HANDBOOK ON A NOVEL METHODOLOGY FOR THE SUSTAINABILITY IMPACT ASSESSMENT OF NEW TECHNOLOGIES

SEVENTH FRAMEWORK PROGRAMME

DISCLAIMER: *"The content of this PROSUITE HANDBOOK does not reflect the official opinion of the European Union. Responsibility for the information and views expressed therein lies entirely with the principal investigators/authors."*

Report prepared within the EC 7th Framework
Project n°: 227078
Project acronym: PROSUITE
Project title: Development and application of a standardized methodology for the PROspective SUstaInability assessment of TEchnologies
Start date project: 1 November 2009
Duration: 4 years
Deliverable N°: 8.6
Date submitted: Month 48

HANDBOOK ON A NOVEL METHODOLOGY FOR THE SUSTAINABILITY IMPACT ASSESSMENT OF NEW TECHNOLOGIES

Principal investigators:
Kornelis Blok
Mark Huijbregts
Martin Patel
Edgar Hertwich
Michael Hauschild
Piet Sellke
Paula Antunes
Stefanie Hellweg
Andreas Ciroth
Claire Mays
Mirjam Harmelink
Andrea Ramirez

Authors:
Anne Gaasbeek
Ellen Meijer

Relying on the Prosuite project library of deliverables, publications, and case studies by the whole team of Prosuite researchers:

Written by

Universiteit Utrecht

Edited by

Designed by
www.studiobu.fr

2013, www.prosuite.org

CONTENTS

PREFACE

Kornelis Blok
Utrecht University
Prosuite Coordinator

We live in a time of rapid technological development and significant interest in sustainability. It is therefore imperative to have tools available for the sustainability assessment of existing and new technologies. This is recognized by the European Commission and they awarded a grant to a consortium of universities, research institutes and companies to develop such tools in the project called **Prospective Sustainability Assessment of Technologies (Prosuite)**.

The project aimed to deliver a broad life cycle assessment (LCA) framework, taking into account the three pillars of sustainability: economic, environmental and social. We targeted an integrated methodology, one that would not just paste existing methodologies together, but instead support the actual holistic decisions that product developers, policy makers and businesses must perform. We also insisted on demonstrating the approach through case study assessments on four emergent technologies of varying scale. Our team included several individuals and organizations who have made important contributions already to LCA, and also dedicated young researchers who have brought new energies. Relying on the vast body of knowledge on assessments in all these areas, we have been able to make an important step forward.

In the four years of the project (2009-2013) we have innovated on all components of sustainability assessment, but especially in building an integrated approach, in terms of both concepts and practical tools. Prosuite proposes to go beyond the traditional three pillars, focusing instead on five major impact categories under which all primary impacts can be grouped. The resulting 5-pillar framework for assessment is supported by a freeware Decision Support System.

This handbook summarizes our achievements from the past 4 years, "unpacking" the Prosuite methodology and providing guidelines for practitioners. Our website www.prosuite.org contains a lot more: tutorials and newsletters, memos, presentations or links to scientific journal publications in the Prosuite Library. We recognize that in the field of technology assessment, this is just a next step, and we trust that much further development of methodologies and tools will be carried out in the future.

I thank the consortium partners for their enthusiasm, inspiration, collaborative values and patience in this complex project. By the end of the project our team had counted as many as 90 participants, from masters' students to senior industrial executives. All of us thank our Advisory Board, our original EC DG Research & Innovation scientific officer, Michele Galatola, for believing in this project and our subsequent officer, Vincenzo Gente, for accompanying us along the way.

October 2013

Throughout the digital version of our handbook you will find live links to pertinent pages of our website www.prosuite.org. The website structure is illustrated inside the back cover for users of the paper edition – produced in 300 copies for our final conference attended by numerous practitioners from across Europe and as far away as Chile.

1 PROSUITE: MEETING THE NEED

Technologies have always been the engine of progress and change. New technologies are developing continuously. Many have drastically changed our lives in the last decades and some have been controversial in terms of the net benefit they bring to society. The challenge is to know upfront, before the technologies are introduced, how sustainable they are.

The term *sustainability* was introduced in 1987 in the context of efforts to reconcile the conflict between environmental protection and economic development. Nowadays it is widely accepted that sustainability should be defined along the three pillars social-environmental-economic, often referred to as people-planet-profit or the 'triple bottom line'. The impact of technologies is often examined in terms of these three dimensions. Sustainability assessment of new technologies is important for many players in society, e.g.:

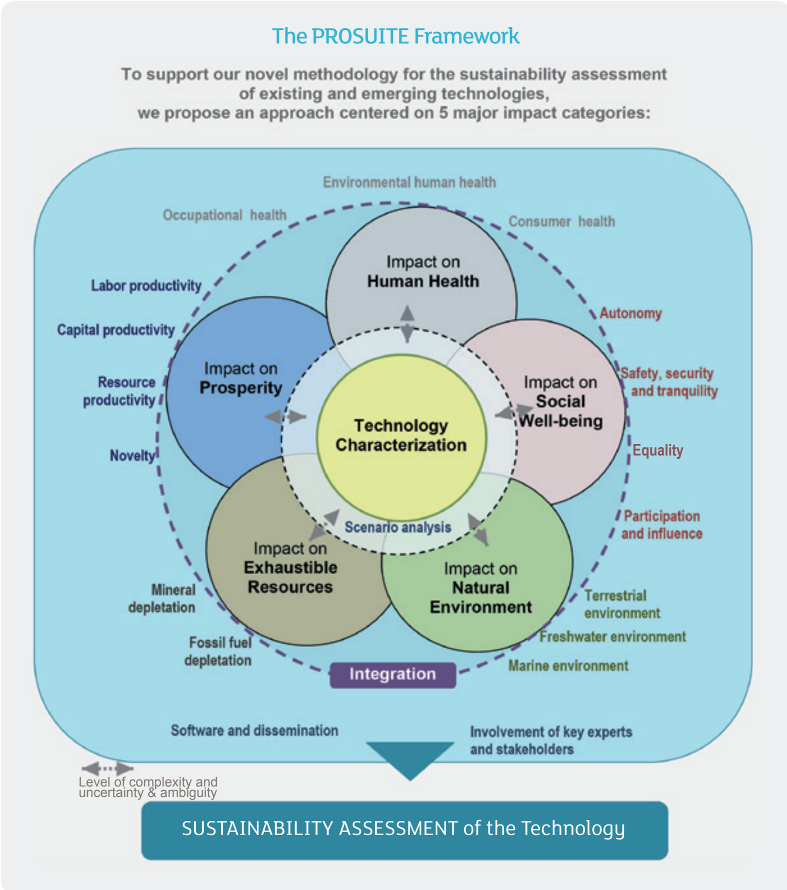
- for the public debate to assess alternative technology pathways
- for companies to decide on strategic investment decisions
- for policy makers to formulate and implement R&D and innovation policies.

Many initiatives aimed at assessing the sustainability of products and/or services have been developed over the years or are under development. These approaches have their merits but are not applicable in a generic way to all aspects of sustainability for a technology. What was missing was an objective assessment methodology to evaluate whether a technology helps to address important sustainability challenges or merely creates new ones. The Prosuite (Prospective SUstaInability assessment of TEchnologies) project was set up to fill this gap. In this project researchers from all over Europe developed and applied a coherent methodology for sustainability assessment of technologies. All the partners involved in this project are listed in annex 1. The final fruit of the project is an online freeware Decision Support System (DSS), based on openLCA with a Prosuite plug-in (see annex 2).

Clearly defined pillars

When sustainability is defined in terms solely of social, environmental and economic dimensions there are overlaps, even to the

Figure 1 The five impact categories for sustainability assessment and their integration model



extent that some impacts could largely include some of the others. For instance, human health and income could be viewed as contributors to the social pillar, since both factors have a large influence on the quality of life of people. They could alternatively be assigned to the economic pillar if both are cast in monetary terms. To be able to do a proper assessment, indicators should be chosen in such a way that there is no overlap and that together they represent all potential sustainability impacts.

Prosuite developed a specific framework that limits this overlap and ensures that each pillar has a unique set of indicators. In fact, to achieve this goal, the framework proposes **five major impact categories** under which all primary impacts can be distinctly grouped. These categories or pillars are (see figure 1):

1. Impact on Human Health
2. Impact on Social Well-being
3. Impact on Prosperity
4. Impact on Natural Environment
5. Impact on Exhaustible Resources.

Download from www.prosuite.org the principal publication detailing and justifying this framework: *A Novel Methodology for the Sustainability Impact of New Technologies*.

Rigorous cause-effect chain

A limiting factor of most current sustainability assessment methodologies is that there is no explicit definition of the cause-effect chain and no scientific and transparent calculation methodology. An exception to this is Life Cycle Assessment (LCA), which allows for the identification of trade-offs between different impacts as well as the shifting of burdens from one life cycle stage to another. A rigorous treatment of the cause-effect chain is followed in the impact assessment, which means that all impacts are calculated in the same way and go through the same steps. These useful elements were applied in the development of the new Prosuite approach. The result is a methodology that includes the strong points of LCA, but that also has many additional strong points. These are revealed throughout this handbook.

The new method provides a scientifically robust and reproducible framework capable of an overarching and comprehensive assessment of different impacts. Figure 2 gives a streamlined overview of the cause-effect chains.

This handbook takes you through the Prosuite sustainability assessment approach. It explains the methodology (illustrated with examples from case studies) and shows how the framework can be applied. The handbook is expected to be useful to persons familiar with sustainability assessment and who have the skills to handle a computerized application.

The methodology for sustainability assessment of technologies is performed through several phases; they are illustrated in figure 3. Each of these phases is illustrated in detail in the chapters of this handbook, starting with the first phase: the goal and scope definition.

Background

Life Cycle Assessment (LCA) is a well established methodology for assessing the environmental performance of products and services. The methodology has been standardized by the International Standards Organization (ISO 2004, 2006a, b). Life cycle thinking is widely used and has taken a more prominent role in environmental policy making in recent years. Renowned institutions such as The World Resource Institute (WRI) and the European Commission, as well as many practitioners, have adopted life cycle thinking.

Figure 2 Schematic representation of the cause-effect chain in the Prosuite 5-pillar sustainability assessment framework

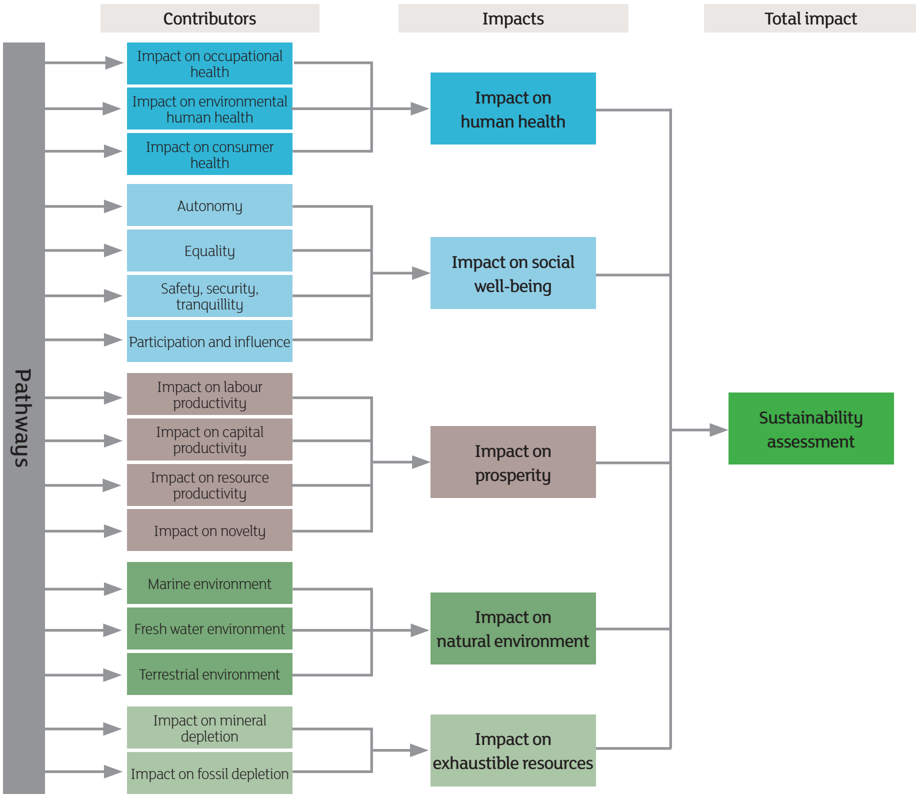
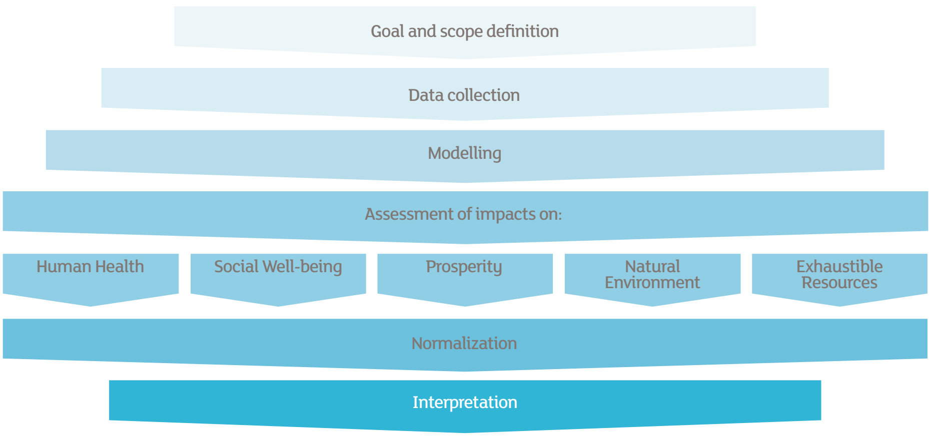


Figure 3 Steps in Prosuite sustainability assessment



2 GETTING STARTED

Goal and scope definition

Defining the goal and scope is the first phase of the sustainability assessment. During this phase several important choices are made that influence the rest of the study and, ultimately, the results. Setting up a goal and scope definition requires three steps:

- Defining the goal
- Defining the technology and its materialization in products
- Defining the scope.

