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Analysis and Strategic Management of Nano-products with Regard to their Sustainability Potential

Nano-Sustainability Check

- Final report -

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Analysis and Strategic Management of Nanoproducts with Regard to their Sustainability Potential

Nano-Sustainability Check

Final report - Sponsored by the Federal Ministry for the Environment, Environmental Protection and Nuclear Safety

by

Martin Möller, Rita Groß, Katja Moch, Siddharth Prakash
Öko-Institut e.V., Freiburg Office , Freiburg, Germany

Andreas Hermann
Öko-Institut e.V., Berlin Office , Berlin, Germany

Dr. Christoph Pistner, Peter Küppers, Angelika Spieth-Achtnich
Öko-Institut e.V., Darmstadt Office , Darmstadt, Germany

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Geschäftsstelle Freiburg
Merzhauser Straße 173
79100 Freiburg

Büro Darmstadt
Rheinstraße 95
64295 Darmstadt

Büro Berlin
Schicklerstr. 5-7
10179 Berlin

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Wörlitzer Platz 1
06844 Dessau-Roßlau
Germany
Phone: +49-340-2103-0
Fax: +49-340-2103 2285
Email: info@umweltbundesamt.de
Internet: http://www.umweltbundesamt.de
http://fuer-mensch-und-umwelt.de/

Edited by: Section III 2.1 General Aspects, Chemical Industry, Combustion Plants
Dr. Wolfgang Dubbert

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1 Executive Summary

As part of the current debate on the opportunities and risks of nanotechnological applications, the debate on possible contributions to sustainable development is becoming increasingly controversial. It should rather be conducted on a more objective level. This objectification, however, can only be achieved on a case-specific basis, performing – as quantitatively as possible – a risk-and-benefit analysis targeted towards the total life-cycle. The methodological basis for such a systemic view, however, is still largely lacking.

Against this background, the Öko-Institut, with the Nano-Sustainability Check, provides an instrument offering a systematic grid for an integrated approach relative to sustainability aspects of nanotechnological applications. The approach chosen allows the Nano-Sustainability Check to serve as a strategic radar system for the management of opportunities and threats, in order to be able, for example, to anticipate beneficial effects for the environment and to identify new markets on the one hand, and on the other to strive to avoid bad investments and dangers to the society.

With the help of the Nano-Sustainability Check, companies that develop or produce nanotechnological products and applications can carry out a self-evaluation of their own business activities.

The aim of the Nano-Sustainability Check is to examine the sustainability of products and applications involving nanomaterials in terms of their practical advantages. The most important feature in this context is an evaluation grid by means of which nanoproducts (i.e. products that are produced with nanomaterials) can be analysed by comparison with an existing reference product that has been manufactured without the use of nanomaterials. In addition, the evaluation grid is able to address any possible threats.

In terms of methodology, the Nano-Sustainability Check is based on PROSA (Product Sustainability Assessment), a tool for strategic analysis and assessment of product portfolios, products and services which has been developed by the Öko-Institut. PROSA takes into account the entire life cycle and analyses and assesses the environmental, economic and social opportunities and risks of future development paths. With its underlying integrated view, PROSA helps to identify system innovations and options for action in line with a sustainable development, and structures the decision-making processes necessary to this end.

The aspects investigated within the Nano-Sustainability Check are represented in the form of a total of 14 key performance indicators. The focus is on aspects of environmental and climate protection, which are – as far as possible – considered from a quantitative point of view. In addition, questions relating to the fields of occupational safety and health are examined, as well as benefit and socio-economic aspects. Due to the complexity of the issue, in many cases only a qualitative assessment is possible with view to these aspects. Even in such cases, however, the use of specifically formulated criteria and key questions enables a transformation of the qualitative approach into a semi-quantitative, comparative assessment between nano- and reference products.

The results of the individual key performance indicators are combined into a single representation. To this purpose, the "SWOT analysis" originally derived from business administration is taken up and adapted for the purposes of the Nano-Sustainability Check. The established tool of strategic management combines an inward-looking strength / weakness analysis with an opportunity / threats analysis which is related to environmental factors.

