migration	Effect 7 - short term - reduced production or closure of EBC fishery	Effect 11 - short term - reduced/zero production from EBC supply chains	Effect 15 - short term - reduced /zero consumption of EBC	Effect 20 - short term – reduced /zero recycling/end-of-life from EBC fishing and processing activities
Effect 2 - improved quality of stock prediction due to improved Stock Assessment Model and improved quality of information provided to ICES	Effect 8 - short term – increased production (= materials stage) in supply chains linked to other HEP sources e.g. aquaculture, wild cod from other locations, terrestrial HEP sources, e.g. animal (beef, pork, etc.), non-animal (soy, beans, etc.)	Effect 12 - short term - increase in production/processing in supply chains producing other HEP sources	Effect 16 - short term - Increased consumption of other HEP sources (other fish,	Effect 21 - short term - Increased recycling/end-of-life of other HEP sources
Effect 3 - improved quality of information ICES provides to EU and other countries	Effect 9 - longer term - increase in EBC quota to production levels to ensure sustainable harvesting from EBC supply chain	Effect 13 - longer term - increase in production/processing from EBC supply chain	Effect 17 - longer term - increase in consumption from EBC supply chain	Effect 22 - longer term - increase in recycling/end-of-life from EBC supply chain
Effect 4 - improved quality of EU Action plan and subsequent quota allocation, more effective EU fisheries regulation, leading to recovery and long term sustainability of cod stocks	Effect 10 - longer term - decreased production(material stage) from other HEP supply chains	Effect 14 - longer term - decreased production/processing from other HEP supply chains	Effect 18 - longer term - decreased consumption from other HEP supply chains	Effect 23 - longer term - decreased recycling/ end-of-life from other HEP supply chains
Effect 5 - continued very low production from or short term closure of EBC fishing areas, to allow cod stock to recover (+ unknown effects on trophic level and energy flows in the marine ecosystem)				
Effect 6 - creation of fish disease index and incorporation into field surveys				
Non-physical change (social, economic, ethical etc.)				
			Effect 19 - increased awareness of sustainability issues relating to fishing / shift towards consumption of more sustainably-produced HEP	

3.4. Phase 4: Evaluating the contributions of the application to SDGs

As required in Assessment Method B, the impact of the identified effects relating to management and decision support (effects 1-6) are distinguished from those which follow the implementation of the decisions or policies and are captured using a life cycle perspective. There are a number of cross-linkages: between the environmental SDGs (12, 13, 14 and 15); between SDG 12 (responsible consumption and production) and SDGs 2 (zero hunger) and 3 (good health / wellbeing); and between SDG 8 (economic growth) and SDG 9 (innovation & infrastructure).

The management and decision support effects are found to have largely positive impacts, as a result of the potential positive impacts they could have both on the Baltic cod fishery and the management of wild fish harvesting worldwide if widely adopted. The only possible negative impacts are the trophic effects – due to predator-prey interactions, such as an increase in seal populations (which eat cod) or a decrease in herring and sprat populations (which cod eat) – allowing the cod stock to recover, which are currently unknown.

Given that the EBC fishery declined in the 1980s and production has been low since that time, including the recent fishery closure (July-December 2019), the magnitude of the adverse effects of continuing the closure (effect 7) are negligible, compared to the potentially large benefits of allowing the EBC species to recover to sustainable levels (SDGs 12 and 14).

Most of the effects relate to the different scenarios which result from the management and decision support elements of the project application. For example, effects 7, 11, 15 and 20 are for the life cycle impacts of reduced/zero production from the EBC in the short term, which is linked to effects 8, 12, 16 and 21, which are for the life cycle impacts of increased production from other HEP supply chains in the short term. Similarly, effects 9, 13, 17 and 22 related to the reopening of and recommencement of production from the EBC fishery at some stage in the future, which is linked to effects 10, 14, 18 and 23, which are the life cycle impacts of decreased production from other HEP supply chains.

Figure 4.11 presents a summary of the SDG impacts of effects across the life cycle stages, and impacts which were evaluated as having negligible effects are not included in the figure. However, comprehensive details of the justification for SDG impacts and the likelihood and magnitude of the impacts for all effects are included in electronic Appendix A. A small amount of contextual information from the literature in provided in Appendix B.

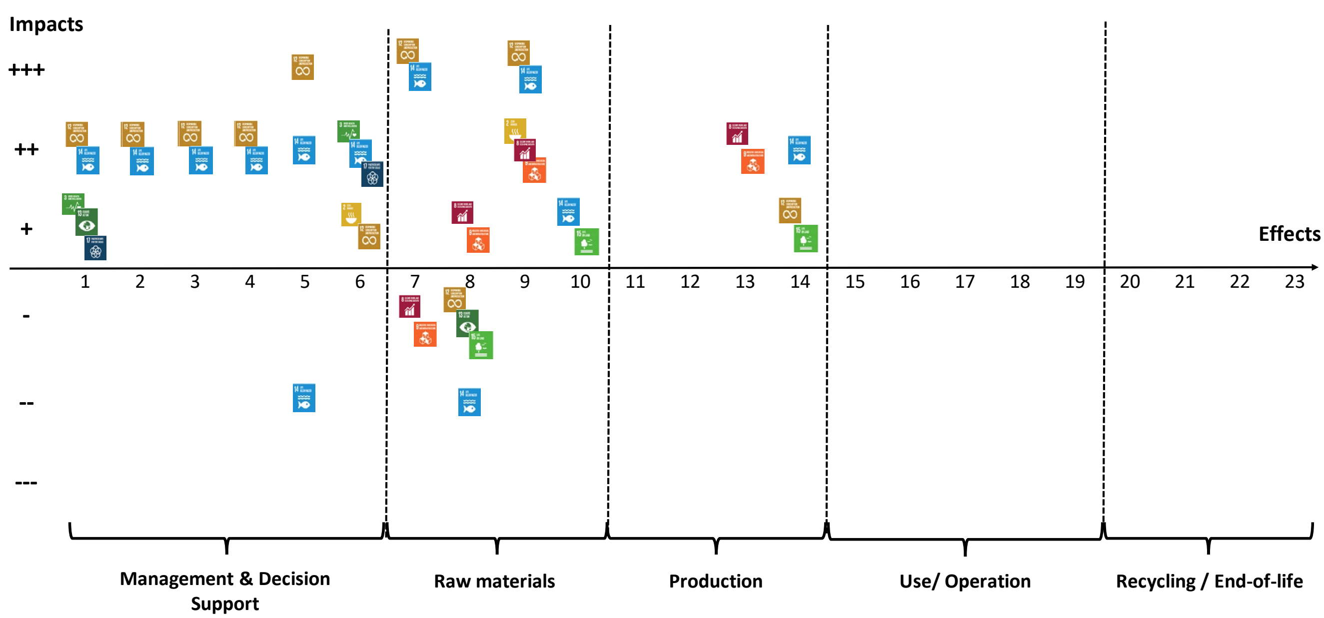

Figure 4.11. SDG effects across the life cycle stages. To make the figure legible, impacts evaluated with negligible contributions are not displayed (hence no SDGs flags for some effects); background scoring of all SDGs and targets is documented for each effect in Table A2 (Appendix A).