Defining the goal

When starting a sustainability assessment the first question that needs to be asked is what is the reason for carrying out the study. Clearly defining and documenting the goal from the start makes the subsequent steps easier. In sustainability assessment a typical goal may be one of the following:

- **Comparison of sustainability impacts of alternative technologies**

Assessment may seek to get a basic understanding about the pros and cons of the various technological developments. Sometimes there are clear alternative pathways for technological development. If these are conflicting or just cannot all be supported by society, choices need to be made. A classic example is the choice made between AC and DC electricity in the second half of the 19th century.

- **Support for the development of sustainability policies**

Assessment can be used to get insight into whether the materializations of a new technology will be better than their conventional alternatives. Governments need to allocate R&D budgets or decide upon whether certain products should get an eco-label or not. Especially for the first case, where R&D will often lead to the development of new technology, the question to be asked is: which technology?

- **Strategic decision making in companies**

Companies may assess as part of their development of strategic planning. Companies need to decide in which direction to develop and where to place their investments, e.g. in R&D or in innovative production facilities.

Defining the technology and its materialization in products

The second step of defining the goal and scope is to determine the reference technology and the prospective technology. These two technologies need to be selected in such a way as to provide a fair and meaningful comparison. The definitions in table 1 and the examples from the case studies in table 2 provide indications. Notice that in some cases a reference technology is difficult to designate, since the prospective technology (e.g. the smartphone, discussed below) does not have a single predecessor.

Technologies are a means rather than an end, so the real impact lies in the products/services that the technology produces. It is not possible to do a quantitative sustainability assessment without thinking of how the technology will materialize in (new) products and services. Therefore the sustainability of the reference and prospective technologies is compared by assessing the sustainability figures associated with the production and use of a reference and of prospective products or services. Table 3 and the case studies examples in table 4 show how a relevant reference and prospective product may be determined. (Note that the so-called "prospective product" may already materially exist at the time of the assessment.)

If the products do not fulfil the same function the comparison would not be fair or meaningful. The selection of a suitable functional unit makes sure the products are compared fairly and thus makes the results more credible. A good functional unit describes

Table 1 Technology definitions

Reference technology	An existing technology providing comparable products or services
Prospective technology	The technology of focus providing a new type of product or service

Table 2 Examples of reference and prospective technologies from case studies

Study subject	Reference technology	Prospective technology
Nanotechnology	Conventional textile production	Nanotechnology in textiles production
Multifunctional mobile devices	No smartphone technology	Smartphone technology
Biorefinery	Coal-fired power plant	Anaerobic digestion
CCS	Coal-fired power plant	Coal-fired power plant with carbon capture and storage

Table 3 Product definitions

Reference product	The product currently being produced by the reference technology that could be substituted by the output of prospective technology
Prospective product	The product of the prospective technology substituting the product of the reference technology; or the product of the prospective technology providing an entirely new functionality

Table 4 Example of reference and prospective products from case studies including the functional unit

Study object	Reference product	Prospective product	Functional unit
Nanotechnology	Polyester textiles treated with triclosan as biocidal agent	Nanosilver textiles which are mainly used in sport activities	Being dressed with a (nano-silver) T-shirt for outdoor activities during one year in Europe, washing it once a week
Multifunctional mobile devices	There is no single product with comparable functionality	Smartphone	One year of smartphone use
Biorefinery	Electricity produced from coal-fired power plants	Electricity produced from biomass by anaerobic digestion	1 kWh of electricity produced
CCS	Electricity produced from a typical coal-fired power plant	Electricity produced from a typical coal-fired power plant with CCS	1 kWh of electricity produced

not only what is achieved by the product, but also how well this is achieved. But sometimes setting the proper functional unit is difficult. For example there is no single reference product that captures all functionalities of the smartphone e.g. telephone, internet, music, etc. Therefore, it is important to specify on which basis the assessment will be done; in the case of smartphones, the comparison can be a "world with smartphones" versus a "world without" such equipment.

The examples from the case studies in table 4 illustrate the setting of an appropriate functional unit.

Defining the scope : System boundary and timeframe

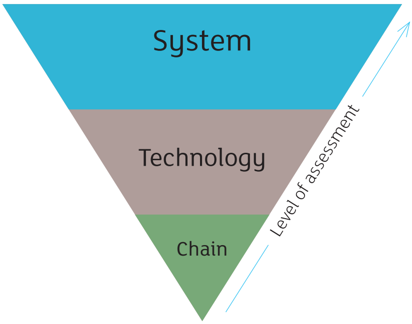
Defining the scope includes setting the system boundary, which describes what will be included and excluded from the analysis. While the functional unit specifies what is analyzed, the system boundary gives more detail on how it is analyzed and what is included in the study.

Another aspect of defining the scope is setting the timeframe that is investigated. The timeframe can differ per impact category. For example the category Natural Environment can have a long-term temporal scope, since the impact of emissions may occur through a long causal chain to emerge at a distant future date, whereas the category Social Well-being might have a much shorter temporal scope, with effects being much more direct.

Level of assessment

In Prosuite three different levels of assessment are used (see Figure 4). The first one corresponds to the assessment of a process chain per functional unit. If the total number of functional unit is known or estimated (e.g., for a given scenario), the level of impact can be calculate by multiplying the impact per functional unit per the total amount of f.u. This is referred to as technology level. The third level goes beyond the process itself and examines the effect of deploying a technology at a System level which

Figure 4 Levels of assessment



also takes into account impacts and changes in other sectors, e.g., the European economy.

Data collection

Once the goal and scope have been defined, the Life Cycle Inventory (LCI) needs to be created. An LCI is a compilation of all the inputs and outputs inside the system boundaries across the life cycle. This includes, for example, material and energy requirements, emissions, waste, monetary flows and social issues. For many general processes average data are already available in open access or proprietary databases, which can be used in the DSS (see annex 2). Processes and amounts that are specific for the life cycle(s) under study require actual data collection. Examples of data which probably need to be collected are production costs, transport distances and the amount of energy that is required to manufacture the product. For each major impact category specific data have to be collected. This is discussed in the chapters about these categories.

Prospective assessment

The prospective assessment of technologies is one of the biggest challenges in Prosuite, which cannot rely on measurement. However, certain characteristics of technologies can be assessed prospectively. Within Prosuite, the methodology is generally based on scenario building. In the nanotechnology case study for instance, scenarios were developed where changes in technology (cost, market penetration), human behavior and future electricity mixes were taken into account to assess the prospective sustainability of the technology. The future electricity mixes (for 2030 and 2050) have been implemented in the DSS tool, which are based on the Blue Map scenario developed by the International Energy Agency.

Modelling

Once the required data are collected they can be entered in the Prosuite Decision Support System to create a model of the technology or product. The DSS is the tool that can be used to carry out a sustainability assessment study and calculate the results. It is integrated in the openLCA software. Guidance on the use and installation of the DSS can be found in annex 2.

Typically you would start modelling with the most basic processes within your system boundary, for example 'Harvesting of cotton fibre'. This process can then serve as an input into higher level processes, such as the 'Spinning of cotton yarn', which could in turn be an input into the process 'Weaving of cotton fabric'.

When the model of the life cycle(s) is complete the impact on each of the pillars can be calculated by the DSS. The application uses the Prosuite method to translate the life cycle inventory into the impact on each of the five pillars. The calculation steps and details of the assessment are different for each pillar and are therefore discussed separately in their respective chapters in this handbook.

For more details practitioners and researchers can download the principal Prosuite publication detailing and justifying the 5-impact category framework: *A Novel Methodology for the Sustainability Impact of New Technologies*, and get guidance from *Prosuite DSS Assessment Framework – Implementation of Modules*.

3 HUMAN HEALTH

The Human Health category describes the impact of a technology on the health of human beings around the world. There are many factors that influence human health, such as food and water, the state of the physical environment in which the person lives, working conditions and of course diseases. Since every human being wishes to live a healthy life negative health impacts should be avoided. Technologies can have a negative health impact, which can be classified as work related (occupational health impacts), environment related (environmental human health impacts) and product consumption related (consumer health impacts).

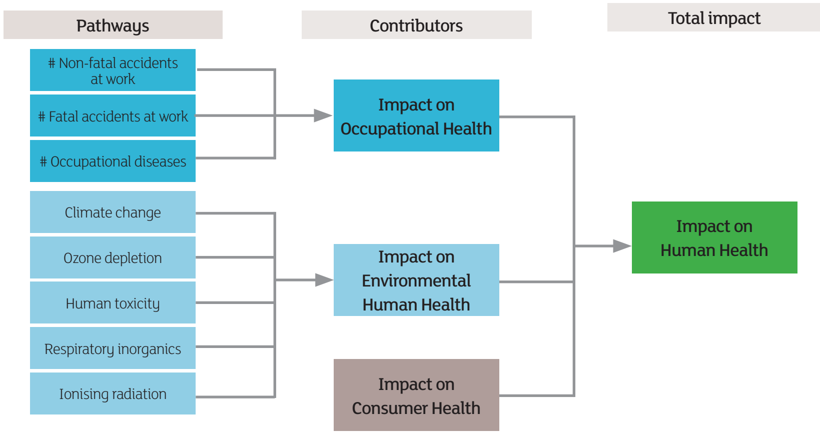
The impact on Human Health is expressed in 'Disability Adjusted Life Years' (DALY), which indicates the number of healthy life years that are lost due to sickness or disability and premature death. This concept combines information on the quality of life and life expectancy in one indicator, which is calculated as the sum of the 'Years Lived with Disability' (YLD) and the 'Years of Life Lost' (YLL). The Years Lived with Disability includes the duration of the disease or disability and a weighting factor that is determined by the severity of the disease or disability, ranging between 0 (complete health) to 1 (death). The DALY concept is well-established and for many types of diseases, disability weights have been established throughout the years[1].

Indicators

Negative impact on human health can occur through different pathways, which are represented in the methodology through three indicators: Occupational Health, Environmental Human Health and Consumer Health (figure 5). Although it is listed as an indicator, a separate methodology has not been developed for Consumer Health. If the assessor suspects that there is a probability of health effects due to exposure via consumer goods, further research is required.

[1] Murray, C.J.L and Lopez, A.D., eds. (1996) *The global burden of disease: a comprehensive assessment of mortality and disability from diseases, injuries and risk factors in 1990 and projected to 2020.* Boston: Harvard University Press.

Figure 5 Cause-effect chain: Human Health



Calculation

Several calculation steps are needed to transform the collected data or life cycle inventory, into impact on Human Health, which is handled by so-called impact assessment methods. As illustrated in figure 5, the three contributors or indicators contributing to the final impact on Human Health occur through very different pathways, creating the need for different approaches to be implemented in their impact assessment methods. Therefore each indicator is discussed separately below. Occupational Health is described in more detail than the others, because the impact assessment methodology for this is completely new.

Occupational Health

The numbers of accidents and diseases that typically occur in the workplace can vary largely depending on sector or region. Therefore, when calculating the impact on Occupational Health, it is necessary to know the impact per employee in different sectors and regions. The data required for this calculation are based on data from the World Health Organization on occupational health problems per sector and region (reference year: 2000) and data from the THEMIS economic input-output model on employees per sector, which are also used in the Prosperity pillar. These data are combined in a database listing the occupational health impact in DALY per employee, distinguishing 129 economic sectors, which can be grouped into 9 main economic sectors, and 6 regions

Table 5 Prosuite Occupational Health database regions and sectors

Regions	Sectors
Europe OECD	Agriculture
Europe other	Mining
America OECD	Manufacturing
America other	Electrical
Asia Pacific	Construction
Africa Middle East	Trade
	Transport
	Finance
	Services

(see table 5). In this database the following occupational diseases and accidents are taken into account:

- Lung cancer
- Leukaemia
- Chronic Obstructive Pulmonary Disease (COPD)
- Asthma
- Noise induced Hearing Loss (NHL)
- Low Back Pain (LBP)
- Injuries (fatal and non-fatal).

The sector- and region-specific DALY figure per employee is combined with data from the THEMIS economic input-output model on employees per sector. The Norwegian University of Science and Technology (NTNU) input-output database is subsequently used to calculate the number of employees that are required to work in the sector per dollar that is spent in that sector. Combined with the economic information about the product or technology under study this allows the calculation of the number of employees in each sector to that is required to fulfil the functional unit. The result is the occupational health DALY related to the technology or product.