In the framework of the Nano-Sustainability Check, the strength / weakness analysis refers to the intrinsic properties and potentials of the product, for example in terms of the product carbon footprint, user benefits and life-cycle costs. Complementarily, the opportunity / threat analysis takes into account external conditions such as employment effects, societal benefits and risk perception. When comparing nano- and reference product, each individual key indicator is assigned to one of these two levels. If, for example, the nanoproduct as compared to the reference product performs better in terms of the product carbon footprint, this key performance indicator constitutes a strength. If, however, the employment effect is lower than that of the reference product, there is a threat according to this key performance indicator. If the indicator is on par with both products, it is regarded to be indifferent and is reported separately. In this way, a "SWOT matrix" is created as a central tool in the communication of results. A more extensive aggregation of the results, as through a one-point assessment, will not take place, as this would involve an excessive loss of information.

Based on the SWOT matrix, recommendations for a strategic optimisation of the investigated application can finally be developed. Their goal is to maximise the positive potential of strengths and opportunities with regard to sustainability while minimising potential negative effects of weaknesses and threats.

Besides the description of the methodical approach, this report contains the results of two case studies in which the Nano-Sustainability Check was first applied as part of a pilot survey. These cases concerned a surface coating of glass with high UV protection (pro.Glass® Barrier 401 by Nanogate Industrial Solutions GmbH) and a concrete catalyst (X-SEED® by BASF SE).

Based on these case studies, it could be shown that the Nano-Sustainably Check allows for a differentiated consideration of sustainability aspects when comparing a nanoproduct to a reference product. Although in both cases, the products under consideration were still in the phase of market introduction, the data required for the key indicators could be determined. The case studies also show that nanoproducts with significant leverage effects in the CO_2 savings potential are currently under development. Both large companies such as BASF as well as small and medium businesses like Nanogate are thus provided with a development-accompanying tool that enables them to quantify and systematically harness the existing potentials of nanotechnological applications. Moreover, knowledge gaps and risks, where they exist, can be identified at an early stage, and appropriate problem solving strategies be developed. The Nano-Sustainability Check offers users the facility of an early warning system and thus provides an important indication as to what direction should be taken in the innovation process of nanoproducts.

2 Introduction

Since nanotechnologies nowadays are referred to as belonging to the future technologies, they give rise to high hopes. In many industrial fields of application, nanomaterials are hence depicted as being the key to innovative product development. Having been produced in a controlled manner, such materials in some cases may generate completely new functionalities and properties which can be used to develop new materials as well as industrial and semi-finished products. The wide range of applications emerging from these technologies open up new paths, in particular with regard to new sales markets, medical progress and the protection of environment and resources.

In view of the products already on the market, however, a more sober picture emerges. Prominent examples, which are often discussed in public, are sunscreens containing titanium dioxide, pouring agents for powdered condiments or textiles supplied with anti-bacterial nano silver.

Yet, there are many other areas of applications or market trends in nanotechnologies in addition to those already mentioned, where significant contributions in addressing the challenges industrialised countries have to face with regard to their climate protection goals[1] might be expected. These primarily include applications in the fields of renewable energy generation, thermal insulation, energy storage, manufacture and building materials and industrial production processes. Initial promising applications or research and development efforts have already been undertaken in all these areas of technology. There are, for example, three different approaches in the area of renewable energies supplied by photovoltaic systems, by means of which the specific costs of this technology could be significantly reduced and thus its level of competitiveness be improved. Specifically, these are nano crystals of copper, indium, gallium and selenium (“CIGS”) which make it possible to manufacture solar modules in a highly efficient “roll to roll” coating process. In addition, cells are developed based on polymeric semiconductors, where fullerenes promote the intermolecular electron transfer. The third approach which has to be mentioned is the so-called “Graetzel cells” concept. These are ruthenium-based dye molecules which induce electron emission to titanium dioxide nanoparticles. The use of nanomaterials in the context of the three outlined development trends is the only means to achieve functionality and to reduce the consumption of resources, which, in turn, is a prerequisite for reducing costs. In the field of thermal insulation, aerogels which are already available as highly efficient nanoporous insulation material can be retrofitted and may thus particularly facilitate the refurbishment of old build-