3.5. Phase 5: Interpretation

Clarifying Box 4.10. Inclusion of sensitivity to different implications of decision support in the assessment

Following the guidelines illustrated in Figure 4.1, Phase 5 in Assessment Method B should include alternative project application scenarios to account for the uncertainties in the consequences or implications from the utilisation of the decision support. In the present case, this has been captured by the inclusion of multiple effects from shifting away from the fished cod consumption to alternative sources of HEP. A large variety of sources of HEP have therefore been included, as captured in Table 4.3 (effects 8, 12, 16 & 21 as well as effects 10, 14, 18 & 23) and characterised in the SDG evaluation phase (see Table A2). In addition to these different alternatives/scenarios, a differentiation between short-term implications and long-term implications was made (see Table 4.3). All these aspects contribute to evaluate the sensitivity of the SDG evaluation and accommodate the relative uncertainty of the project application (utilisation of decision support), as required in Assessment Method B. Other approaches to accommodate this uncertainty are possible, e.g. detailed scenario analysis, etc.

The interpretation of the results can be summarised with the following points:

- The results of the project application are largely positive, indicating that the negative aspects of continuing the current very low production rates or reclosing the EBC fishery seem to be outweighed by the longer term positive benefits.
- The *most important positive SDG impacts* relate to SDG 12, as a result of the wild harvesting of EBC being carried out within new, more accurate maximum sustainable yield levels and SDG 14, maintaining the aquatic biodiversity in the Baltic Sea. In addition, there may be some positive benefit to SDG 2 (zero hunger) due to the development and use of improved forecasting processes which ensure that the wild harvest of fish stocks in sustainable in the longer term.
- The *most important negative SDG impacts* relate to potential adverse trophic effects of allowing EBC stocks to recover (impacts currently not known) which may lead to increases in seal populations (with flow on effects to parasitic nematode infection rates) and the decrease other fish which cod feed on (effect 5); the adverse economic effects of the short term decrease/closure of the EBC fishery (effect 7); and impacts associated with short-term increased production from other HEP supply chains, particularly aquaculture (which is associated with higher eutrophication and ecotoxicity impacts) and meat-based terrestrial HEP supply chains (which threaten terrestrial biodiversity) (effect 8).
- *Hotspots to prioritise for improvements* – the most significant negative hotspots relate to the raw material production stage, particularly economic issues due to the reduced production from the EBC (SDGs 8 and 9 from effect 7), which can be managed by providing compensation to fishermen adversely affected by the closure including funding to decommission vessels, thus possibly having a positive impact of removing older, less efficient vessels from the fleet. In terms of the adverse impacts to climate change (SDG 13) and biodiversity (SDGs 14 and 15) due to increased production from other HEP supply chains (effect 8), these adverse impacts could be minimised by supporting the production of other HEP sources associated with lower impacts, such as non-meat or fish from sustainably managed aquaculture operations.
- *Potential trade-offs* – given that the EBC fishery had been operating at a substantially reduced capacity since the 1980s, there was a recent (July – December 2019) closure of the fishery, the current operation is at very low harvesting rates, there is a high likelihood of the EU compensating affected fishermen and there are other fish resources in the Baltic Sea, the short term adverse impacts of extending the EBC fishery harvesting restrictions far outweigh the potential longer-term benefits of allowing the EBC fish stocks to recover. At some stage in the future it is anticipated that the EBC fishery will reopening, using the new, improvement

estimates from the SAM which include the new factors from this study, thus ensuring the long term sustainability of both the underlying EBC fish resource and the industries which rely economically on harvesting them.

- *Scalability* – given that the current project application was geographically limited to cod stocks in the Baltic Sea, one potential positive outcome of the project is the use of the improved Stock Assessment Model (SAM), with the fish disease index and climate change impacts included, to predict the maximum sustainable wild fishing yields of other fish stocks in the Baltic Sea or fish stocks in other geographic location. This is indicated by SDG 17, and would require additional scientific research in those locations on issues such as diseases, subpopulation migrations and climate change impacts, which could be supported by countries such as Denmark.
- *Short-term recommendations to stakeholders conducting the project*: there may be a benefit in reassuring stakeholders, particularly communities dependant on income sources from EBC fishing, that the current short term closure will hopefully ensure the preservation of the species in the Baltic Sea and the recommencement of income from this resource once the stocks have recovered. It is also vitally important to ensure that the new data and the way it is incorporated into the SAM leads to improved forecasting.
- *Long-term recommendations to stakeholders* in charge of implementing the project results into the society – the magnitude of the impact of the management and decision support actions is largely dependent on the degree of international dissemination and cooperation. The results from this project will be incorporated into the SAM model which is used by ICEM and used for enhancing forecasting to enable the EU to set sustainable quotas, but the enhanced methodology could be used in other locations where overfishing has depleted wild fish stocks.

3.6. References

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Parker R (2012) Review of life cycle assessment research on products derived from fisheries and aquaculture: a report for Seafish as part of the collective action to address greenhouse gas emissions in seafood. Online on Seafish website: http://www.seafish.org/media/583639/seafish_lca_review_report_final.pdf

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Ziegler, F., Nilsson, P., Mattsson, B., & Walther, Y. (2003). Life cycle assessment of frozen cod fillets including fishery-specific environmental impacts. International Journal of Life Cycle Assessment, 8, 39-47.

3.7. Appendices

3.7.1. List of content

Appendix A (Electronic Excel file)

- Table A1. Documentation of linkage between identified effects and SDGs-targets (Step 1 of Phase 4)

  Contains justification of SDG impact and the cross-SDG links (Table 2.6 as template)

- Table A2. Documentation of evaluation of SDGs-targets impacts (Step 2 of Phase 4)

  Contains detailed SDG impact evaluation, incl. evaluation scores and justifications of likelihoods and magnitudes of the SDG impacts (Table 2.11 as template)

Both Tables A1 and A2 are documented within the Excel-based tool used for the case study, which constitutes Appendix A (provided as is).