The impact is calculated by combining the information on the impact on occupational health per employee with the number of employees that are required per functional unit. This is done per sector and region, using the database mentioned above. The result is an overview of the total expected health issues related to the technology or product, expressed as the indicator Occupational Human Health.

Environmental Human Health

The impact assessment method for Environmental Human Health determines which emissions contribute to the impact pathways. For example, emitting CO_2 into the atmosphere contributes to the climate change pathway, which in turn contributes to more extreme weather conditions and can thus impact the major category Human Health. Impact assessment methods specify the severity of the contribution of an emission to a pathway and allow the pathways of all emissions to be combined into the impact on Environmental Human Health.

The pillar Human Health is closely related to the pillar Natural Environment, since many emissions that have an impact on ecosystems affect the health of humans as well. As a result the impact on Environmental Human Health is affected via many of the same pathways that affect the impact on the Natural Environment. Since impact on Environmental Human Health has been explored thoroughly in the past many impact assessment methods are already available. During the development of the new method these existing methods were analyzed, resulting in a list of recommended methods. These recommendations are largely based on the ILCD Handbook.

Consumer Health

Consumer Health needs to be included if situations can occur during the product use phase, where e.g. accidents or emissions occur that can be harmful for humans. An example is paint resins for domestic use. During the use phase the consumer will apply the paint to a surface and emissions are released when it dries. These emissions are inhaled by the consumer and could potentially be harmful. In this case study the impact of the emissions during the use phase, measured in DALY, can be used in the results as impact on Consumer Health.

Practical implementation

A practical example of the impact on Human Health can be found in the Prosuite case study about smartphones. This study looks at two different future scenarios (figure 6): maximum smartphone sales (max), where each consumer will keep on buying replacement smartphones, and slowly declining smartphone sales (mid). The study includes the impact on Occupational and Environmental Human Health.

The calculated impact on Occupational Health for the reference year 2010 and the two prospective scenarios can be seen in figure 7. The calculation shows an increase in the impact resulting from smartphone use

Figure 6 Smart scenarios for smartphones Worldwide

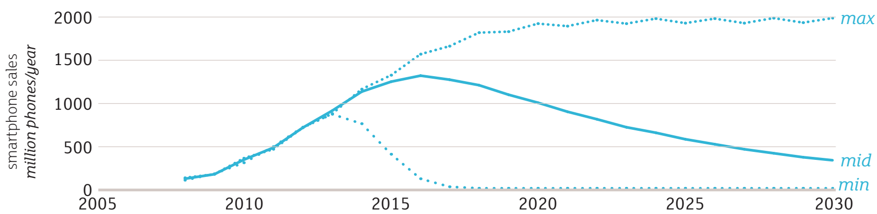


Figure 7 Total impact on Occupational Human Health from the smartphone case study

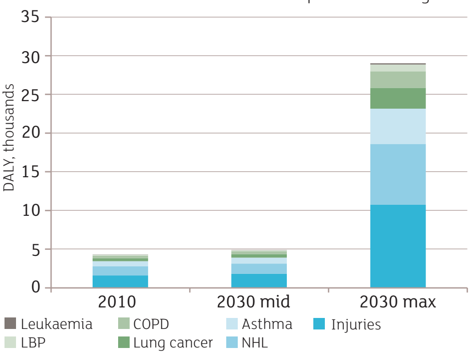
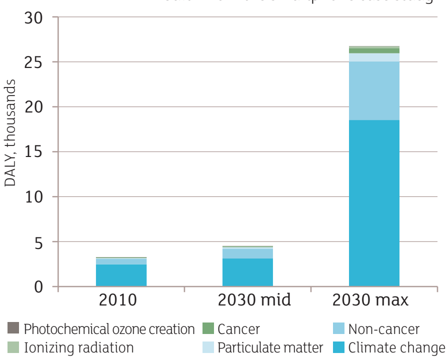


Figure 8 Total impact on Environmental Human Health from the smartphone case study



for the max scenario compared to the 2010 level. The mid scenario ends up only slightly higher than the 2010 level, since sales numbers in 2030 are assumed to be similar to those of 2010.
The impact on Environmental Human Health shows a similar increase for the max scenario. The impact was found to result mostly from climate change impacts and non-cancer human toxicity, as can be seen in figure 8.

Discussion

The lack of a specified method for Consumer Health is a weakness of the proposed methodology to calculate the impact on Human Health. Where it is relevant the practitioner will have to select a method of including Consumer Health, and add the output manually to the summed results. However, it is only relevant in a limited number of cases so this weakness will affect only a small number of studies.
A downside of the calculation method for Occupational Health is that the regions and sectors are very generic. The calculated impact is therefore also very generic and could be quite different in reality. However, this is the first calculation method that has been developed for Occupational Health so it is already a large improvement on the traditional approach, where occupational health impacts were either left out, or treated in a qualitative fashion. Additionally the results are very useful as an indication of whether occupational health is something to be concerned about for the technology or product under study. The smartphone study, for example, shows that environmental and occupational health impacts can be of similar magnitude.
Ideally data about the number of accidents and diseases from the actual production sites should be used. However, obtaining these data would be very time intensive and a lot of cooperation from the sites is needed. A short term improvement, left to future developers, would be to increase the number of regions and sectors in the generalized database. This would allow for more detail in the study and would make the results represent reality more correctly.

4 SOCIAL WELL-BEING

Treatment of social well-being is relatively new in the field of quantitative impact assessment at product and technology level. Prosuite has made one of the first attempts to develop a comprehensive method to measure the impact on social well-being with a life cycle perspective. The social impact assessment includes impacts on human well-being that are related to inter-human relationships. This includes a broad range of pathways that affect the quality of life of people on both an individual and a collective basis.

Indicators

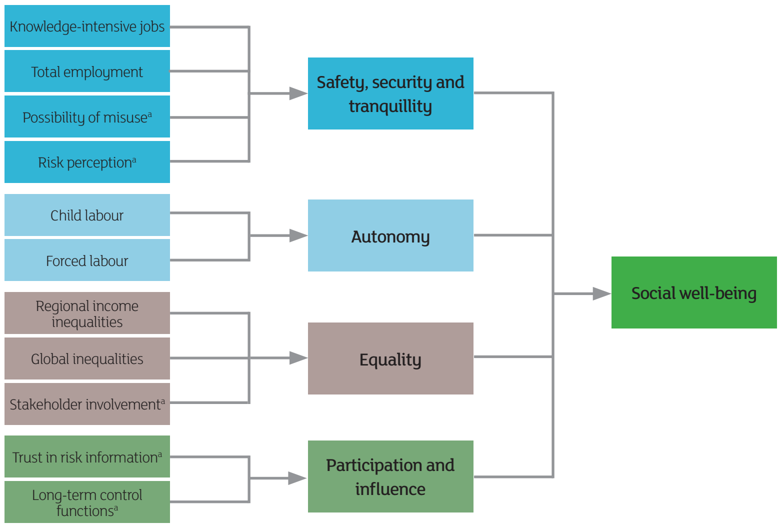
In Prosuite, impacts on social well-being are grouped in four categories (based on the work of Bo Weidema[2]):

- Autonomy: 'being in control of oneself and one's resources'. Autonomy is negatively impacted by for example, forced labour or slavery
- Safety, Security and Tranquillity: as a combination of 'freedom from threats to personal health (Safety)', 'freedom from threats to personal property (Security)' and 'freedom from excessive stress (Tranquillity)'. Safety, Security and Tranquillity are for example negatively impacted by unemployment
- Equality: representing the level of disparity among countries and regions. Equality is for example negatively impacted by increasing disparity in income distribution
- Participation and Influence: 'the act of taking part or sharing in something and affecting the course of events'.

There are many possible indicators to address impacts of a technology on Social Well-being. With the help of a Delphi group technique, the Prosuite Social Assessment team narrowed down the list to eleven indicators selected as most relevant for the technologies considered in the project (see figure 9). This set is by no means exhaustive and can later be expanded as soon as primary impacts are identified that

[2] Weidema, B.P. (2006). The integration of economic and social aspects in life cycle assessment. *International Journal of Life Cycle Assessment 11, Special Issue 1,89-96.*

Figure 9 Cause-effect chain: Social Well-being



[a] qualitative indicators

are relevant for other technologies.

Six of the indicators are quantitative and can be assessed using tools available in the decision support system. The remaining five are qualitative indicators which can be mapped using expert elicitation. In the deliverable *Prosuite Practical Guidance Document for Social Assessment*, some methods to use and complement expert elicitation are recommended. Qualitative indicators were used only when no suitable quantitative indicators were available. A future objective for the field is to develop the methodology in the direction of more quantitative indicators. The analysis for the social assessment targets the system level (i.e. impacts on the European economy). Results at the chain level (per functional unit) are used just to further improve understanding of the impacts.

Operationalization of indicators

Definition of quantitative indicators

- Knowledge-intensive Jobs, regarding the effect of the prospective technology on the amount of highly-skilled employment. The indicator is used together with the indicator on total employment as a proxy for the value of employment in society.
- Total Employment, regarding the total employment caused by the introduction of the prospective technology. Total Employment is the working share of the labour force (the overall part of society that is available for work).
- Regional Income Inequalities, regarding the

degree to which regional income inequalities are affected by the introduction of the prospective technology. Regional Income Inequalities are structural disparities between salary levels, which represent the gap between the rich and poor within a region.

- Global Income Inequalities, regarding the degree to which global income inequalities are affected by the introduction of the PROSPECTIVE technology. Global Income Inequalities regard the disparities between GDP levels around the world.
- Child Labour, regarding the change in the number of children working in hazardous forms of child labour caused by the introduction of the prospective technology. Child Labour is defined by the number of children under legal age who perform hazardous work with companies active in the supply chain of the technology.
- Forced Labour, regarding the forced labour caused by the introduction of the PROSPECTIVE technology. Forced Labour is all work or service which is exacted from any person under the menace of any penalty and not undertaken voluntarily by the person.

Qualitative indicators

- Risk Perception, regarding the potential public resistance with regard to the introduction of the prospective technology. Change in Risk Perception is the difference between the attribution by the general public of hazard due to the introduction of the new technology compared to the reference technology.
- Possibility of Misuse, regarding the potential to misuse a technology so that it harms people or the environment. Although possibility of misuse is related to not only the technology characteristics but also the intention of the user, in Prosuite only the former is currently assessed, by linking Possibility of Misuse to change in asset vulnerability.
- Trust in Risk Information, regarding the confidence that one will be informed in case of hazard due to the introduction of the prospective technology.
- Stakeholder Involvement, regarding the degree to which the interested parties are involved in decision-making processes concerning the prospective technology, and the quality and intensity of these participation procedures.
- Long-term Control Functions, regarding the degree to which people trust that the technology is adequately controlled. Long term Control Functions are governance or technical instruments such as regulating authorities or systems that ensure long-term control.

Input data

For the social assessment it is important to consider the impact in all tiers of the supply chain; this allows for insight into the behaviour of suppliers in different countries and sectors. For example, it is not sufficient to know that there are no issues with Social Well-being in the factory in Western Europe where final products are assembled. You also need to know that there are no issues in the other tiers such as the mining in Liberia or primary assembly in Ghana. Therefore additional inputs are necessary, namely:

- Global production, export and trade statistics. Most of these data are already incorporated in the DSS related to the prosperity assessment

- The production location (country and/or region) of the various suppliers. Some products can have hundreds of suppliers. It is not always possible to collect data for all these suppliers. In that case a selection of the most relevant suppliers can be made, e.g. those who supply 95% of the raw materials
- In which organizations and sites the processes are located. In case of difficulties in obtaining these data, sector level data will suffice

To ensure feasibility of methodology, the complexity has to be reduced: e.g. it is unlikely that data can be collected on hundreds of suppliers. Processes are therefore divided into foreground and background processes.

- If a specific product or technology is analyzed, i.e. product a of company *b* produced in site *c*, it is necessary to collect site- and product-specific data. These are defined as **foreground processes**.
- If, in contrast, a general product or technology *d* available in country *e* is the object of analysis, collected data should be on a more general level. For these **background processes** a less comprehensive indicator system is to be applied. Data for background processes should be considered on country-specific sector level, i.e. on a more general level. Whether data for foreground processes should be more specific depends on the goal of the study.

For the six quantitative indicators (Knowledge-intensive Jobs, Total Employment, Regional Income and Global Inequalities) the THEMIS economic model is used, as developed for the Prosperity pillar. For Child Labour and Forced Labour, the input-output model in THEMIS has been linked to information provided in databases of the International Labour Organization. Results for the six quantitative indicators are at the system level and take into account the full life cycle of the technology.

The impact on the qualitative indicators (Possibility of Misuse, Risk Perception, Trust in Risk Information, Stakeholder Involvement and Long-term Control) must be determined through expert elicitation. In the deliverable *Prosuite Practical Guidance Document for Social Assessment*, some methods to use and complement expert elicitation are recommended. The results can be entered manually into the DSS. They should contain an essay justifying the assessment of the indicator and a preliminary evaluation regarding whether there are reasons for (major or minor) concerns. This is referred to as 'flagging the indicator'. The quality of the assessment will depend on the transparency and explicitness of this analysis. Currently, it is only possible to carry out the assessment taking into account key foreground processes and therefore the assessment of qualitative indicators does not include the full life cycle of the technology.