[1] According to the research project “Modell Deutschland” (the German model) which has been carried out by Prognos AG, Öko-Institut and Dr. Hans-Joachim Ziesing on behalf of the WWF, the anthropogene global emissions have to be dramatically reduced with regard to limiting global warming to no more than 2°C above the pre-industrial level. For Germany, this requires reductions of 95 per cent up to the year 2050, which means a scant ton of greenhouse gas emissions per capita. 60% of these savings must be generated by technologic innovations, see http://www.oeko.de/aktuelles/dok/982.php

ings. In addition, research on (i.e. translucent) elements is being conducted with regard to the thermal insulation of windows. Depending on the degree of solar radiation, these elements unfold thermal insulation or power-generating properties. Furthermore, lithium-ion batteries which are currently being discussed as nanotechnological energy storage sytems for regeneratively produced power have to be emphasized. Finally, gas membranes made of new materials with carbon nanotubes can provide for an essential contribution to efficient CO_2 capture from industrial processes (such as steel production).

As we have seen, the present and especially the future range of applications of nanomaterials is very broad, however, as with the introduction of any new technology, their potential threats and undesired rebound effects have to be considered and weighed against the potential benefits. Due to their small size, nanoparticles can penetrate biological barriers such as cell membranes, which are impassable for larger objects. There is evidence that these special properties of nanomaterials on the one hand are the basis for a multitude of technological innovations, and thus also have various potentials for environmental relief, while on the other hand they may pose potential threats to humans and the environment if they accidentally penetrate the human body or are released diffusely and uncontrolled into the environment. On the basis of animal experiments, it could be shown that certain nanomaterials have a relevant toxicological hazard potential. Foremost among these genetic damage, organ damage and inflammations potentially inducing tumors have to be mentioned. Free nanoparticles which are not firmly embedded in a matrix and can therefore penetrate the human body via inhalation are considered to pose a particular risk to human health. From an ecotoxicological point of view, nanoscale titanium dioxide and zinc oxide, for example, are considered to be relevant, since testing on water fleas has shown the substances to be detrimenttal to the insects. Furthermore, in view of the increasing use of nano-silver, it cannot be excluded that beneficial bacteria present in the environment will be harmed, too.

The ecological and economic potential on the one hand and the still unresolved questions about the risks on the other hand result in tensions. In particular, many issues regarding the human-toxicological and ecotoxicological effects of nanomaterials are still unresolved and need to be addressed urgently. According to the precautionary principle, the entire life cycle of nanomaterials has to be investigated with a view to the potential risks to men and environment. This includes the whereabouts and possible release of nanoparticles at the end of the life cycle, in terms of waste recycling or disposal, for example. At the same time, there are an increasing number of new nanotechnology products and applications entering the market. In practice, however, the resolution of the outstanding risk-related issues is usually time- and cost-consuming, as these issues need to be discussed on the basis of sound scientific analysis. For this reason, current security research in the field of nanotechnology is systematically lagging behind product development. In addition to filling the remaining knowledge gaps in the field of security research, it will also be important to explore how the existing innovation potentials of the individual nanotechnological applications can contribute to sustainable development. To date, however, there are only very few case studies and comparative evaluations addressing this issue.