Appendix B

- Detailed documentation behind the identification of effects (Phase 3) (please refer to the excel spreadsheet for the detailed information on each effect).

3.7.2. Appendix B – Detailed documentation for Phase 3

As identified in Phase 2 and summarised in Figure 4.10, the main consequence of the project application is improved knowledge being used in the existing management and decision support system, ultimately leading to a continuation of the current harvesting restriction in the EBC fishery in the short term. The expected outcome is that the EBC stocks will recover and the fishery will be able to reopen at some stage in the future with annual quotas set at a level at or below the maximum sustainable yield level. The stages in the management and decision support process are separate effects as there are discrete decision points included in each effect, but effects 2-4 could have been grouped.

The outcomes of the management and decision support system mean that, in the short term, other food supply chains will continue to need to make up the HEP required, although in the longer term the reverse will be true. It is difficult to predict exactly what the reduced EBC production is currently being replaced with, as the fishery was closed from July – December 2019 and the fishery is currently operating at very low harvest levels compared to other fisheries in the Baltic Sea. The HEP source which is replacing the HEP could be: cod from another wild fishery; fish from aquaculture; meat from terrestrial food supply chains; or non-meat HEP alternatives.

It was considered pertinent to include a non-physical change relating to outcomes from the project and wider management of wild fisheries impacting on consumer behaviour. It is possible, if not probable, that stories in the media relating to the sustainability (or apparent lack thereof) of wild fisheries may influence consumer behaviour, either directly or through the use of consumer labelling schemes which indicate the sustainability of the fish product.

Similarly, there were a number of processes which are not likely to change, most particularly the large amounts of data currently being obtained as part of field surveys. It has been assumed that the capture of new data relating to the disease status of the fish will be included in field surveys at some stage in the future, to enable the assessment of how the fish disease status will impact projected stock numbers on an ongoing basis.

Relevant background information for effects 1 - 6, 7, 9 and 11.

The following background information is taken from the most recent ICES report (ICES, 2019). The largest catches by weight in the Baltic Sea are from the pelagic mid-water trawl fisheries for the **sprat** and **herring** species, which are widespread. The demersal bottom-trawl **cod** and **flatfish** fisheries are concentrated in the south and west of the Baltic Sea, and decreases in cod fishing in the central Baltic Sea are balanced by increased fishing of the herring and sprat species. Of the nine countries with fishing vessels operating in the Baltic Sea, only Russia is not an EU member, and their proportion of fish landings is quite small (about 10% of the total).

The Baltic Cod is a known predator to sprat, herring and juvenile cod and a possible predator to flounder and plaice. Eastern Baltic cod populations declined in the late 1980s and have not recovered, leading to larger populations of herring and sprat due to decreased predation. Immature cod feed on benthic prey, and increased areas with hypoxia due to environmental change have caused lower feeding levels and increased mortality in juvenile eastern Baltic cod populations. There are three species of seal in the Baltic Sea which eat cod, flounder, herring, salmonids and spray, and birds, mainly cormorants, eat fish, but the effect on these species on fish stocks has not been assessed. One of the seal species is the definitive host of the parasitic nematode in this study, and the cod are one of several intermediate hosts, and it is not clear if the recently observed higher parasitic infection rate is a cause or effect of low cod condition. This means that the trophic effects (predator-prey interactions) of Baltic cod populations could be positive or negative (effect 6).

Relevant background information for effects 7-11.

The following background information of the life cycle impacts of trawl fishing was taken from (Ziegler et al., 2003), which used the functional unit of 400 g of frozen cod fillet at a consumers’ house in Sweden, caught by Swedish fisherman in the Baltic Sea and processed in Sweden. The seven impact categories included in the analysis were acidification potential, aquatic ecotoxicity, eutrophication potential, global warming potential, nitrogen eutrophication potential, phosphorus eutrophication potential and photochemical ozone creation potential. The fishery life cycle stage, particularly the fishing vessel fuel consumption, dominated all impact categories except eutrophication, which was dominated by emissions from the production/processing stage. Demersal species like cod are non-schooling, which explains the higher trawler fuel use and therefore carbon footprint compared to other species such as mackerel and herring (Ziegler et al., 2013).

The following background information on the comparative impacts of wild caught cod, farmed salmon and chicken is taken from (Ellingsen and Aanondsen, 2006). The functional unit was 0.2kg of fillets and the system boundaries included wild harvest/ farming, processing and transportation. For all three meat types, the primary production stage dominated all impact categories – for the wild caught cod, this was a consequence of fuel consumption in the fishing vessels, whereas for the farmed salmon and chicken, it was due to the production of feed. Chicken was the most efficient in terms of energy use, followed by farmed salmon then cod. Using eco-indicator 99, which includes the impact categories of fossil fuel consumption, acidification, eutrophication, ecotoxicity, climate change, respiratory inorganics and carcinogens, cod fish fillet had a value of 0.085 Pt/functional unit, while farmed salmon had a value of 0.065. Cod fish had higher values for the fossil fuels and respiratory inorganics impact categories due to fuel consumption in the fishing vessel, while farmed salmon had a higher value in the ecotoxicity category, due to the copper emissions from salmon farming. Chicken and salmon had higher scores for eutrophication than cod.

According to a paper by Stucki and Jungbluth, 2012, poultry and pork (monogastrics) had a slightly lower carbon footprint than cod, but lamb, beef and veal (ruminants) had higher carbon footprints that cod by factors of 2.5, 3 and 4 respectively. Using the ecological scarcity method, cod had the lowest score, poultry was the next (higher by a factor of 2), then pork (higher by a factor of 3), then lamb and beef (factors of approximately 2.2 and 2.6), but farmed salmon and veal were about the same (higher by a factor of over 4).

4. PROJECT ON DEVELOPMENT OF AN ENVIRONMENTAL SUSTAINABILITY ASSESSMENT METHODOLOGY FOR CITIES (Assessment Method C)

4.1. Phase 1: Considered application of the research project

The urban population of the world is growing, and by 2050, 68% of the world population is expected to be urban (United Nations, 2019). Cities are responsible for more than 70% of greenhouse gas (GHG) emissions worldwide and consume 80% of the world's energy (United Nations Development Program, 2016). The overall aim of the research project is to investigate whether or not cities can limit their environmental impact within finite resource capacities and environmental boundaries that would preserve a safe operating space for humanity, and if so how to achieve it. In short, how can we transform current cities to be environmentally sustainable in absolute terms? In the context of the project, environmental sustainability can be regarded as having an impact lower than or equal to an allocated share of the total available environmental operating space. To answer the research question, the project will develop a city assessment methodology, which will enable to quantify comprehensively the environmental impacts of cities and benchmark the results against absolute sustainability boundaries.