Expert elicitation is the synthesis of opinions of experts on a subject where there is uncertainty due to insufficient data, or where such data are unattainable because of physical constraints or lack of resources. When conducting an expert elicitation we advise following the guidelines below:

- Select the experts
  - Include at least three individuals with academic or practical experience in the field

– When possible include persons from different disciplines and different professions (i.e. research, consultancy, government, NGO's, industry). This should minimize unintended biases
– Do not attempt to exclude experts with contradictory viewpoints

- Provide an explicit report of which experts are selected and why
  – Justify the choices. Why are these persons considered to possess the knowledge that is lacking in quantitative terms?
  – Indicate the relevant details of the background of the persons selected, their disciplines and their areas of expertise
- Provide complete and explicit results of the consultation
- Summarize the overall conclusion
- Seek out and recognize uncertainties and document them.

Assessment

In contrast to the environmental domain, where the desired direction for each indicator is clear (minimize the impact of a substance in the environment) and the magnitude is based on absolute quantities, social indicators are more complex. As incommensurable data must be combined and the desired direction of the indicators changes (e.g., to increase Social Well-being we would like to decrease child labour but we would like to increase employment). Furthermore, social assessment includes ethical and cultural issues that require values-based decisions as to what is considered desirable.

Quantitative indicators

Results for the quantitative indicators are provided by the Prosuite DSS using the THEMIS database. For the assessment we are interested in the absolute difference between the values provided for the reference and the prospective technology at the system level (this difference is directly calculated and reported by the DSS). With exception of the indicators for equality, as these only have meaning at the system level, the DSS also provides information at the chain level (i.e. per functional unit). When available, information at the chain level is valuable to better understand the impact of the technology, as some impacts can be significant at the chain level but insignificant at the system level (because of the low contribution of the technology to the whole economy). For example, in the nanotechnology case study total employment goes down in comparison to the reference technology, meaning fewer work hours are needed for the prospective technology and product (see figure 10 for

Figure 10 Impact on total employment at the chain level from the nanotechnology case study.

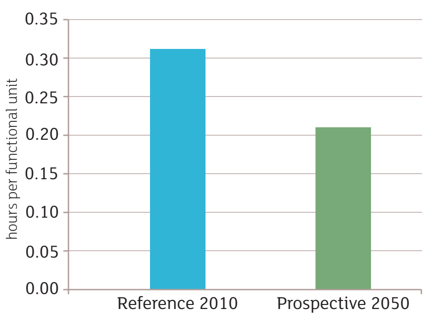


Table 6 Proposed PRPs and flag interpretation for the qualitative indicators

Performance Reference Points (PRPs)	Expert elicitation (indicators Risk Perception, Possibility of Misuse)	Expert elicitation (Trust in Risk Information, Stakeholder Involvement and Long-term Control Functions)
2 No reasons for concern	A decrease	An increase
0 No significant change	A negligible change	A negligible change
-2 Reasons for concern	An increase	A decrease

results at the chain level). This is because fewer textiles will be needed in the prospective situation to provide the same function. At the system level however, the reference background economy has 7533 billion work hours in the world per year, with 52357 working hours from the functional clothes sector relevant for the functional unit (2010). Due to the change induced by the nanosilver textiles, this number would decrease by 2600 work hours in 2050, which is less than 1 billionth of the total.

In the case of a truly novel technology (e.g. smartphones) no reference technology is available for comparison. In that case the impact is compared to the background economy instead of the reference technology. In general the impact of a technology will be much lower when comparing to the background economy (embodied in the THEMIS model).

The assessment, and later integration of these assessments, uses the values reported in the DSS. The *Prosuite Practical Guidance Document for Social Assessment* however provides a number of performance reference points (PRP), which can be used to support the interpretation of the results. These PRPs are discussed in more detail below.

Qualitative indicators

As previously indicated the assessment of the qualitative indicators (i.e. Risk Perception, Possibility of Misuse, Trust in Risk Information, Stakeholder Involvement and Long-term Control Functions) is made by use of expert elicitation. To support the interpretation of the assessment on whether or not a given indicator should be 'flagged', the development of performance reference points, which allow a kind of benchmarking on the level of effect, is encouraged. PRPs are target values for indicators that are specified in the goal and scope of a study. PRPs must be defined in such a way that they allow a clear assessment of each indicator value to the available assessment scores, i.e. from 1 to 5 with scale A or from -2 to +2 applying scale B. An example of such PRPs is shown in Table 6.

Aggregation

The quantitative indicators are aggregated in order to come to one overall quantitative score for the impact on Social Well-being. Aggregation is automatically performed by the DSS for the quantitative indicators only. Results of the qualitative indicators should be provided as extra information and are

Table 7 Summary of the results found for the quantitative indicators at the system level in the CCS case study

Indicator	Absolute difference (prospective to reference)	Observed Trend	Desired Trend
Total employment	515,500 hours	Increase	Increase
Knowledge-intensive Jobs	92,240 hours	Increase	Increase
Child Labour	5,553 hours	Increase	Decrease
Forced Labour	384 hours	Increase	Decrease
Regional Income Inequality	0,0000000101	Decrease	Decrease
Global Income Inequality	-12,770,000,000[1] Euro	Decrease	Decrease

1: the negative number is due to the fact that the value is produced as the difference between GDP of non-OECD and GDP of OECD, with the former being larger than the latter.

not included at this point in the aggregation methodology. The aggregated impact is calculated as the arithmetical mean of the normalised and weighted value of the quantitative indicators (which in each case are reported as the absolute difference between the prospective and reference technologies at the system level). The overall score for the endpoint on Social Well-being (the Social Well-being index *I*) is then calculated as follows:

$$S_{wB} = \sum_{i=1}^{6} W_{a,i} \times \left(\frac{I_i}{N_i}\right)$$

where *Ii* is the value of an indicator *i*, *Wi* is the weighted factor for indicator *i*, *Ni* is the normalised factor for indicator *i*.

In Prosuite, *per capita* global normalisation factors are used for the aggregation so that the assessment is harmonized with the other assessments in the framework. More details can be found in the Prosuite deliverable *Normalisation factors for environmental, economic and socio-economic indicators*.

An important aspect of the social assessment is the fact that indicators have different directions and this is taken into account explicitly in the aggregation method. In Prosuite it is considered e.g., that an increase (calculated as the difference between the values for the prospective and reference technology) in Total Employment and Knowledge-intensive Jobs is positive for Social Well-being while an increase in Child Labour, Forced Labour and Inequalities is negative. To reflect this in the aggregation procedure, positive impacts should be included as positive numbers and negative impacts as negative numbers. The value of the aggregation is then the net result on Social Well-being. Table 7 shows an example for the CCS case study.

Practical implementation

A practical example of the assessment on Social Well-being can be found in the case study of CCS. The assessment indicates that implementation of the technology (under the scenario studied) results in an increase in Total Employment and Knowledge-intensive jobs, and a decrease in Regional and Global Income Inequality. However, increases in Child and Forced Labour are also observed (See Table 7). The qualitative indicators point out that issues such as trust in risk information, long term control functions, stakeholder involvement can become bottlenecks for the deployment of the technology and need to be carefully addressed as part of project development and implementation.

Discussion

As already indicated the Prosuite methodology represents one of the first attempts to develop a comprehensive and quantitative method to measure impact on social well-being. Further improvement is expected, for example regarding developing a method that allows measurement of indicators in the unit 'Well-being Adjusted Life Years'. This indicator, comparable to the DALY measure for human health, would express the years of well-being that are lost compared to an ideal state of uncompromised social well-being. Further research is needed to determine the incidence and duration of the social impacts on a person and the weight factors that indicate the degree to which certain impacts influence Social Well-being.

5 PROSPERITY

Technological innovation is universally accepted to be an important source for economic growth. The major impact category Prosperity focuses on the potential impact of technologies on affluence.

The economic impact of a technology/product can be linked to a change in the added value created by introducing the new technology, measured as Gross Domestic Product (GDP). GDP is a generally accepted and widely available measure for prosperity. Gross Domestic Product allows us to express the economic impact of new technologies in monetary terms.

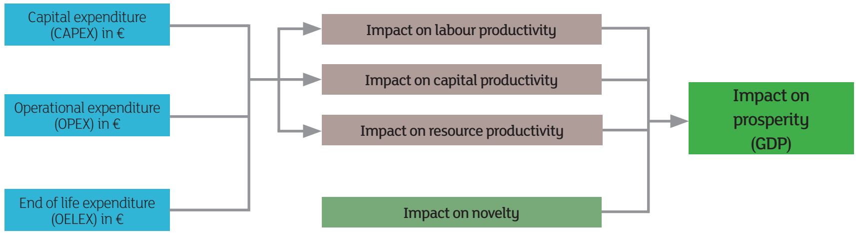
Indicators

The cause-effect chain for Prosperity is schematized in figure 11. Changes in Labour Productivity, Capital Productivity and Resource Productivity can all affect the GDP. These items can in turn be affected by expenditure on: Capital, Operations and End of Life. The Prosperity assessment consists of two steps: firstly the micro assessment to gain insight into all the expenditures related to the technology (CAPEX, OPEX, OELEX), and secondly the macro assessment to gain insight into how these expenditures influence macro level impacts (Labour, Capital and Resource Productivity and ultimately Gross Domestic Product). The micro and macro assessments are discussed separately below.

Micro-economics analysis

Economic performance is an important approximation for the existence and future of a technology. Therefore careful and precise assessment of all costs related to a technology is of the greatest importance to determine the prospects of a technology.
The micro analysis not only allows for an estimation of the total production costs for a given product (micro-economics), it also provides a substantial share of the inputs required for the macro-economic analysis namely the

Figure 11 Cause-effect chain: Prosperity



CAPEX, OELEX and OPEX. The Prosuite methodology uses the factorial approach in which cost components are estimated using factors and percentages based on purchased equipment costs, geared towards chemical plants. This approach can be realized using a limited amount of data, namely a list of equipment required for the technology. Therefore it is especially practical for the assessment of new or emerging technologies. This methodology estimates the costs of a technology with a margin of uncertainty of ±30%.

Assessment

A model to perform the micro analysis is included in the Prosuite DSS. Formulas have been included to estimate the costs at the right functional unit and capacity level. The DSS takes the user through the required steps and executes the calculations using the on-board database of costs information from the chemical sector. Because this database solely focuses on chemical data, the micro assessment tool in the DSS is not applicable for non-chemical plants. Assessments for technologies or products outside the chemical sector therefore require a separate manual calculation of micro costs using the same formulas. These are found in the *Recommended methodology and tool for cost estimates at micro level for new technologies* available in the Prosuite online library.

The micro economic model included in the DSS applies the factorial methodology to determine the total capital investments for a technology. These steps include:

1. *Identify the major pieces of equipment purchased*
   ... together with specifics such as capacity, material of construction, additional concerns such as extreme pressures or temperatures, etc.
2. *Estimate the purchased and the installed costs for each piece of equipment*
   The database contains a large set of equipment from which a selection can be made.
3. *Estimate the fixed capital investment including all direct and indirect costs*
   Since many of the actual costs are unknown, certainly for future technolo-

gies, estimation factors have been developed for each investment. The investment factors are based on extensive literature research; the background documentation can be accessed in the Prosuite library: *Recommended methodology and tool for cost estimates at micro level for new technologies*.

4. *Estimate working and startup capital*
   Based on the fixed capital investment estimate, the working capital and startup capital can be determined. The working capital is usually between 15% and 30% of the total capital investment. The total capital investment includes two components: the fixed-capital investment and the working capital. Once the fixed-capital investment is estimated, the working capital in turn is estimated on this basis.

When the actual manufacturing of the product starts the total capital investment is gradually recovered. The capital recovery is included in the total production costs, which can be estimated with the following steps:

- Estimate the costs of raw material, utilities (water and electricity) and expenses for environmental measures: The amounts of raw materials required for the manufacturing of the product are estimated based on a material balance. The DSS can estimate the costs of 700 chemicals and utilities such as diesel, gasoline, electricity and water.
- Estimate the labour cost: The labour costs are estimated in two parts, as operating labour costs and direct supervisory and clerical labour costs. The direct supervisory and clerical labour costs are estimated to be between 10 and 20% of the operating labour costs.
- Estimate the total production costs including all (semi-) variable and fixed cost factors for maintenance and repairs and operating supplies: The fixed costs that are taken into account are general plant overhead, administrative costs and R&D. These are assumed to be certain percentages of the labour and operating costs. Maintenance and repairs costs are estimated to be between 10 and 20% depending on the complexity of the process.
- Capital recovery: The initial capital investment is determined through depreciation which is based on the discount rate and the lifetime of the manufacturing plant. The depreciation method is also likely to be different according to different government and tax regulations in the various countries. In the DSS a simplified method is used to calculate capital recovery.

Interpretation

The DSS provides estimations for all the following indicators:

- Production cost – Operational: Cost expressed per functional unit that include all ongoing expenditures.
- Production cost – Capital: Cost expressed per functional unit that include all capital expenditures.
- Production cost – End of Life: Cost related to the retirement of capital per functional unit.
- Direct labour requirements: The labour required by the prospective/reference technology in order to deliver the functional unit. For the example of nano-fibre, this is the labour employed in the actual manufacture of nanoparticles, which excludes, for exam-

ple, the labour used in cotton farming, or oil extraction (for synthetic fabric).