Against this background, a development-accompanying consideration of the relevant risk-related issues, but also of the anticipated opportunities in terms of a sustainable development, plays a crucial role. An integrated evaluation considering future opportunities and risks in the course of the research and development process of nanoproducts, however, cannot be a substitute for a meticulous assessment, particularly of risk aspects, under security research. Yet, an early consideration of sustainability issues may provide developers with valuable information on the actual contribution that can be made by the innovation potential of the individual nanotechnology applications to a sustainable development. Moreover, it should also be checked under which framework conditions the expected or suspected strengths can be achieved in practice and which risks and rebound effects have to be taken. According to the experiences gathered by the Öko-Institut, the establishment of innovations tends to be most successfully when the strategic technology assessment is carried out on a specific product during its development and when all relevant stakeholders are involved. Thus, leeways in the political and social environment can be utilised highly efficiently. Until now, however, appropriate guidance and indicators tailor-made for nanotechnological products and applications, allowing for a quantitative approach as comprehensive as possible, are still missing.

3 Goal Setting

The aim of the project is to develop a tool, the use of which allows us to evaluate sustainability aspects relating to nanotechnology products and applications by employing uniform criteria. In doing so, aspects of environmental and climate protection should be prioritised, assessing them quantitatively to the greatest possible extent. The focal point of the project is therefore the development of an analysis grid intended to evaluate nanotechnological products and applications in comparison with a non-nanotechnology reference product, thereby taking into account the entire life cycle. Besides the benefits provided for the environment and climate protection and the realization of opportunities with regard to sustainability aspects, the analysis grid should have the capability to adequately reflect any existing risks. The criteria used to determine these benefits and risks them can be implemented in the form of uniform key indicators, which may be both of a quantitative nature (with a view to CO_2e savings, for example) or, in the case of other aspects of utility (such as user benefits, symbolic benefits, societal benefits), of a semi-quantitative nature. Alternatively, arguments may be described verbally.

In this context, the "SWOT analysis", which originally is a business management approach, is borrowed and adapted accordingly. It is a tool of strategic management, which both considers internal strengths and weaknesses as well as external opportunities and threats.

The evaluation of the individual key indicators leads to an integrated overall view, on the basis of which recommendations for the strategic optimisation of the specific application can eventually be developed, these recommendations both relating to strengths and weaknesses and to opportunities and threats alike. In this respect the objectivel is to maximise positive sustainability potentials of strength and opportunities while minimising rebound effects that might occur due to weaknesses and threats.

In the scope of the project, the developed analysis grid should be applied to selected case studies on the basis of actual data in order to verify its practicality. In this context, it should also be specifically checked whether the tool is applicable to small and medium-sized enterprises (SMEs), the responsibility for data collection lying with the companies concerned. Yet, the Öko-Institut offers methodical assistance, thereby treating company secrets confidential.

Therefore, the results of the project are primarily intended for companies that, in the context of the development and marketing of nanoproducts, apply the Nano-Sustainability Check as a **self-evaluation tool** for the monitoring of nanoproducts in terms of their specific benefits for a sustainable development (“radar for sustainability”).

Furthermore, the project also aims at ministries and authorities, as the analysis grid itself as well as the results from the consideration of case studies may be used by government bodies and funding agencies to focus and realign funding or to adjust the legal framework.

The target group of the project last but not least consists of environmental and consumer protection associations, as well as the general public which is increasingly interested in quantifying the opportunities and threats of nanotechnology applications and products.

4 Preliminary Work and Methodological Approaches

In the following chapter, an overview is given on the relevant preparatory work and methodological approaches which were taken up and developed further in the framework of the project in order to achieve the objectives set out above. Foremost among these are the PROSA method of the Öko-Institut (see section 4.1), the SWOT analysis (see section 4.2) and the specific criteria of thematic group 2 of the nano dialogue (see section 4.3). Besides, in section 4.4 three further points of reference are presented in an overview.

4.1 PROSA

PROSA (Product Sustainability Assessment) is a method developed by the Öko-Institut for a strategic analysis and assessment of the sustainability potential of product portfolios, products and services (see Griesshammer et al. 2007, www.prosa.org). Compared to the traditional life-cycle assessment, PROSA particularly concentrates on the simultaneous analysis of social and economic aspects as well as on the consideration of various aspects of utility and consumer research.

The aim of the method is the identification of system innovations and options for appropriate action towards sustainable development. PROSA structures the necessary decision-making processes and thereby reduces the inherent complexity to the essentials.