This methodology/tool is envisioned to be used by urban, regional and national policy makers after the project ended, thus supporting more informed decisions on sustainable urban planning. In this assessment, the utilization of the methodology (= application of the project outcome) is assumed limited to *municipalities*, as municipal decision makers will have the largest influence on actual changes to urban systems. If this project is successful, the results will provide recommendations to policy-makers to achieve a sustainable city, for example in terms of the necessary density, square-meters per person, distance to public transport, energy/electricity/water sources, mix of functions (commercial, residential, industrial), etc. The geographical scope of on the assessment is limited to larger cities, which are also believed to be the main target users of the to-be-developed methodology. For this assessment, it is assumed that cities across the world with a population of more than 1 million are relevant recipients of recommendations. The time horizon is considered up to 2030 to match the SDG agenda.

The project can be characterised as knowledge support for decision or policy management. Hence it is categorised under Project Type 2 (see Figure 4.1). As the uptake of the methodology by policy makers and the subsequent actions taken as a result of its application to individual urban systems are largely uncertain, Assessment Method C will be used for the SDG assessment (see Figure 4.1 and Clarifying Box 4.11).

Clarifying Box 4.11. Use of decision tree and selection of the Assessment Method.

The project activities consist of a methodology development (with associated methods and models). The outcome is the methodology/tool itself which can deliver assessments of environmental sustainability of cities and serve as policy support. It therefore falls under "Project Type 2" (see Figure 4.1). Due to the large uncertainties in the use of the methodology and the follow-up actions from its application (e.g. urban policies to curb large environmental impacts or change consumption/lifestyle patterns), it is considered that there are no tangible consequences of the project ("unpredictable use of the support provided"). This calls for application of Assessment Method C, in which the focus is mainly on the project activities and on the exploration of the knowledge support use (under different scenarios) –see Figure 4.1.

4.2. Phase 2: Scope of the assessment

4.2.1. Delimitation of the baseline system

In the baseline system municipalities make decisions based on existing knowledge, and in many cases the focus is likely not on concrete actions to reduce environmental impact. The quality of the existing knowledge varies depending on the municipality, country and regions. Most countries within the European Union have to some extent an environmental sustainability agenda, which may influence decisions at a municipal level, but in developing countries, the focus is likely on social and/or economic aspects of sustainability, with no decision support based on environmental factors available. Thus, the baseline system is illustrated in Figure 4.12 as a black box with decision support based on existing information (see also Clarifying Box 4.12).

4.2.2. Definition of the new system

The new system covers the added knowledge during and after this project; its scope is defined in Figure 4.12. As illustrated in Figure 4.12, the project activities are highly theoretical and are expected to have no significant effect on existing products, technologies and services. Following the steps of first analyzing causes of impacts, building a model, utilizing this model to quantify impacts, analyzing the results, extracting recommendations and communicating these to municipalities worldwide, no major interactions with other technological systems are taking place. The final step, illustrated as another black box, assumes that the project is successful, and recommendations are eventually used as decision support. Here, changes may happen to existing structures and processes. This uncertainty of the use of the provided support is treated further in Phase 4 in the form of possible uptake scenarios.

Clarifying Box 4.12. Phase 2 in Assessment Method C, and its constraints

As specified in the methodology part, Phase 2 in Assessment Method C focuses on the project activities itself up to the generation of the decision/management support. The utilization of this support, which is where most of the uncertainties lie, is subject to possible scenarios as part of a sensitivity analysis. That sensitivity analysis is introduced and further specified in Phase 4.

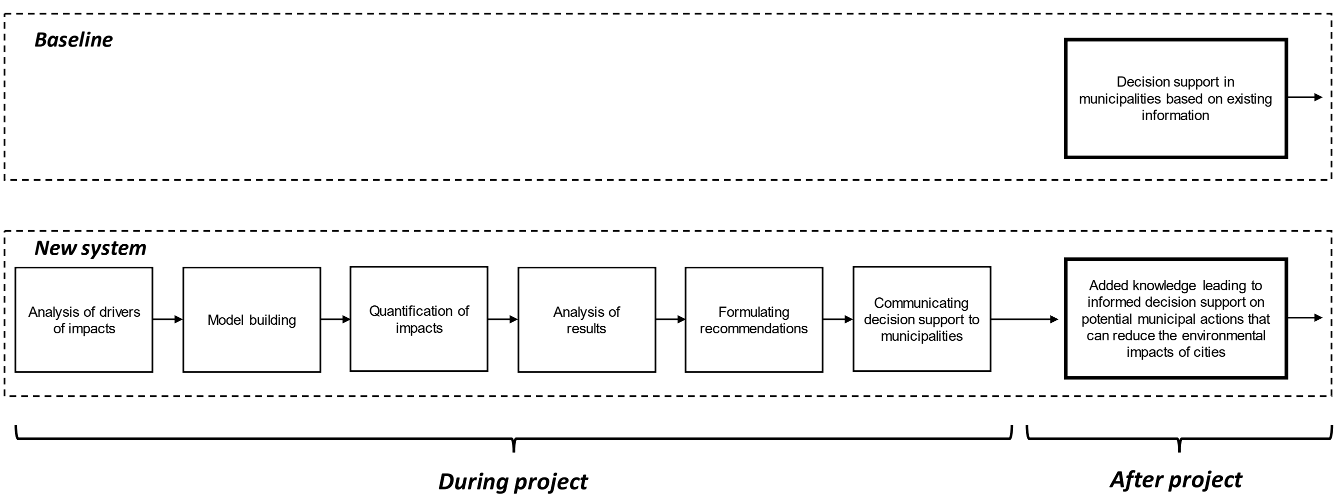

Figure 4.12. Scope of the baseline and new systems

4.3. Phase 3: Inventory of effects from the applications

In Table 4.4, the effects of the added knowledge during and after the project are presented, building upon the scoped system in Figure 4.12. Note, that the activities related to the project work itself are not reflected in the table, as they are not changes themselves or considered negligible (e.g. use of a laptop, which would have been used in a baseline system too). The focus is on the added knowledge from the scientific advances during the project work and on the potential actions taking place in cities following the project outcomes and its new knowledge.

Table 4.4. Effects of the new system compared to the baseline system, illustrating the added knowledge

During project work	After project work
Effect 1: Added knowledge/scientific advances on assessments of environmental sustainability of cities.	Effect 2: Added knowledge leading to informed decision support on potential municipal actions that can reduce the environmental impacts of cities.