- Total labour requirements: The total labour requirements to deliver the functional unit, which includes the labour requirements of all upstream processes.

Macro-economic analysis

The macro analysis aims to give insight into the impacts of a technology on the economy when it has fully penetrated the market. It aims to answer the question whether a technology has a macro-economic impact. More precisely: does the selection of a specific technology lead to additional economic growth that would not happen if one had invested in a different technology/sector instead? The macro analysis is conducted with the model THEMIS. THEMIS is a hybrid input-output model, developed from the EXIOPOL database with related projects for the Prosperity impact category.

Assessment

An important step in the macro assessment is a market analysis to estimate the potential market volume. This requires a survey or another form of market research. Estimation of the market is necessary because environmental, economic and social aspects become relevant or apparent only if the technology reaches and exceeds a certain level of implementation. Investigating the impact of technology through only the functional unit ignores this aspect, so analysis must occur at full-scale implementation. It's only then that resource constraints or resource conflicts, macro-economic effects and social tensions can become apparent. An estimate of the macro-impact of a technology hence requires the estimation of the production volume of the technology output.

Most inputs for the macro assessment can be obtained from the micro assessment, such as the purchased equipment cost, installed equipment cost, indirect cost, con-

Example

Mobile devices

Like many emerging products, smartphones are not preceded by similar products in the market. They do however have an observed time series of sales from 2008-2012. By using this time series and a widely used market diffusion model it was possible to estimate the sales development of smartphones over the next few decades. The same model was applied to total mobile phones market to test the validity of the model and to have an overview of the potential mobile phone technologies market, which would eventually replace smartphones. Based on the results, the sales of smartphones are forecasted to grow rapidly until 2020, at which time they will have saturated the markets, and repeat purchases will gradually begin to decline.

tingency and capital recovery. Some new inputs are e.g. the sector in which the reference and prospective technologies are to be classified and the region in which the product is produced.

Indicators

The Prosuite DSS provides estimations for all the following indicators.

- Pervasiveness - Backward Linkage: Measures the relative contribution of other products to the operation of the technology. Measures how dependent the production process is of complex products – does the process use large quantities of processed goods/services, or is it largely reliant on primary resources? This indicator is a ratio and has therefore no unit.
- Pervasiveness - Forward Linkage: Measures the importance of the product for other sectors of the economy. If a product is economically important, it would be expected to have high forward linkages. For instance, considering electricity versus a television: many industries are reliant on a consistent source of electricity and not on a television. This indicator is a ratio and has therefore no unit.
- Import Dependency Economy Wide: Shows how much of the total value produced per functional unit is imported into the region of analysis (OECD Europe in Prosuite case studies), as the total value of imports into the economy relative to the domestic gross production. The relative reliance on imports is compared to total inputs. The indicator is calculated per functional unit and includes total upstream imports (e.g. imported oil, into domestic refineries).
- Structural Index: The employment of a technology can change economic structures, i.e. by shifting the demand in the economy from one sector to another. For instance, bio-fuels will benefit agricultural producers but may hurt traditional oil production. The higher the resulting index the more tertiary production is required.
- Financial Risk: A crude proxy for capital intensity per functional unit. If the production of a functional unit requires a lot of capital, this implies the producer faces a relatively large share of sunk costs, that is, fixed costs that will not respond to production volumes. This increases the risk for the producer.
- Capital Productivity: The economic output achieved per unit of capital expenditure.

Example

Carbon capture and storage

The CCS case study shows that the CCS plants generate higher backward and comparable forward sales compared to the reference technology (non-CCS). The interpretation is that a 1€ additional sale in with-CCS-produced electricity induced 2.64€ worth of forward linkages down the production value chain (e.g. wholesale and retail trade) and 2.84€ of backward linkages up the production chain (coal extraction, equipment sales, accounting services etc.). The higher backward linkages are due to the fact that CCS requires more intermediate inputs per € of delivered product than non-CCS, which has a large tax cost. The lower forward linkages are due to the higher self-consumption of electricity in the technology.

- Labour Productivity: The economic output achieved per hour worked.
- Resource Productivity: The economic output achieved per ton of material extraction.
- Novelty: The new market created for the prospective product. Novelty occurs where new demands are created. In other words: if consumers will buy more functional units of this product, then it has novelty; if they won't, then it improves the process of supplying the current market.
- GDP: Total value added in the domestic (EU) and global economy.

Interpretation

The Prosuite DSS output for the economic study is a full table with aggregated results. The presentation displays results for the full scale implementation of the technology, given estimates on uptake in the economy.

The case study on biorefineries calculated the impact on Prosperity of using bio-refined organic waste as fuel for electricity generation compared to the reference technology of coal fired power plants. The results are shown in table 8. An important conclusion of the calculation is that the prospective technology would not be competitive or even profitable without subsidies on renewable energy. However, energy from silage maize digestion has the lowest financial risk, which is mostly due to the lower capital investment per kWh.

Table 8 Impact on Prosperity from the biorefineries case study

	Reference System	Prospective System - silage maize	Prospective System - Domestic organic waste
Production Volume (Monetary)	58.3 million	4.33 million	72.9 million
Production Volume - functional units	387 million	387 million	387 million
Total Price (€ per FU)	0.15	0.01	0.19
Direct Capital Requirements (€ per FU)	0.02	0.00	0.06
Direct Compensation of Employees (€ per FU)	0.01	0.03	0.06
Total Compensation of Employees (€ per FU)	0.04	0.05	0.12
Import Dependency - FU - %	5%	7%	5%
Financial Risk - FU Capital Cost/Total Cost	16%	3%	31%
Total Compensation of Employees - Economy Wide	55.100 billion	55.100 billion	55.100 billion
Total Capital Compensation - Economy Wide	17.200 billion	17.200 billion	17.200 billion
Import Dependency - Economy Wide - €	1600 billion	1600 billion	1600 billion
Backward Linkages - Economy Wide	2.03	1.84	3.71
Foreword Linkages - Economy Wide	2.73	1.37	2.84
Structural index - Economy Wide	467.81	467.81	467.81
Capital Productivity - €/€	6.74	6.74	6.74
Labour Productivity - €/€	2.10	2.10	2.10
Labour Productivity - €/hours	15,361,702	15,361,696	15,361,701
Resource Productivity	796668	796669	796669
Novelty			
Domestic GDP - Economy Wide - €	21417 billion	21417 billion	21417 billion
Global GDP - Economy Wide - €	11600 billion	11600 billion	11600 billion

6 NATURAL ENVIRONMENT

The impact category Natural Environment describes the impact of technologies on the natural ecosystems around the world[3]. Negative impacts on ecosystems can occur as a consequence of exposure to chemicals, biological and physical interventions such as cutting wood or mining. Essentially the category Natural Environment aims to provide insight into change to and loss of species richness. The impact on Natural Environment is expressed as the potential number of species disappearing over time. The unit for this is species*year, which can be interpreted as the number of species that has a high probability of no occurrence in a region, due to unfavourable conditions, integrated over time.

Indicators

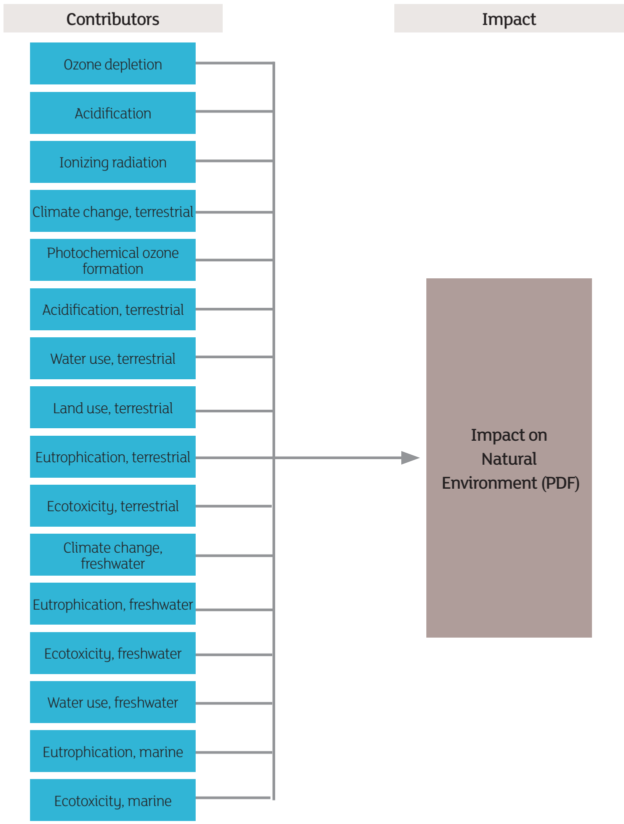
The analysis of the impact on Natural Environment focuses on the negative impacts on freshwater, marine and terrestrial (land) ecosystems, though some contributors affect all three (see figure 12). The negative impacts can be caused by several contributors such as land use, acidification and climate change. The impact of each contributor on the natural environment is calculated to get insight into the total impact on the natural environment.

The definitions of the contributors in figure 12 are as follows:

- **Ozone Depletion:** Ozone depletion refers both to the general progressive loss of ozone in the stratosphere, which in 2013 has been occurring for at least the past three decades, and on a more localized scale the loss of ozone taking place over the polar regions at a greater rate, but on a seasonal basis.
- **Acidification:** Acidification is caused by direct outlets of acids or by outlets of gases that form acid in contact with air humidity and are deposited to soil and water. These acid depositions have negative impacts on natural ecosystems and the man-made

[3] European Commission - Joint Research Centre - Institute for Environment and Sustainability (2010) *International Reference Life Cycle Data System (ILCD) Handbook - General guide for Life Cycle Assessment - Detailed guidance. First edition March 2010. EUR 24708 EN.* Luxembourg: Publications Office of the European Union.

Figure 12 Cause-effect chain: Natural Environment



environment including buildings.

- **Ionizing Radiation:** Ionizing radiation has enough energy to break chemical bonds. It has the potential to damage DNA.
- **Climate Change, Terrestrial:** Climate change describes changes in the global, average surface-air temperature and subsequent change of various climate parameters. This affects parameters such as storm frequency and intensity, rainfall intensity and frequency of flooding. Climate change is caused by the greenhouse effect which is induced by emission of greenhouse gases into the air. This indicator describes the impact of these effects on terrestrial ecosystems.
- **Photochemical Ozone Formation, Terrestrial:** Photochemical ozone formation is caused by emissions that react with the light energy of the sun.
- **Acidification, Terrestrial:** Acidification is

caused by direct outlets of acids or by outlets of gases that form acid in contact with air humidity and are deposited to soil and water. These acid depositions have negative impacts on natural ecosystems and the man-made environment including buildings.

• **Water Use, Terrestrial:** Terrestrial water use is concerned with the amount of water that is removed from the environment and the consequences of this removal for terrestrial ecosystems.

• **Land Use, Terrestrial:** Land use is related to use (occupation) and conversion (transformation) of land area by product-related activities such as agriculture, roads, housing, mining etc. Land occupation considers the effects of the land use, the amount of area involved and the duration of its occupation.

• **Eutrophication, Terrestrial:** Terrestrial eutrophication is generally associated with the environmental impacts of excessively high levels of nutrients on land that lead to shifts in species composition and further affect the consumers of this land.

• **Ecotoxicity, Terrestrial:** Terrestrial ecotoxicity is the potential environmental toxicity of residues, leachate, or volatile gases that affect terrestrial plants and animals. Ecotoxic substances alter the composition of the species of ecosystems, destabilizing it thereby and additionally threatening some species in their existence.

• **Climate Change, Freshwater:** Climate change describes changes in the global, average surface-air temperature and subsequent change of various climate parameters. This affects e.g. storm frequency and intensity, rainfall intensity and frequency of flooding. Climate change is caused by the greenhouse effect which is induced by emission of greenhouse gases into the air. This indicator describes the impact of these effects on freshwater ecosystems.

• **Eutrophication, Freshwater:** Freshwater eutrophication is generally associated with the environmental impacts of excessively high levels of nutrients in fresh water that lead to shifts in species composition and further affect the consumers of this water.

• **Ecotoxicity, Freshwater:** Freshwater ecotoxicity is the potential environmental toxicity of residues, leachate, or volatile gases that affect freshwater plants and animals. Ecotoxic substances alter the composition of the species of ecosystems, destabilizing it thereby and additionally threatening some species in their existence.

• **Water Use, Freshwater:** Freshwater water use is concerned with the amount of water that is removed from the environment and the consequences of this removal on freshwater ecoysystems.

• **Eutrophication, Marine:** Marine eutrophication is generally associated with the environmental impacts of excessively high levels of nutrients in marine water that lead to shifts in species composition and increased biological productivity, for example as algal blooms.

• **Ecotoxicity, Marine:** Marine ecotoxicity is the potential environmental toxicity of residues, leachate, or volatile gases that affect marine plants and animals. Ecotoxic substances alter the composition of the species of ecosystems, destabilizing it thereby and additionally threatening some species in their existence.