PROSA spans complete product life cycles and value chains; it assesses and evaluates the environmental, economic and social opportunities and threats of future development trajectories, drawing upon already existing, well-established individual tools (mega-trend analysis, LCA, life-cycle costing, SLCA, et cetera) to the greatest possible extent.

Thanks to its open structure, PROSA can also be used to analyse sustainability at the level of technologies. In contrast to LCA and life-cycle costing, the benefits in PROSA will furthermore be analysed much more intensively, as they ultimately determine consumer acceptance, and because an assessment at higher ecological or social risks has to be reasoned and answered for in terms of product policy (see also the socio-economic benefit analysis in REACH or the Eco-Design Directive of the EU).

Against this background, the PROSA approach is also particularly suited for the development of a comparative study of nanotechnology products and applications, their contributions to sustainable development having been increasingly discussed in the current debate (cf. BMU NanoDialogue). To this purpose, a systematically structured integrated weighing up of opportunities and threats is required, for which, however, a common method is not available yet.

PROSA serves as a methodological basis for the Nano-Sustainability check, which provides the management with a strategic radar for opportunities and threats in order to identify future markets and new consumer needs, thus helping to avoid misinvestment and to be able to realise the opportunities associated with the development and introduction of nanotechnologies.

The chronological order of the PROSA procedure is oriented towards the typical stages of strategy finding processes and is structured by a so-called pathfinder (cf. figure 1).

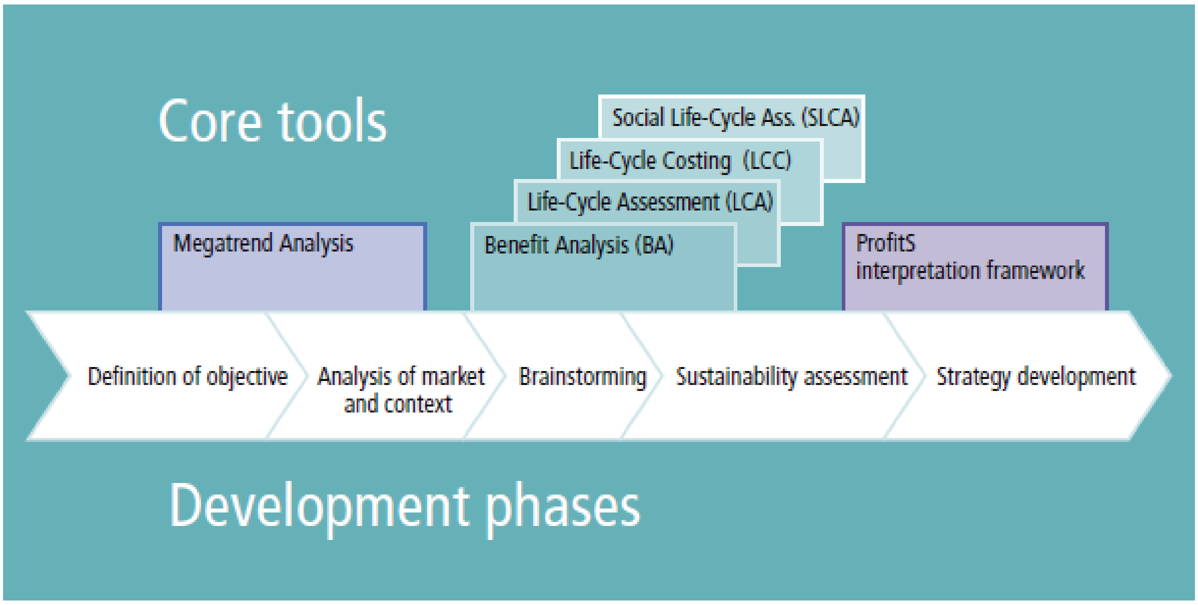

Figure 1: PROSA pathfinder (Griesshammer et al. 2007)

The pathfinder sets out the prototypical performance of PROSA. When used by companies, the company's own specific management tools, checklists or interpretation frameworks can be readily used. The performance of PROSA is process-led and iterative, while initial, orient-tative analyses are pursued in greater depth later on, new ideas or unexpected findings can change the course of the process or can cause previous phases to be reworked.