4.4. Phase 4: Evaluating the contributions of the application to SDGs

At present, it is still unknown what recommendations can be derived from the project results. However, based on knowledge collected so far, the activities responsible for the majority of urban environmental impacts are often related to: (1) consumption of resources and mismanagement of waste, (2) infrastructure dominated by personal internal combustion engines (ICE) vehicles, (3) consumption of energy supplied by fossil fuels combustion (electricity, heat), and (4) impactful agricultural systems to support food supply.

With little knowledge on the final municipalities' recommendations, it is expected and deemed highly likely that they will revolve around these four areas of activities. Depending on the uptake in municipalities in cities worldwide, the impacts on SDGs can be assessed. For this assessment, a sensitivity analysis is used with two scenarios of uptake in municipalities are considered, a best and a worst case (see Clarifying Box 4.13). In the best case scenario, it is assumed that 95-100% of municipalities in cities larger than 1 million worldwide adopt all the recommendations and implement them before 2030. In the worst case scenario, it is assumed that only 0-5% of municipalities in cities larger than 1 million worldwide adopt all the recommendations and implement them before 2030. Based on this, the SDG assessment is carried out and presented in Figure 4.13A (best case) and 4.13B (worst case). Both best and worst case scenario assessments are documented in Appendices A and B, respectively.

Note that the sensitivity analysis conducted here focuses on investigating the relative geographical scalability of the uptake and follow-up actions from the decision support, and as such it can serve as inspiration for exploring scalability of specific project applications under Assessment Methods A and B (see Clarifying Box 4.14).

Clarifying Box 4.13. Use of sensitivity analysis to address large uncertainties in use of knowledge support

To address the large uncertainties associated with the utilization/implementation of the knowledge/ management support (specificity of Assessment Method C), a sensitivity analysis is performed. Here two scenarios (best & worst cases) are considered, but these are examples and more refined scenarios can be taken. It is notable that those scenarios can explore different angles. For example, in the present case, scenarios could be defined to address only actions on systems providing food to the cities or on actions aiming to bring more renewables within the energy systems (incl. transport systems), or on both, depending on whether or not the analyst has specific insight into possible utilization of the knowledge support.

Clarifying Box 4.14. Sensitivity analysis on scalability of SDG impacts and relevance for other Assessment Methods

In the present case, scenarios reflect explorations of scalability of the impacts on SDGs depending on the level of uptake. Since the geographical scope of the assessment was defined as the entire world in Phase 1, hence this sensitivity analysis is an integral part of the Assessment Method C (to handle the large uncertainties). However, note that such study on investigating scalability can also be used in Assessment Methods A and B to expand an assessment scope, which may have been limited in terms of geographical boundaries in Phase 1 and which could enable estimating the impact on SDGs in a global context.

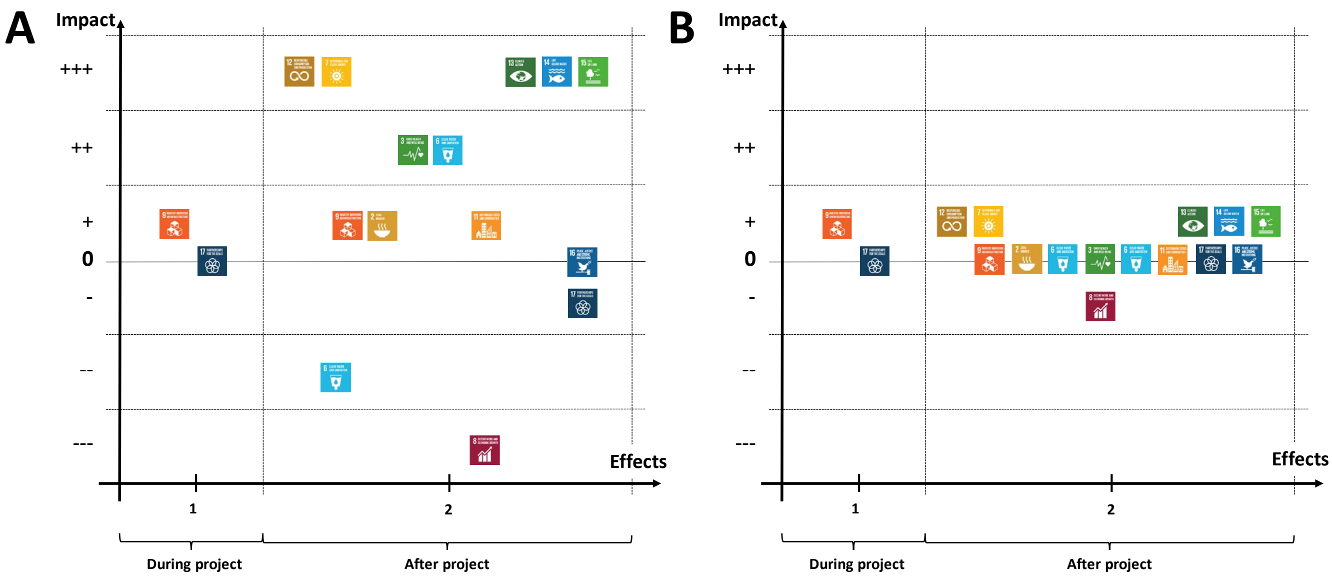

Figure 4.13 Visual representation of SDG impact assessment for the project of providing informed decision support for municipalities to reduce the environmental impact of cities in (**A**) a best case scenario with 95-100% uptake, and (**B**) a worst case scenario with 0-5% uptake in cities larger than 1 million worldwide. Background scoring for all SDGs is documented for both scenarios in Appendices A and B.

4.5. Phase 5: Interpretation

It can be observed that the majority of SDG impacts will occur after the project work and especially if the uptake in municipalities is high. In the best case scenario strong positive impacts for SDGs related to the environment and human health may be achieved (SDG 3, 6, 13, 14, 15) as well as for SDGs closely linked to these (SDG 12 and 7). These positive impacts are smaller if the uptake is lower, and fewer municipalities adopt the recommendations based on this project. Small impacts may still be seen for SDG 12, 7, 13, 14 and 15, but the magnitude of the other impacts can be expected to be negligible as the environmental impact of cities will only be reduced locally.

In both the best and worst case scenarios, negative impacts occur on SDG 8. This is related to the possible costs of implementing the recommendations. Some might require major investments in new infrastructure or technologies, which may hinder economic growth over the years. Negative impacts are also observed for SDG 16 and 17. This is related to the risk of leaving some countries behind with the recommendations. Changes to agriculture (e.g. more produced locally) may damage crucial export from developing countries (SDG 17), and similarly, some developing countries may not be able to live up to the recommendations and thus hinder their possibilities of participating in global governance (SDG 16).