Calculation of the impact on Natural Environment requires data about all relevant processes throughout the life cycle, for example the amount and type of materials that are used and the transport type and distance. These data are combined into the Life Cycle Inventory (LCI). Several calculation steps are needed to transform the LCI into the impact on Natural Environment, which is handled by Life Cycle Impact Assessment (LCIA) methods. These methods firstly determine to which impact category a certain emission contributes, e.g. emitting CO_2 into the atmosphere causes climate change, which contributes to impact on both terrestrial and freshwater ecosystems. Then the severity of such impacts is specified, which allows the effects of all emissions to different impact categories to be combined into the impact on Natural Environment.

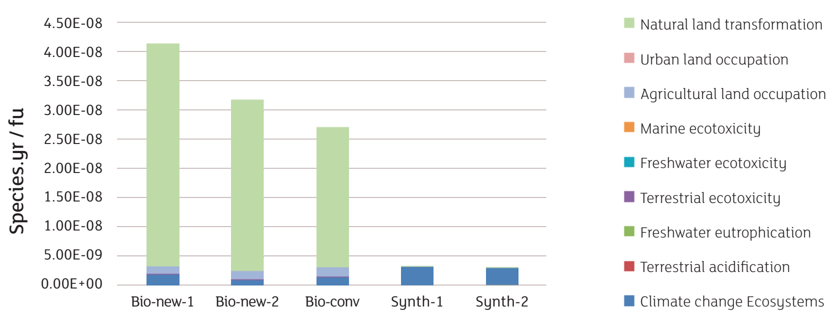
Since impact on Natural Environment has been explored thoroughly in the past, many LCIA methods are already available. Prosuite analyzed many of the methods in the ILCD handbook together with the newly developed methods from the LC-IMPACT project. The outcome is available online: *Recommended assessment framework, characterisation models and factors for environmental impacts and resource use*.

Interpretation

Once the data have been manually included in the Decision Support System, the impact can be calculated and interpreted. The case study of paint resins is used to illustrate how interpretation can be done. In this study five types of paint resin are compared, with the main difference that three of these are bio-based and two are synthetic.

The results of this case study for the impact on Natural Environment are shown in figure 13. The five types of paint resin are listed on the X-axis, with the 3 bio-based resins

Figure 13 Impact on Natural Environment from the paint resins case study



on the left and the synthetic ("neo") resins on the right. The impact per f.u. is shown on the Y-axis.

When interpreting the results shown in figure 13 it is clear that significant differences exist between the impacts caused by the bio-based and synthetic paint resins. The impacts of the bio-based resins are mainly caused by natural land transformation. This is due to the land that is needed for growing the bio-based ingredients. The impact of the synthetic resins is much lower, and is mainly caused by impact of climate change on ecosystems. This makes sense, since fossil resources are needed to produce these synthetic resins, and the use of fossil resources is often related to impact on climate change.

Discussion

The impact assessment methods recommended in the ILCD handbook were used as the primary basis for method selection by Prosuite. The ILCD handbook methods are viewed as the best alternatives for each specific impact category available at its time of publication, such as climate change and terrestrial ecotoxicity. For other categories, Prosuite retained newly released methods from the LC-IMPACT project. These updates were developed in light of the the ILCD handbook suggestions for improvement, and were thus identified by Prosuite as the new best available methods.

7 EXHAUSTIBLE RESOURCES

The impact category Exhaustible Resources concerns the removal of resources from the earth, whether this is for the production of fuel or as a raw material. The category encompasses only abiotic non-renewable resources, which are non-living resources that cannot be regenerated in a reasonable timeframe. Examples are crude oil, coal, iron and gold.

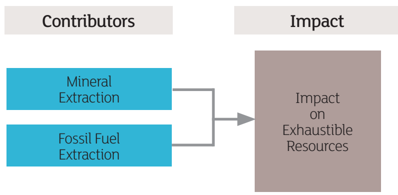
The removal of exhaustible resources from the earth results in a decrease of the total available stock. As a result less of these resources will be available for future generations. Furthermore, the most accessible stock is usually recovered first, meaning that future generations will need more effort to reach the following stock available. Both the reduced availability and increased difficulty to reach future stock will result in a resource shortage and increased resource costs.

The impact on Exhaustible Resources is expressed in US dollars. This indicates the expected cost increase caused by the extraction of resources now.

Indicators

Exhaustible Resources can be separated into the impact of mineral extraction and fossil fuel extraction, as is illustrated in figure 14.

Figure 14 Cause-effect chain: Exhaustible Resources



Calculation

Impact on Exhaustible Resources has been explored thoroughly in the past, so several impact assessment methods were already available. The ILCD handbook analyzed existing impact assessment methods and found a number of weaknesses in the methods for

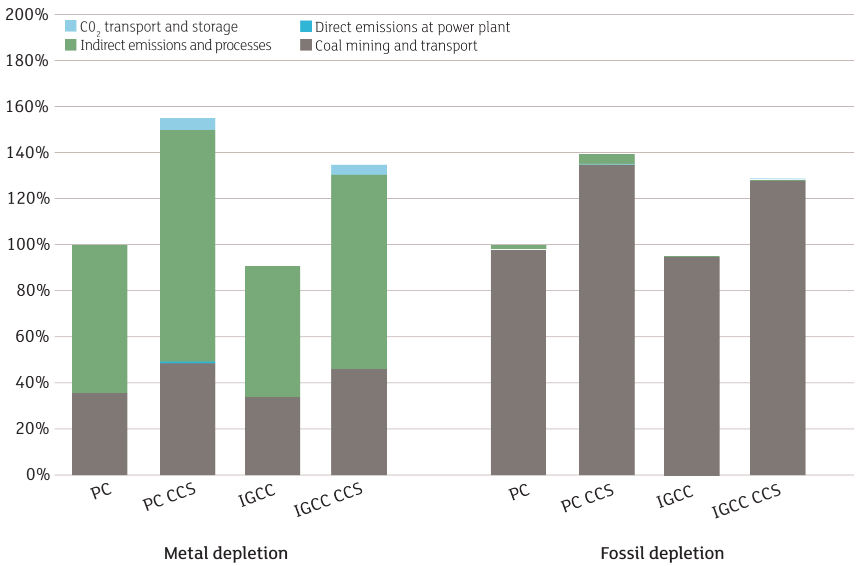
Exhaustible Resources. Taking account of these weaknesses new methods were developed by the LC-IMPACT project. These new methods are more scientifically robust and reliable than previous methods, and are thus recommended for the sustainability assessment of technologies. The full list of recommended methods for use can be found in the Prosuite document *Recommended assessment framework, characterisation models and factors for environmental impacts and resource use.*

Practical Implementation

The case study on Carbon Capture and Storage (CCS) found that switching from the reference technology (no CCS) to the prospective technology (including CCS) causes an increase in the impact on Exhaustible Resources (see figure 15). In this figure the following situations are included: a Pulverized Coal power plant (Ref (PC)), a Pulverized Coal power plant with CCS (PC CCS), an Integrated Gasification Combined Cycle power plant (Ref (IGCC)) and an Integrated Gasification Combined Cycle power plant with CCS (IGCC CCS). This main contributor to the increase on metal depletion is the required update of the power plant infrastructure. An additional contributor is the required infrastructure for CO_2 transport and storage. All combined, almost 50% more metals are required for the prospective technology.

The increased impact on fossil fuel depletion results directly from the lower efficiency of power plants when CCS technology is added.

Figure 15 Impact on Exhaustible Resources from the CCS case study



8 AGGREGATION

The ambition of the sustainability assessment of technologies is to enable:

- Comparison of the sustainability impacts of alternative technologies to provide a given service
- Support for the development of sustainability policies (e.g. product policy, technology action plans)
- Strategic decision making in companies.

An aggregate sustainability impact end score alone would not fully serve such goals - underlying values are very relevant as well. Many important insights spring from examination of the contributors, such as impact on labour productivity, occupational health or land use, etc. Still the Prosuite methodology allows the practitioner to obtain an end score by going through the steps of optional weighting and then, weighted aggregation.

Normalisation

Normalisation is a procedure needed to show to what extent an impact category has a significant contribution to the overall sustainability outcome. This is done by dividing the impact category indicators by a "reference" value. There are different ways to determine the "reference" value. The most common procedure is to determine the impact category indicators for a region during a year and, if desired, divide this result by the number of inhabitants in that area. The impact of the product under study can then be compared to the impact of an average inhabitant of a region in a year.

The normalised results show the order of magnitude of the problems generated by the product's life cycle, compared to the total sustainability loads in Europe.

A set of comprehensive normalisation factors was developed for the pathways, contributors and the impact categories. The normalisation factors for the impact categories can be found in table 9, the normalisation factors for the pathways and contributors are accessible in the Prosuite Library: *Normalisation factors for environmental, economic and socio-economic indicators*. All

Table 9 Overview of normalisation references for the Impact categories

Impact categories	Normalisation references	Unit
Natural environment	7,30E-05	species loss.yr/person/year
Human health	3,31E-02	DALY/person/year
Exhaustible resources	1,04E+02	USD2010/person/year
Prosperity Global GDP - Economy Wide - €	9.24E+03	€/person/year
Social well-being	Already normalized after weighting and aggregation procedure	-

the normalisation factors are also integrated in the DSS.

Display of normalised results

At the end of the Prosuite assessment the normalised impact values for each major impact category are graphically displayed by the DSS, as illustrated in figures 16 and 17. The aggregation graphics use both images and figures to communicate the performance of tested technologies on each of the major impact categories and will help users to understand the main differences and trade-offs between them.

Weighting

Weighting is a step needed to further aggregated normalised values into a single sustainability score. To aggregate to one score a weight is assigned to each major impact category. This weight indicates the relative importance of a given category that is attributed by the assessor or evaluator. Weighting is the most controversial step in life cycle impact assessment, as *in fine* it is a subjective value-based judgment. Nevertheless, in order to contribute to the transparency and founded basis of such subjective evaluations, a set of "examples of weighting factors" is provided in Prosuite regarding the five major impact categories of the methodology. These weighting factors were developed through workshops with interested parties of various nationalities. The report of the weighting workshops is downloadable as *Obtaining weighting factors for PROSUITE impact categorys*. Table 10 shows the proposed default set of weights that resulted from these small workshops (and should not be taken as definitive statements).

Table 10 Examples of weighting factors for major impact categories

Impact categories	Weighting factor
Human health	0.30
Social well-being	0.25
Prosperity	0.10
Natural environment	0.25
Exhaustible resources	0.10

Figure 16 Generic display of aggregate outcome

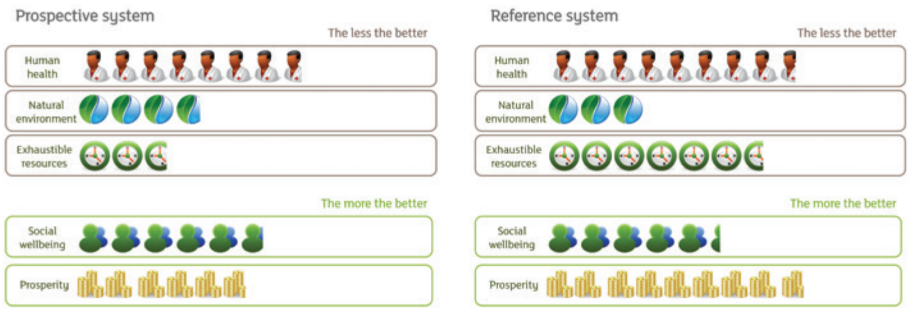
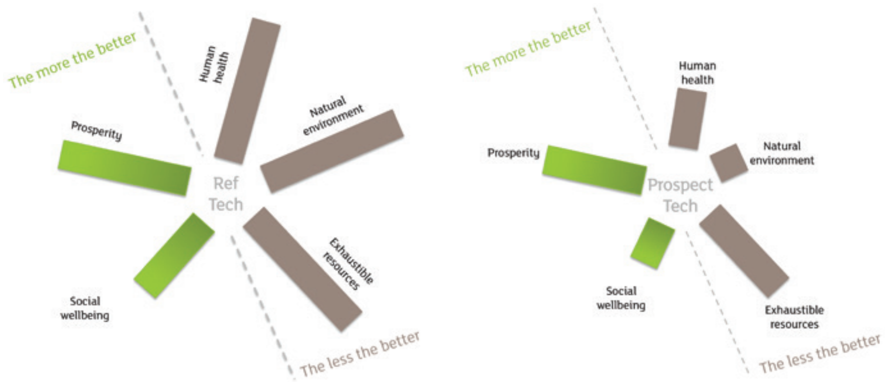


Figure 17 Generic 5-impact display of test cases



Aggregation

There are several methodologies that can be used to aggregate indicators. In Prosuite two are recommended: aggregation to weighted sum and outranking analysis. Both are briefly discuss below. The framework developed in Prosuite recommends that the user should perform both aggregation methods and assess the results together with the graphical display and supplementary information (e.g. results of the qualitative indicators in the social assessment) before drawing a conclusion on the sustainability of the technology under study.