The major components of PROSA include

- The product portfolio sustainability analysis,
- Life-cycle costing (LCC)
- Life-cycle assessment (LCA),
- Social life-cycle assessment (SLCA) and the valuation model SocioGrade,
- Benefit analysis (BA) and the evaluation model BeneGrade as well as
- The integrated interpretation framework ProfitS

Thereby, PROSA resorts to a set of existing, well-established tools for individual dimensions. The tools are predominantly standard and elaborate tools that are usually applied in most large companies and in product policy, such as megatrend analysis, consumer research, or LCA. The three core tools that were newly developed for PROSA are the Social LCA, the benefit analysis (based on consumer research) and the assessment framework of ProfitS (Products fit to Sustainability).

As part of the Nano-Sustainability Check, products that have already been selected are to be analysed with view to their opportunities and threats. Hence, the tools on eco-efficiency analysis, life-cycle costing, social LCA and benefit analysis (BeneGrade) play a particularly crucial role.

The implementation of LCA is described in detail in the ISO standards 14040 and 14044 (ISO 14040, ISO 14044). The basic structure of LCA, with its four phases (goal and scope definition, inventory analysis, impact assessment; interpretation) and the basic methodological approach of LCA have been – as far as possible – directly adopted in the other core tools, i.e. life-cycle costing and social LCA; where this was not possible, they were adopted in a slightly modified way. Life-cycle Costing (LCC) is used to ascertain the relevant costs arising for one or more actors in relation to a product and its alternatives in the course of a product life cycle.

Another core tool used within PROSA is SLCA. In the course of implementation, care must be taken to coordinate the key parameters with LCA and Life-cycle Costing. Social aspects are investigated throughout the product life cycle and system, normally in comparison to some alternative. Stakeholders should be involved as far as possible. Lastly, the benefit analysis is used to analyse and evaluate the utility of products and services from the perspective of users or – where necessary – from the perspective of product policy. Users are predominantly private households and / or consumers, but may also be commercial users, the public administration or large organisations, such as churches. The benefit analysis is used to analyse – depending on the issue – user benefits, symbolic benefits and societal utility.

As regards the individual core tools within PROSA, breadth and depth of analysis may partly be significantly greater than those that can be realised in the context of the targeted self-evaluation of companies through a Nano-Sustainability Check. Therefore, an adaptation of inspection and evaluation depth is required. Furthermore, the various tools have to be adapted to the specific questions arising in the field of “nanotechnology”.

4.2 SWOT Analysis

The SWOT analysis is a formalised strategic planning tool for the evaluation of internal strengths and weaknesses and of external opportunities and threats in projects or business processes. SWOT is an acronym for “strengths”, “weaknesses”, “opportunities” and “threats”.

The roots of the SWOT analysis reach far back to the fifth century BC. Already at that time, the principles of an analysis that is based on both intrinsic and environmental factors were propagated in China in the context of strategic military planning (Grant 2000). The contemporary instrument for strategic planning in companies originates in the sixties and seventies of the past century. In this context, some sources mention a research project which was carried out by Albert Humphrey at Stanford University at that time with the aim to identify entrepreneurial planning errors (Morrison 2011). Humphrey coined the term "SOFT Analysis" (acronym for "satisfactory", "opportunity", "fault" and "threat"), which was taken up by Urick and Orr in 1964 and transferred into the acronym "SWOT" that is used to date. In addition, the concept of SWOT analysis was also introduced in the UK, where it was widely acknowledged by strategic planners and management consultants (Thakur 2010). Other sources, however, attribute the modern origins of the SWOT analysis to the Harvard Business School (Kotler et al. 2010; Friesner 2011).