A trade-off is apparent for SDG 6, which appears as both a negative and positive impact in the best case scenario. Possible recommendations have the potential to influence SDG 6 positively, e.g. by focusing on reducing emissions from both agriculture and mining activities. Furthermore, water as a resource may be treated more responsibly, by e.g. focusing on less water-intensive crops in the food supply chain. However, a shift from non-renewable energy to renewable energy may in some regions of the world include an increasing share of hydropower, which will impact SDG 6 negatively.

A recommendation based on this assessment is that the level of municipal uptake should be as high as possible to have an impact on the SDGs. It should be the focus throughout the study to ensure awareness on the project, not only within the scientific community, but with decision makers at local, regional and national scales. Furthermore, the negative impacts on SDG 8 should be kept in mind as well. Ensuring that the recommendations provided are economically feasible should be a priority, so as to not risk burden shifting. Finally, the potential negative impacts on SDG 16 and 17 caused by the risk of leaving developing countries behind, the recommendations should especially be feasible and beneficial for developing countries to ensure uptake in these regions as well.

4.6. References

United Nations, "World Urbanization Prospects. The 2018 Revision", *United Nations Department of Economic and Social Affairs*, 2019.

United Nations Development Program, "Sustainable Urbanization Strategy. UNDP's support to sustainable, inclusive and resilient cities in the developing world" 2016.

4.7. Appendices

4.7.1. List of content

<u>Appendix A (Electronic Excel file) – BEST CASE SCENARIO</u>

- Table A1. Documentation of linkage between identified effects and SDGs-targets (Step 1 of Phase 4)

  Contains justification of SDG impact and the cross-SDG links (Table 2.6 as template)

- Table A2. Documentation of evaluation of SDGs-targets impacts (Step 2 of Phase 4)

  Contains detailed SDG impact evaluation, incl. evaluation scores and justifications of likelihoods and magnitudes of the SDG impacts (Table 2.11 as template)

Both Tables A1 and A2 are documented within the Excel-based tool used for the case study, which constitutes Appendix A (provided as is).

<u>Appendix B (Electronic Excel file) – WORST CASE SCENARIO</u>

- Table B1. Documentation of linkage between identified effects and SDGs-targets (Step 1 of Phase 4)

  Contains justification of SDG impact and the cross-SDG links (Table 2.6 as template)
- Table B2. Documentation of evaluation of SDGs-targets impacts (Step 2 of Phase 4)

  Contains detailed SDG impact evaluation, incl. evaluation scores and justifications of likelihoods and magnitudes of the SDG impacts (Table 2.11 as template)

Both Tables B1 and B2 are documented within the Excel-based tool used for the case study, which constitutes Appendix B (provided as is).

5. PROJECT ON STUDY OF EXOPLANETARY ATMOSPHERES (Assessment Method D)

5.1. Phase 1: Considered application of the research project

- ***The research project –*** the research project will observe and characterise the atmospheres of exoplanets (planets that orbits stars other than the Sun), using telescopes on earth and in space and new instruments such as the Transiting Exoplanet Survey Satellite (TESS), James Webb space telescope (JWST) and giant earth-based telescopes. Previous research has focused on large hot-gas giant planets, but newer telescopes can allow the study of smaller planets, down to the size of Earth. At the current point in time, Mars and Venus are the planets in our solar system with the most similar size and mass to Earth to have been studied, but their atmospheres are very different from Earth's in terms of composition, surface pressure and their evolutions over time. This research therefore aims to provide additional data on how the atmospheres of planets with a similar size to Earth evolve over time.
- ***Selected potential application –***The project research can contribute to a better understanding of the chemistry and physics of planetary atmospheres, with related issues such as the effect of stellar irradiation and surface-atmospheric interactions and possibly assist with the identification of biosignatures, which may indicate the presence of life. It could then be useful to better understand climate change on Earth.
- ***Assessment Method*** – the project is fundamental research project with no direct decision or policy support (Project Type 3) and Assessment Method D is therefore applied, with a dominant focus on the research project itself (see Clarifying Box 4.15).

Clarifying Box 4.15. Use of decision tree and selection of the Assessment Method.

The project is a basic science project, with fundamental research conducted. The knowledge generation from the project has no direct application for decision or policy making. So the project falls under "Project Type 3" (see Figure 4.1). It has no direct societal application, justifying the application of Assessment Method D, in which the assessment focuses on the project activities themselves (see Figure 4.1).

5.2. Phase 2: Scope of the assessment

5.2.1. Delimitation of the baseline system

The baseline system is the continuation of existing research activities to study planetary atmospheres, which include: (1) research into the atmospheres on the other 7 planets within our Solar System (namely Mercury, Venus, Mars, Jupiter, Saturn, Uranus and Neptune) by direct measurement using probes from spacecraft and observation using telescopes; and (2) observations of the atmospheres on large, hot-gas giant exoplanets using telescopes. The telescopes required for this work are giant, earth-based telescopes and space telescopes. Giant, earth-based telescopes need to be located on the top of mountains and away from populated areas, to avoid interference, and include Gran Telescopio Canarias (GTC) in the Canary Islands and the Large Binocular Telescope (LBT) in Arizona. Existing space telescopes include the Hubble telescope, which was launched in 1990 and the Kepler space telescope, which was launched in 2009. The baseline system is illustrated in Figure 4.14.

5.2.2. Definition of the new system

The new system, which includes the project research activities, is identical to the baseline in terms of technologies involved. It includes the new, more sensitive equipment, which will enable enhanced observations of smaller exoplanets. Examples of this new equipment include the Transiting Exoplanet Survey Satellite (which was launched in 2018), the James Webb space telescope (which will partially replace the Hubble telescope, which is currently being commissioned), the Large Synoptic Survey Telescope (LSST) in Cerro Pachon, Chile (which will be commissioned in 2020) and new giant earth-based Giant Magellan Telescope planned for Las Campanas in Chile (which will be commissioned in 2021). These telescopes also exist in the baseline but are not used for the purpose of the research project. The forthcoming telescopes are not built as a need from or result of the current project. The project will however use data obtained by these telescopes. The new system is outlined in Figure 4.14.