Weighted sum

When the impact on each major impact category has been weighted, the results can be aggregated into a single score, as in the following formula:

$$V_j = \sum_{i=1}^{n} v_{i,j} \times w_i$$

$$\sum_{i=1}^{n} w_i = 1$$

where:

V_j denotes the aggregated score for alternative *j*, $V_{i,j}$ denotes the normalised score for impact category *i* for alternative technology *j*, w_i denotes the weight assigned to impact category *i*, and *n* denotes the number of impact categorys. Note that impact categorys with different directions of preference should have opposing signs in the computation of the aggregated score. For instance, if the aggregated score is formulated as total impact on sustainability (pressure) (for which a higher score is worse) then the normalized values for prosperity and social well-being should be subtracted (included in the formula with a minus sign), while the values for human health, natural environment and resources should be added.

This methodology is quite simple and easy to understand by decision-makers. However, the method implies that 'bad' scores in one category can be compensated by 'better' performance in others. When reporting an aggregated score it is important to keep track of values that may be considered critical. For example if there are serious concerns about child labour involved with the technology under study, this should not be masked in an aggregated score, but reported separately.

Outranking analysis

Outranking means that a given option beats (outranks) another option in a pairwise competition. Outranking analysis starts by ranking the alternatives according to the relative preference recorded on each criterion. In Prosuite the value of an impact category is taken as this measure of preference. For each impact category the ranking of each alternative is compared with all the others; the user should count a 'win' for the winning alternative in each pairwise confrontation. If one alternative beats all the others in these pairwise comparisons, it is the winner (the best performing technology in the sustainability assessment). If there is no such absolute winner, the 'wins' for all criteria are added and the alternative with more 'wins' is considered to outperform the others. More information on the aggregation methodologies is provided in the deliverable *Integration in PROSUITE – guidelines for case studies*.

9 UNCERTAINTY ASSESSMENT

When the technology assessment has been conducted for one or multiple major impact categories, before interpreting the final results it is important to do a number of checks to see if the conclusions you want to draw from the study are adequately supported by the data and by the procedures used. This so-called uncertainty assessment estimates the degree of confidence that can be placed on the data and the model. Assessment of uncertainty is critical to more fully evaluate the implications and limitations of the technology assessment. All data in life cycle models have some uncertainty. One can distinguish three main types:

- Data uncertainties
- Uncertainties about the correctness (representativeness) of the model
- Uncertainties caused by incompleteness of the model.

A memo on this subject can be found in the Prosuite Library as: *A Proposal for Uncertainty Classification and Application in PROSUITE.*

Data uncertainty

In the ideal situation the data used are the best data available. The 'best data available' are determined by sampling many different measurements, to ensure overall consistency. The final number is usually the mean value of a lognormal distribution. These distributions can be characterised by a geometric standard deviation (GSD). The more accurate the data, the lower the SD will be. The pedigree matrix originally developed by Weidema and Wesnaes (1996) is used to estimate the geometric standard deviation. Each data point is assessed regarding the following six criteria:

- The reliability indicator relates to the sources, acquisition methods and verification procedure used to obtain the data
- The completeness indicator relates to the statistical properties of the data: how representative is the sample, does the sample include a sufficient number of data and is

the period adequate to "even out" (avoid undue influence by) normal fluctuations
- The temporal indicator represents the time correlation between the year of study (as stated in the data quality goals) and the year of the obtained data
- The geographical indicator illustrates the geographical correlation between the defined area (as stated in data quality goals) and the obtained data
- The technological indicator is concerned with all other aspects of correlation aside from the temporal and geographical considerations.

These criteria are used to calculate the standard deviation. For all major impact categories a pedigree matrix has been developed; these can be found in annex 3. In the process data of the DSS you will find a string of six figures, for example 1.2.1.5.1.3, in each comment field. These numbers refer to how the uncertainty was estimated using the pedigree matrix. In figure 18 a small part of an environmental pedigree matrix is illustrated.

With insight into the uncertainty of the data we can now use the Monte Carlo analysis to calculate the overall uncertainty of the model. The Monte Carlo analysis gives an uncertainty distribution of each impact. For each impact category a bar chart is shown with an uncertainty distribution. This shows the range in which 95% of the results lie. Thus Monte Carlo analysis can be used to find impacts characterized by high uncertainty.

The basic concept of Monte Carlo analysis can be explained using a simple example. Suppose you are interested in the SO_2 emission from an oil fired furnace that is used to dry wood. You have the following data:
- SO_2 emission from burning 1 kg of heavy oil is 10 grams on average, but in 95% of the cases the value lies between 5 and 15 gram, depending on the sulphur content of the oil.
- The oven in which you burn this oil generates 40 MJ of heat per kg of oil. Due to differences in maintenance and age, the value will vary about 5%. The actual value will be

Figure 18 Sample lines from an environmental pedigree matrix

Indicator score	**1**	**2**	**3**	**4**	**5** (default)
Reliability	Verified[5] data based on measurements[6]	Verified data partly based on assumptions ***or*** non-verified data based on measurements	Non-verified data partly based on qualified estimates	Qualified estimate (e.g. by industrial expert)	Non-qualified estimate
Completeness	Representative data from all sites relevant for the market considered, over an adequate period to even out normal fluctuations	Representative data from >50% of the sites relevant for the market considered, over an adequate period to even out normal fluctuations	Representative data from only some sites (<<50%) relevant for the market considered ***or*** >50% of sites but from shorter periods	Representative data from only one site relevant for the market considered ***or*** some sites but from shorter periods	Representativeness unknown or data from a small number of sites ***and*** from shorter periods

between 38 and 42 MJ.

- The process that is operated requires on average 10 MJ, but there is an uncertainty of about 50%. This means that the actual requirement can be between 6.7 and 15 MJ.

During a Monte Carlo analysis the computer takes a random variable for each value within the uncertainty range that was specified and calculates the result, which is stored. Next the calculation is repeated taking different samples within the uncertainty range and this result is also stored. After repeating the procedure for instance 1000 times, we obtain 1000 distinct answers. These answers form an uncertainty distribution.

Correctness of the model

Uncertainty on the correctness of the model refers to the fact that there is not a single agreed way to make a model of reality. In each sustainability assessment, one will have to make more or less subjective choices in order to make a model. Some examples are:

- Allocation basis: There is no single way to choose an allocation basis
- Future events: Many LCAs deal with products that have a long lifetime. This means these products will be disposed of in a few decades. No one really knows how waste treatment will be organized at that time
- Choice of functional unit: It is often not clear on which basis products should be compared.

All these factors can have significant impacts on the results, but are not always easy to handle. In order to see the influence of the most important assumptions, it is strongly recommended to perform a sensitivity analysis during the assessment and at the end of the sustainability assessment. The principle is simple: change the assumption and recalculate. With this type of analysis you will get a better understanding of the magnitude of the effect of the assumptions you make. You will find that the outcome of the sustainability assessment can be quite heavily dependent on some of the assumptions.

This does not need to be a problem as long as the conclusions of your assessment are stable. However, if you find with one assumption that product A has a higher load than B, and with a different assumption that product B has a higher load than product A, you need to report carefully the assumptions under which your conclusions are valid. You may also conclude that there is no single answer, as everything depends on the assumptions.

POSTFACE

In the Prosuite project, we have worked towards a life-cycle based method for full sustainability assessment. Making use of the rigorous and well-established approaches in environmental life-cycle analysis, our multidisciplinary team developed a full framework for sustainability assessment, primarily for prospective technologies, but probably also useful for sustainability assessment of regular products and services. At the end of our project we can review what has been done, but also the useful research paths that certainly remain open today.

In our approach, we recommend that the traditional breakdown of sustainability into the three pillars social, economic and environmental be adapted into a set of precisely defined impact categories. We have chosen Human Health, Social Well-being, Prosperity, Natural Environment and Exhaustible Resources as the five major impact categories. To our knowledge, they cover all relevant impacts, while at the same time they are well separated.

When developing the assessment methods which are integrated into our DSS, we were able in the case of certain impact categories to rely largely on mature concepts and tools of environmental life-cycle analysis. Incremental improvements of course are necessary and in some cases we provided these. For Human Health we have added Occupational Health as a contributor. At the end of our project we view that this category should benefit from even further development, to include other health impacts, e.g. to the consumer.

Similarly, for the impacts on Prosperity, we could draw to a large extent on existing methods in economic analysis, notably input-output analysis. Future developments might do well to focus on methodologies to assess the prosperity impact of products that open completely new markets.

As far as the impacts on Social Well-being are concerned, we must acknowledge that we are still in an early stage in terms of quantitative analysis. In Prosuite we were able to quantify some of the impacts, but rigorous aggregation to a full

Social Well-being indicator still needs reflection, testing and research. Today's practitioners must take into account that with respect to social well-being impact analysis we stand where environmental life-cycle analysis stood two decades ago. There is a particular need to find suitable measures of the impact that social interventions may produce in regard to the well-being of individuals.

In the analysis of Social Well-being and Occupational Health, we made use of the results of economic input-output analysis. Further integration of life-cycle analysis methods across impact categories could be possible.

Prosuite also sought to provide an integration of the five impact categories. We developed the first set of comprehensive normalisation factors. The underlying basis is reported transparently. This will very likely be pursued as an area for further investigation, as will that of overall integration methods. We provide sets of weighting factors, based on limited panel variety. Acknowledging that weighting of impacts will always remain a matter of preferences, it is nevertheless useful to investigate how preferences vary, e.g. across world regions, social classes and political preferences.

All the work presented in our handbook is condensed in a Decision Support System. This system is open source and that must be considered as an invitation to keep on developing it towards a broadly accepted and widely used analytic tool for sustainability assessment.

ANNEX 1
PARTNERS AND PARTICIPANTS

A: Partners' logos

B: Contact

Please visit our website www.prosuite.org to learn more about our team and obtain contact details.

For questions about the project you can contact:

Andrea Ramírez
Utrecht University
phone: +31 30 253 7639 e-mail: c.a.ramirez@uu.nl

C: Project participants

Name of consortium partner	Abbr. partner	Country	First Name	Last Name
Utrecht University	UU	Netherlands	Kornelis	Blok
			Mirjam	Harmelink
			Martin	Patel
			Andrea	Ramirez
			Wouter	Schakel
			Mark	Sanders
			Lex	Roes
			Berthe	van Haaster
			Deepak	Rai
			Luis	Apatalis
			Marielle	Corsten
Norwegian University of Science and Technology	NTNU	Norway	Edgar	Hertwich
			Richard	Wood
			Anders H	Stromman
			Tuva	Grytli
			Carmen	Moles
Technical University of Denmark	DTU	Denmark	Michael Zwicky	Hauschild
			Arne	Wangel
			Yan	Dong
			Alexis	Laurent
			Louise Camilla	Dreyer
Dialogik	Dialogik	Germany	Ortwin	Renn
			Piet	Sellke
			Regina	Schroeter
			Rainer	Kuhn
New University of Lisbon (FFCT)	FFCT/UNL	Portugal	Paula	Antunes
			Rui	Santos
			Nuno	Videira
			Ines	Cosme
Swiss Federal Institute of Technology Zurich	ETH	Switzerland	Stefanie	Hellweg
			Tobias	Walser
			Stephan	Pfister
			Annette	Koehler
Institut Symlog	SYMLOG	France	Claire	Mays
			Nina	Schneider
Finnish Environment Institute	SYKE	Finland	Jyri	Seppala
			Petrus	Kautto
			Sirkke	Koskela
			Tuomas	Mattila
			Jáchym	Judl
Ghent University	UGent	Belgium	Jo	Dewulf
			Steven	DeMeester
			Rodrigo	Alvarenga

International Institute for Applied Systems Analysis	IIASA	Austria	Joanne Michael Sylvain Florian Marijn Wolf Heinrich Sabine	Bayer Obersteiner Leduc Kraxner van der Velde Reuter Fuss
Hungarian Academy of Sciences Institute of Sociology	MTA SZKI	Hungary	Anna Zoltan	Vàri Ferencz
Universitat Autònoma de Barcelona	UAB	Spain	Gara	Villalba
Universitat Autònoma de Barcelona/INSEAD	UAB/INSEAD	Spain/France	Robert Laura	Ayres Talens
Pré Consultants	PRE	Netherlands	Mark João Anne Ellen	Goedkoop Fontes Gaasbeek Meijer
GreenDelta	GD	Germany	Andreas Imo Sebastian	Ciroth Graf Greve
FORTH	FORTH	Greece	Costas John	Galiotis Pathen
Solvin	Solvin	Belgium	Zdenek Michel Jacques	Hruska Bande de Gerlache
Organic Waste Systems	OWS	Belgium	Bruno Steven Aline Andt	De Wilde Verstichel Vercruyssen Peene
Nokia	Nokia	Finland	Arja	Mehtala
HeiQ Materials AG	HeiQ	Switzerland	Murray	Height
Paul Scherrer Institut	PSI	Switzerland	Christian Mohamed	Ludweg Tarik
Sony Ericsson	Sony Ericsson	Sweden	Emma Ellinor Pontus	Kimfalk Nilsson Alexandersson
DSM	DSM	Netherlands	Ad Armin	Hofland Michel
Radboud University Nijmegen	RU	Netherlands	Mark Rosalie	Huijbregts Van Zelm
Hybrid Plastics Inc.	Hybrid	USA	Joe Carl	Lichtenhan Hagstrom

D: Advisory Board

Organization	Country	First Name	Last Name
CEFIC AISBL (European Chemical Industry Council)	Belgium	Gernot	Klotz
IEEP	Belgium	Doreen	Fedrigo
Natural Resources	Canada	Maria	Wellisch
Finnish Institute of Occupational Health	Finland	Kai	Savolainen
Commissariat à L'Energie Atomique (CEA)	France	Frédéric	Schuster
Evonik Rexim S.A.S	France	Andreas	Karau
International Energy Agency (IEA)	France	Paolo	Frankl
OECD Science, Technology and Industry Division	France	Alexandre	Bartsev
European Bioplastics	Germany	Harald	Käb
ENEA / CALCAS project	Italy	Paolo	Masoni
Joint Research Centre (JRC) Ispra	Italy	Giuseppe David	Munda Pennington
Rio Tinto	Switzerland	Jürg	Gerber
United Nations Environment Programme (UNEP)	UN	Surya	Chandak
Manchester University	United Kingdom	Adisa	Azapagic
Unilever Safety and Environment Assurance Centre	United Kingdom	Llorenç Tony	Milà i Canals Saunders
U.S. Environmental Protection Agency (EPA)	USA	Alan	Hecht
Rio Tinto	Switzerland	Jürg	Gerber
Special thanks			
European Commission DGENTR	Belgium	Achim	Boenke
European Commission DG Environment		Michele	Galatola
European Commission DG Reseach and Innovation		Vincenzo	Gente

ANNEX 2
DECISION SUPPORT SYSTEM (DSS)

The decision support system is developed on the existing basis of openLCA. OpenLCA is a open source software originated and maintained by Prosuite partner GreenDelta. It can be freely downloaded from the openLCA website. To make the DSS operational for the five-impact category sustainability assessment it is necessary to:

- Install the Prosuite openLCA Plugin which includes the input-output THEMIS database.
- Purchase if desired any pertinent database or transfer your existing license(s).