From a methodological point of view, SWOT analysis is a comparatively simple instrument that does not require technical skills or extensive training. However, a comprehensive understanding of the characteristics and the present situation of the specific company and its business environment is required (Mehta 2000). The main idea of a SWOT analysis is to raise awareness for one's own strengths and weaknesses, for example in achieving a corporate target or in the development of a product, and also to carefully investigate the environment in terms of existing opportunities and threats[2]. In this context, the strengths show where a specific actor (e.g. a certain company) already has done a good job concerning processes or product development, while the weaknesses relate to procedures or aspects of product development that do not ultimately work so well in practice. Opportunities include all framework conditions that are potentially favourable to the investigated processes, whereas obstacles and bottlenecks that may possibly occur are addressed in the context of threats.

Based on this analysis on the current state, the company will then decide on which of the identified strengths and which opportunities are to be realised. Thus, SWOT analysis provides a basis for successfully implementing a project or schedule. It enables policymakers to develop strategies in order to effectively and efficiently achieve the desired results. This, however, presupposes that appropriate goals or final states have been defined.

A general guide for carrying out a SWOT analysis in a company does not exist. In practice, however, companies usually apply the following established approach:

1. Defining a clear objective or final state;
2. Exploring strengths and weaknesses in the framework of an internal corporate analysis;
3. Exploring the relevant opportunities and threats in an external "environmental analysis"[3];

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[2] It should be noted that the term "threats" has not to be understood as a result of the probability of occurence and the potential scale of damage (definition in engineering science and environmental sciences), but, according to the economics point of view, implies risks of business operations that may have a significant impact on the achievement of goals.

[3] The focus is not primarily on the natural environment, but rather on the socio-economic "environment" of the company. Hence, the term "environmental analysis" is commonly used.

4. Evaluation and consolidation of corporate and environmental analysis in order to maximise the benefits offered by the strengths and opportunities and minimise the losses associated with weaknesses and threats;
5. Consideration of the aspects that enable the achievement of goals;
6. Strategic planning taking into account the current findings.

Against this background, the approach recommended for the successful application of the SWOT method suggests to summarise the findings in the form of a matrix. A matrix can be presented in a variety of ways and may have different objectives.

One way to set priorities is the 2X2 matrix proposed by Weihrich (1982), which links the internal strengths and weaknesses with external opportunities and threats in order to derive strategic implications from this data. Thus, all identified aspects of the four categories can be brought together and viewed as an integrated whole (see table below):

Table 1: 2X2-matrix for the derivation of strategic implications (according to Weihrich 1982)

	Internal Strengths (maintain, reinforce and make effective use of them)	**Internal Weaknesses** (corrective action or exit)
Internal View (prioritise and optimise)	**Consideration of Combination of Strengths / Opportunities** obvious natural priorities	**Consideration of Combination of Weaknesses / Opportunities** potentially attractive options
External View (to counter-hold)	**Consideration of Combination of Strengths / Threats** easy to defend and counter	**Consideration of Combination of Weaknesses / Threats** potentially high risk

The bringing together of strengths and opportunities indicates how the inherent strengths can contribute to the realisation of existing opportunities. The combination of strengths and threats shows how strengths can be used to avoid or minimise external threats. The weaknesses-opportunities-relation may give a signal to seize external opportunities in order to address internal weaknesses, and the confrontation of weaknesses and threats provides evidence on which actions should be avoided.

Having increasingly gained in strategic importance to companies in the past few years, social environmental requirements must also be adequately reflected in strategy formulation. Hence Meffert and Kirchgeorg (1998) suggested that, depending on the “extent of exposure” to which the company is susceptible to environmental issues, strengths and weaknesses derived from the corporate analysis should be contrasted with opportunities and threats associated with ecological issues, in order to derive therefrom strategic decisions for environmental management (see table below):

Table 2: Example of a SWOT Matrix for the management of environmental issues (Meffert / Kirchgeorg 1998)

	Opportunities	**Threats**
Strengths	In contrast to competitors, company is in a position to translate its technical know-how to the market for environmentally protective goods. Extending the scope of activities.	Company addresses the inclusion of environmental criteria in the purchasing decision[4] by offering environmentally friendly products.
Weaknesses	New environmental laws offer new sales opportunities. Lack of management flexibility prevents timely market entry.	New scientific findings about the negative ecological effects of the product range cannot be considered due to insufficient funding.