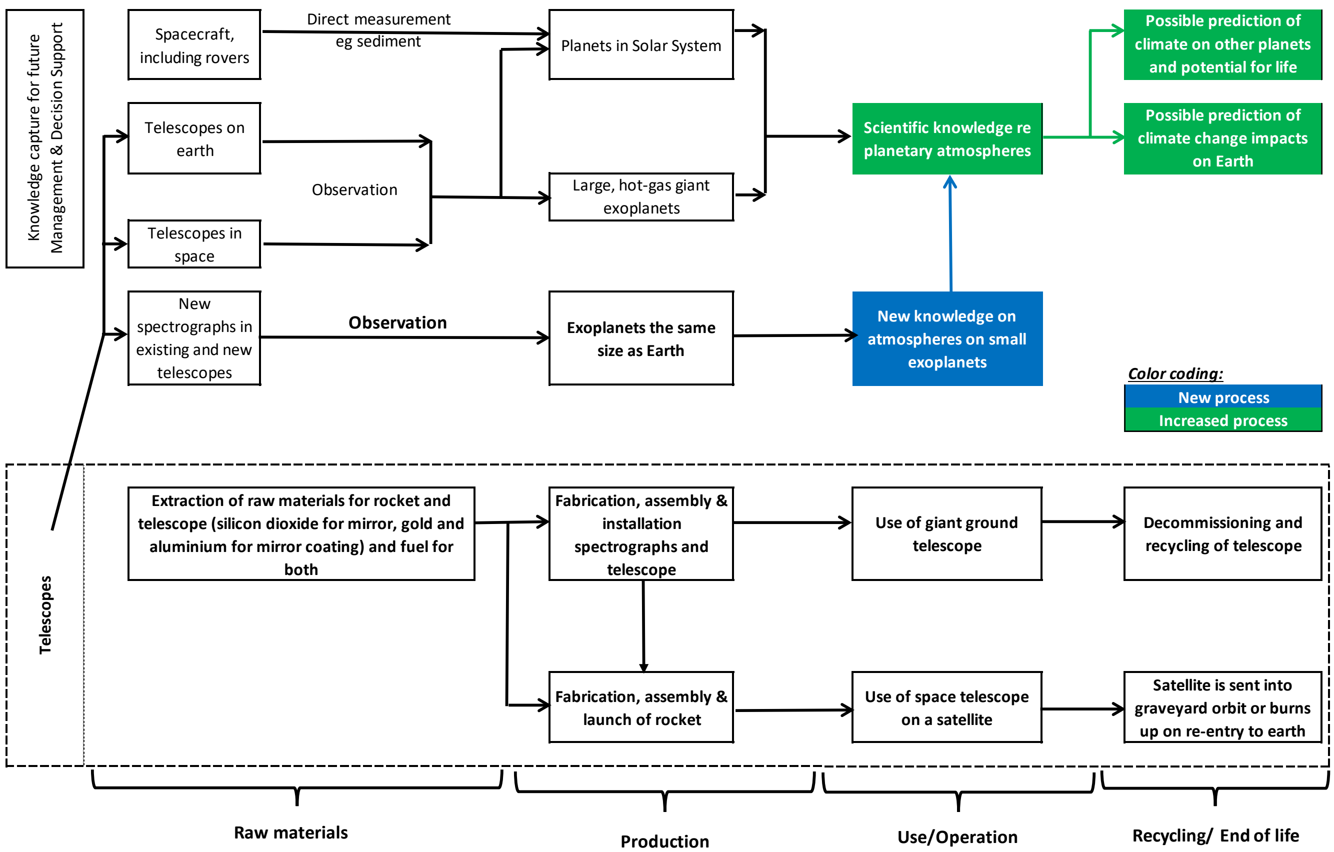

Figure 4.14. Scope of the baseline and new systems

5.3. Phase 3: Inventory of effects from the application

The main effects of the project application are presented in Table 4.5. The project activities mainly consist of research involving data processing on computers and as such, only negligible changes can be expected from them in the new system relative to the baseline system. Therefore, the main effect of the project relates to the knowledge increase about exoplanet atmospheres and its potential implications, e.g. Earth's climate system. Detailed justifications of the effect are included in Appendix B; see also Clarifying Box 4.16.

Clarifying Box 4.16. Phase 3 in basic science projects

In the case of fundamental projects, Phase 3 will often be limited to inventorising only one effect that may not be negligible, that is knowledge increase or creation resulting from the project research. Because there is only one effect, it may not be necessary to report it in a table, as it is done in Table 4.5. Instead, a short justification/description of the effect in text can be sufficient.

Table 4.5. Direct and indirect effects of the new system where green text indicates increased processes.

Knowledge creation & Support	Raw materials	Production	Use / Operation	Recycling / End of life
Physical changes				
NA	NA	NA	NA	NA
Non-physical changes				
Effect 1: Increased knowledge about exoplanet atmospheres and potentially about Earth's climate system				

5.4. Phase 4: Evaluating the contributions of the application to SDGs

Figure 4.15 summaries the results of the assessment of the potential SDG impacts from the project and its application. Two main SDGs are expected to be impacted: SDG 17 due to the establishment of new partnerships during and after the project, and SDG 13, assuming that the fundamental research outcome can provide relevant insights to Earth's climate systems, and thus contribute to a better understanding of climate change.

Comprehensive details of the impact of each effect on individual SDGs and linkages between SDGs are included in Appendix A.1; scoring of the likelihood and magnitude of the potential impact of each effect on the identified SDGs is included in Appendix A.2.

It should be noted that the increased fundamental knowledge from the project may have impacts on sustainability that go beyond the SDGs. These are addressed in Phase 5.

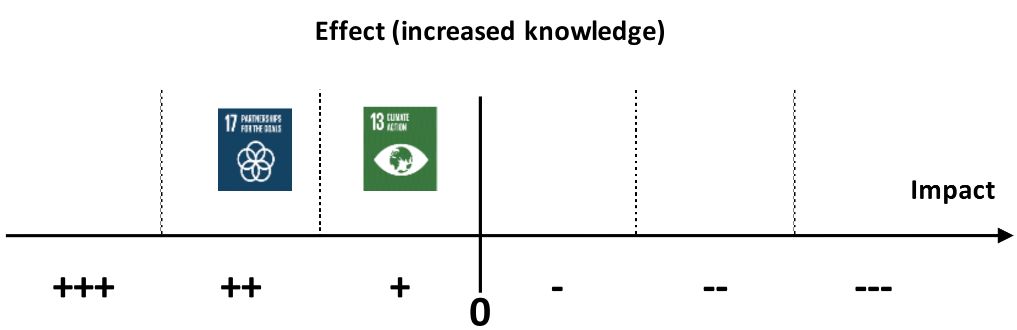

Figure 4.15. Visual representation of SDG impacts for the project. Negligible effects (= on the vertical scale) are not included here but are included in Table A.2.