Below some advice on how to use openLCA is given. Detailed guidance on how to use openLCA can be found in its wiki documentation, as well as in the Prosuite DSS Framework implementation guidance.

The first step is to create a database and then import your database and THEMIS Input-Output database. The micro assessment or SCENT tool although developed in the context of Prosuite is separate from the Prosuite assessment. This is because it is optional to use the SCENT tool for the micro assessment; the micro analysis can also be done manually. The output of the SCENT tool, when used, will be written into the SCENT Excel tool. The results then are read back into openLCA for the assessment.

To start the assessment, select Prosuite/Sustainability Assessment in the openLCA main menu. A dialog box to select a database will open. After selection of a database to work with, the sustainability assessment wizard opens.

On the first page you have to select the reference technology and the prospective technology to which you want to compare the reference technology and scope the region and timescale for each technology.

You can run a full 5-impact assessment in the DSS, but you can also select traditional Environmental, Economic, Social assessment and aggregation.

If Environmental Assessment is selected, it is recommended to use the Prosuite Endpoint impact method, since this impact method is specifically developed for Prosuite.

Now you can start modeling the life cycles of your reference and prospective technology. Typically you would start modeling with the most basic processes, for example 'Harvesting of cotton fibre'. This process can then serve as an input into the process above that, such as the 'Spinning of cotton yarn', which would in turn be an input into the process 'Weaving of cotton fabric'.

For many general processes, also called background processes, average data are already available in databases. These include data on, for example, transport emissions and electricity use, such as the emissions from electricity generation in France. Using these existing databases or background data saves a lot of time that otherwise would be spent on collecting such data.

Processes and amounts that are specific for the life cycles under study, also called foreground processes, still require actual data collection. The prospective technology and product in particular will consist largely of foreground data, but some data collection will also be required such as production costs, transport distances and the amount of energy drawn for the reference technology and product. Every major impact category requires different foreground data, specified in the respective chapters.

The method translates the life cycle inventory into the impact on each of the five major impact categories and combines these impacts into a single result. The inputs for the DSS are different for each category and are described in the respective handbook chapters. Further guidance on how to get the inputs can be found in the Prosuite library as *Prosuite DSS Assessment Framework - Implementation of Modules*.

ANNEX 3
PEDIGREE MATRIXES

A: Pedigree matrix

Indicator score	1	2	3	4	5 (default)
Reliability	Verified[5] data based on measurements[6]	Verified data partly based on assumptions ***or*** non-verified data based on measurements	Non-verified data partly based on qualified estimates	Qualified estimate (e.g. by industrial expert)	Non-qualified estimate
Completeness	Representative data from all sites relevant for the market considered, over an adequate period to even out normal fluctuations	Representative data from >50% of the sites relevant for the market considered, over an adequate period to even out normal fluctuations	Representative data from only some sites (<<50%) relevant for the market considered ***or*** >50% of sites but from shorter periods	Representative data from only one site relevant for the market considered ***or*** some sites but from shorter periods	Representativeness unknown or data from a small number of sites ***and*** from shorter periods
Temporal correlation	Less than 3 years of difference to the time period of the dataset	Less than 6 years of difference to the time period of the dataset	Less than 10 years of difference to the time period of the dataset	Less than 15 years of difference to the time period of the dataset	Age of data unknown or more than 15 years of difference to the time period of the dataset
Geographical correlation	Data from area under study	Average data from larger area in which the area under study is included	Data from area with similar production conditions	Data from area with slightly similar production conditions	Data from unknown ***or*** distinctly different area (North America instead of Middle East, OECD-Europe instead of Russia)
Further technological correlation	Data from enterprises, processes and materials under study	Data from processes and materials under study (i.e. identical technology) but from different enterprises	Data from processes and materials under study but from different technology	Data on related processes or materials	Data on related processes on laboratory scale ***or*** from different technology

B: Modified pedigree matrix for site-specific social data

Score / Indicator	1	2	3	4	5
Reliability	Verified data from primary data collection	Verified data partly based on assumptions or non-verified data based on primary data collection	Non-verified data partly based on assumptions or data based on grey, but scientific documents	Qualified estimate (e.g. by expert) or data based on non-scientific documents	Non-qualified estimate or unknown origin
Completeness	Representative data for organisation and site under study	Data from more than 75% of all individuals within the estimated sample	Data from more than 50% of all individuals within the estimated sample	Data from more than 25% of all individuals within the estimated sample	Data from less than 25% of all individuals within the estimated sample
Temporal correlation	Less than 1 year of difference to the time period of the dataset	Less than 2 years of difference to the time period of the dataset	Less than 3 years of difference to the time period of the dataset	Less than 5 years of difference to the time period of the dataset	Age of data unknown or data with more than 5 years of difference to the time period of the dataset
Geographical correlation	Data from organization and site under study	Average data from several sites of the organization in the same region in which the site under study is included	Data from other sites within the same organisation and region with similar production conditions	Data from sites from other organizations in the same region with similar production conditions or regional average sector data	Data from unknown or distinctly different organisations, sites and regions

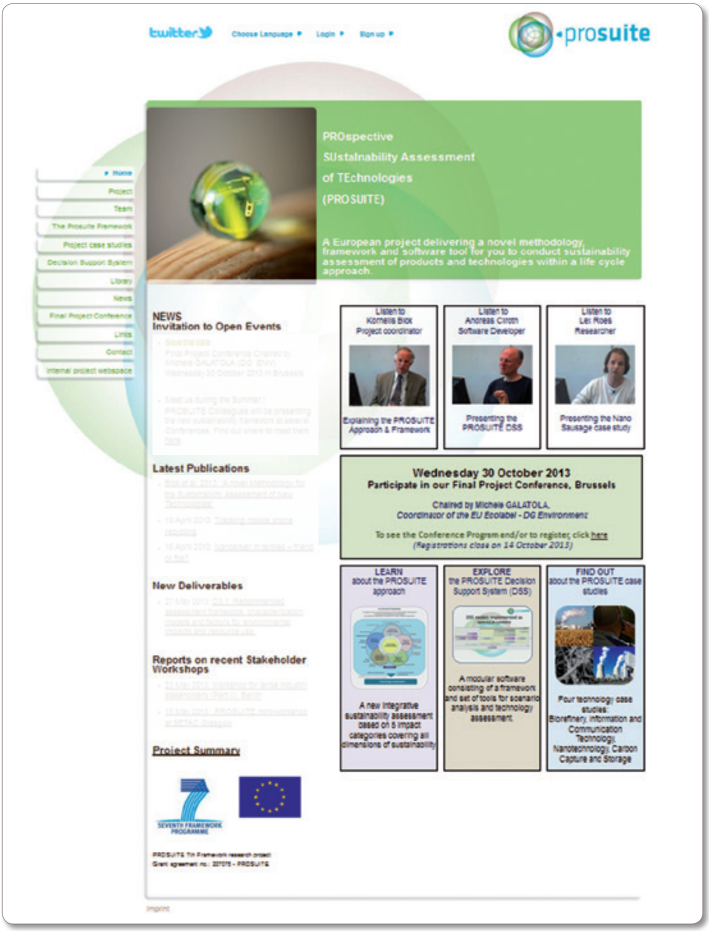
C: Modified pedigree matrix for sector-specific social data

Indicator \ Score	1	2	3	4	5
Reliability	Verified data from primary data collection	Verified data partly based on assumptions or non-verified data based on primary data collection	Non-verified data partly based on assumptions or data based on grey, but scientific documents	Qualified estimate (e.g. by expert) or data based on non-scientific documents	Non-qualified estimate or unknown origin
Completeness	Representative data for organisation and site under study	Data from more than 75% of all individuals within the estimated sample	Data from more than 50% of all individuals within the estimated sample	Data from more than 25% of all individuals within the estimated sample	Data from less than 25% of all individuals within the estimated sample
Temporal correlation	Less than 1 year of difference to the time period of the dataset	Less than 2 years of difference to the time period of the dataset	Less than 3 years of difference to the time period of the dataset	Less than 5 years of difference to the time period of the dataset	Age of data unknown or data with more than 5 years of difference to the time period of the dataset
Geographical correlation	Data from organization and site under study	Average data from several sites of the organization in the same region in which the site under study is included	Data from other sites within the same organisation and region with similar production conditions	Data from sites from other organizations in the same region with similar production conditions or regional average sector data	Data from unknown or distinctly different organisations, sites and regions

D: Pedigree matrix with 5 quality indicators for cost data

Indicator score	1	2	3	4	5
Reliability of source	Verified data based on measurements	Verified data partly based on assumptions or non-verified data based on measurements	Non-verified data partly based on assumptions.	Qualified estimate (e.g. by industrial expert)	Non-qualified estimate or unknown origin
Completeness	Representative data from a sufficient sample of sites over an adequate period to even out normal fluctuations	Representative data from a smaller number of sites but for adequate periods	Representative data from an adequate number of sites but from shorter periods	Representative data but from a smaller number of sites and shorter periods or incomplete data from an adequate number of sites and periods	Representativeness unknown or incomplete data from a smaller number of sites and/or from shorter periods
Temporal differences	Less than 0.5 years of difference to year of study	Less than 2 years difference	Less than 4 years difference	Less than 8 years difference	Age of data unknown or more than 8 years of difference
Geographical differences	Data from area under study, **same currency**	Average data from larger area in which the area under study is included, **same currency**	Data from area with slightly **similar cost conditions, same currency, or with similar cost conditions, and similar currency**	Data from area **with slightly similar cost conditions, different currency**	Data from unknown area or area with very **different cost conditions**
Further technological differences	Data from enterprises, processes, and materials under study	Data from processes and materials under study from different enterprises, **similar accounting systems**	Data from processes and materials under study but from different technology, **and/or different accounting systems**	Data on related processes or materials but same technology	Data on related processes or materials but different technology

ANNEX 4
LIST OF FIGURES, TABLES AND ILLUSTRATIONS


twitter
Choose Language
Login
Sign up
prosuite
PROspective
SUstainability Assessment
of TEchnologies
(PROSUITE)
A European project delivering a novel methodology, framework and software tool for you to conduct sustainability assessment of products and technologies within a life cycle approach.
Home
Project
Team
The Prosuite Framework
Project case studies
Decision Support System
Library
News
Final Project Conference
Links
Contact
Internal project webspace
NEWS
Invitation to Open Events
Latest Publications
New Deliverables
Reports on recent Stakeholder Workshops
Project Summary
Listen to
Kornelis Blok
Project coordinator
Explaining the PROSUITE Approach & Framework
Listen to
Andreas Ciroth
Software Developer
Presenting the PROSUITE DSS
Listen to
Lei Roes
Researcher
Presenting the Nano Sausage case study
Wednesday 30 October 2013
Participate in our Final Project Conference, Brussels
Chaired by Michele GALATOLA,
Coordinator of the EU Ecolabel - DG Environment
To see the Conference Program and/or to register, click here
(Registrations close on 14 October 2013)
LEARN
about the PROSUITE approach
A new integrative sustainability assessment based on 5 impact categories covering all dimensions of sustainability
EXPLORE
the PROSUITE Decision Support System (DSS)
A modular software consisting of a framework and set of tools for scenario analysis and technology assessment.
FIND OUT
about the PROSUITE case studies
Four technology case studies:
Biorefinery, Information and Communication Technology, Nanotechnology, Carbon Capture and Storage
SEVENTH FRAMEWORK PROGRAMME
Imprint


HUMAN HEALTH
SOCIAL WELL-BEING
PROSPERITY
NATURAL ENVIRONMENT
EXHAUSTIBLE RESOURCES