5.5. Phase 5: Interpretation

Despite an outlooking focus from Earth, the overall impact of the project is found to be positive, with impacts ranging from moderately positive (++) to positive (+) for two SDGs potentially impacted. The two positive SDG impacts were: (1) the enhanced knowledge providing insights for tackling climate change, which might result from the new knowledge (SDG 13); and (2) the improved international collaboration that may results from the project (SDG 17). In reality, the major contribution of the project will relate to SDG 17 and the potential for international collaboration, given that there are a limited number of telescopes, the relatively small community researching this specific area and the field of research (i.e. small exoplanets) is relatively new. It is important to note that the positive benefits to SDG 13 may be significant if they occur, but it is highly uncertain as to whether this will occur during the project, or at all.

This project highlights the current orientation of the SDGs towards the most pressing issues currently facing humanity in the short to medium term, and have a strong focus on topics of socio-technical nature, including socioeconomic systems (Filho and McCrea 2019). As a result, issues pertaining to the advancement of basic science knowledge without an immediate application to these pressing issues are only encompassed to a limited extent. This is the case for example of the cultural sustainability dimension (sustainability of communities, cultural/spiritual beliefs; although some aspects are covered under targets 4.7 (cultural diversity) and 11.4 (Strengthen efforts to protect and safeguard the world's cultural and natural heritage)) or scientific domains within humanities, which are difficult to link to the SDG framework, albeit having relevance in the broader sustainability context. Several branches within astronomy, e.g. cosmology or astrophysics, fall in the same situation, where their linkage to the SDGs is not obvious. The present project is such an example within astronomy (see also Clarifying Box 4.17).

Short and Long-term recommendations – the most significant benefit of this project is the significant opportunities for international partnerships (SDG 17) and the less certain outcome of improved knowledge about climate change on earth (SDG 13).

Clarifying Box 4.17. Linkage to SDGs in Assessment Method D cases

Many projects, which lead to application of Assessment Method D, are likely to be challenging to connect to the SDG framework because of their strong focus on fundamental research. In such cases, as recommended in the methodology Section 4 in Chapter 2, the analyst should adopt a broader perspective on sustainability and include a discussion – as referenced as possible, using existing literature – of how the project could contribute to sustainable development at large (hence not limited to the scope of the 17 SDGs).

5.6. References

Filho, W.L. & McCrea, A.C. (2019) *Sustainability and the Humanities.* ISBN 978-3-319-95335-9. Springer Nature, Cham, CH.

Forget, F. & Leconte, J. (2014) Possible climates on terrestrial exoplanets, *Phil. Trans. R. Soc. A* 372:20130084.

Grenfell J.L. (2019) Exoplanetary Biosignatures for Astrobiology. In: Cavalazzi B., Westall F. (eds) Biosignatures for Astrobiology. Advances in Astrobiology and Biogeophysics. Springer, Cham

Pont, F.J. (2014) Alien skies: Planetary atmospheres from earth to exoplanets, 1st edn, Springer New York.

5.7. Appendices

5.7.1. List of content

<u>Appendix A (Electronic Excel file)</u>

- Table A1. Documentation of linkage between identified effects and SDGs-targets (Step 1 of Phase 4)

  Contains justification of SDG impact and the cross-SDG links (Table 2.6 as template)

- Table A2. Documentation of evaluation of SDGs-targets impacts (Step 2 of Phase 4)

  Contains detailed SDG impact evaluation, incl. evaluation scores and justifications of likelihoods and magnitudes of the SDG impacts (Table 2.11 as template)

Both Tables A1 and A2 are documented within the Excel-based tool used for the case study, which constitutes Appendix A (provided as is).

<u>Appendix B</u>

- Background for identification of effects (Phase 3)

5.7.2. Appendix B – Background for identification of effects

The identification of effects was based on Figure 4.14, which highlights the processes associated with the project but only one process, which will actually change as a result of this project, namely the increased amount of knowledge pertaining to the atmospheres on small exoplanets.

Although the study of atmospheres on exoplanets may provide an indication of biosignatures which may indicate the presence of life, this project aims to look at the existence and evolution of atmospheres, which may have relevance for climate change science. Therefore, only the effect of improved knowledge for climate change was included. As there are already new telescopes which can study exoplanets and exoplanet atmospheres on large planets have been studied, as this project will look at exoplanet atmospheres on exoplanets of a similar size to Earth, effect 1 was classified as an increased process, rather than a new process.

Glossary

Term	Definition
Application	Concrete application of the expected outcome of the project in socioeconomic systems, i.e. result of transforming the applied research to full-scale deployment/implementation.
Baseline	A situation, where the application would not have occurred (i.e. the project did not exist or did not yield any implementable results). The definition of the baseline situation starts by considering the entire world and then refine the scope boundaries to only include existing products, technologies or services that the application (from the Goal definition phase) can potentially replace and/or impact.
New system	The baseline system with all the effects (= changes or consequences) that occur when the application of the research outcomes is introduced
Effects	Consequences and changes that the application brings to the baseline (thereby transforming it into the new system); they can be of very diverse nature: physical, economic, social, ethical, etc.
Direct effects	Direct changes – typically intended – from implementing the application in society. They reflect the purpose of the project and its application, and tend to be limited to the main products, technologies or sectors targeted by the application
Indirect effects	Consequences – often unintended – that the application implementation has on other products, technologies or systems than the systems targeted by the application. Indirect effects may include rebound effects, e.g. efficiency increase that reduces specific product or service costs, itself causing a rising demand, which lead to overall larger consumption, thus canceling out the original savings (cf. Jevons paradox).
Process	An element of the life cycle, for which input and outputs can be quantified in the form of energy, materials or resources (for inputs) and products, waste or emissions (for outputs). It typically refers to a physical activity and can represent a single specific activity, e.g. rolling of steel, or a larger entity, e.g. an entire facility that contains many different processes
Life cycle	Systemic view of any predefined entity (product, service, organization, country, etc.) that includes all interlinked stages of its life with all the processes that are drawn upon. The life cycle is typically divided into four stages, each potentially comprising many individual processes: (i) extraction of raw materials necessary to the materials manufacture, (ii) production and/or setting up of the entity, (iii) use or operation of the entity, and (iv) end-of-life (disposal or recycling).
SDG impact	The consequence or contribution that an effect has for an SDG or some of its underlying targets. Both negative and positive contributions are considered alike with the term "SDG impact". Both negative and positive contributions are considered alike with the term "SDG impact".
Environmental impact	Impacts that an entity has (or may have) on ecosystems, human health and/or natural resources. They can be related to known environmental problems like climate change, particulate matter formation, chemical pollution, eutrophication, water stress, land use, etc. While SDG no. 13 (climate change) targets one type of environmental impact or SDG no. 15 (Life on land) combines multiple environmental impacts like acidification, photochemical ozone formation, land use and toxic impacts on land ecosystems.