A specific SWOT analysis is illustrated using a case study on the introduction of an ecological certification scheme for forestry in Finland. This case study was chosen because it is an interesting application of the SWOT method in an environmental initiative that has helped to clarify a number of partially conflicting factors.

In the late nineties of the twentieth century, the Finnish forestry sector considered the introduction of new certifications and eco-labels in order to increase its acceptance and competitiveness at an international level (Kurttila et al. 2000). The central question was whether to convert to a certified forestry or to stay with the conventional, quantity-based economy. To answer this question, external experts carried out a SWOT analysis, and then, in collaboration with the director of the forestry department, compiled a list of key factors for the new policy option of a certified forestry (see table below):

Table 3: Results of the SWOT analysis of the Runni Centre (according to Kurttila et al. 2000)

Strengths • Existing competencies for the development of a certification system • Lower dependence on wood products • Low “eco-costs” due to certification (thanks to favourable forestry structures)	**Opportunities** • Changing the consumption patterns (growing demand for certified wood) • Attaining premium prices for certified wood • Enhancing biodiversity in the natural environment
Weaknesses • Relatively small wooded areas available • Monotonous forests • Declining receipts of woodcut	**Threats** • Reducing profitability • Diminishing the usage possibilities • Negative image if certification system would be abandoned

Due to its applicability in the context of strategy and product development, the SWOT analysis is also particularly suitable for the comparison of strengths, weaknesses, opportunities and threats in the scope of the company's internal analysis of the sustainability connected

[4] In this context, the purchasing decision concerns the consumer’s choice.

with the company's own nanotechnology applications. Hence, on the basis of a SWOT analysis, it can be ascertained where the strengths of a nanoproduct lie and how appropriate solutions to social issues might be developed building on these strengths. At a case-specific level, an overview will additionally be provided on the potentially prevalent internal weaknesses and external threats, which may be balanced against the strengths and opportunities in an integrated approach. However, in practice there is the difficulty to identify all relevant threats and opportunities as part of an environmental analysis. In particular, this is not easy if the SWOT analysis begins at a relatively early stage in the development process and the assumptions made regarding the use phase and the stage after use are still associated with a considerable degree of uncertainty. Furthermore, it should be avoided to confuse the opportunities identified in the environmental analysis with intrinsic strengths. This is particularly likely if the products or product systems under consideration are neither sufficiently clearly defined nor there is sufficient clarity about the criteria and indicators used.

If the above-mentioned difficulties and challenges are observed, however, the methodology of SWOT analysis is considered an appropriate approach to create a basis for strategic planning in the company and for making decisions in regard to detailed questions (for example, concerning the selection of one nanomaterial out of a number of suitable nanomaterials) with a view to a self-evaluation during the development process. Separately recording and comparing strengths and weaknesses, opportunities and threats (cf. Table 2), the SWOT matrix as set out in the case study exemplified above, is the recommended form of presentation which enables a structured, yet transparent presentation of several indicators or criteria. This basis provides a good starting point to pinpoint, in a next step, strategic optimisation potentials by comparing the relevant indicators in the areas of strengths and weaknesses as well as opportunities and threats.

4.3 List of Criteria of Issue Group 2 of the NanoDialogue 2009-2011

In the NanoCommission's first dialogue phase (2006 to 2008), a number of nanoproducts were characterised according to their potential risks and benefits. As it was difficult to compare these descriptions and interpret the results, issue group 2 in the second dialogue phase (2009-2011) was assigned the task of developing a method that would allow the potential benefits and risks of nanoproducts to be systematically identified, transparently described and assessed. The assessment tool was to be designed so that a variety of user groups would be able to apply it, and at least two examples of products were to be used as test cases." (BMU 2011)

The key outcome of the work conducted by the stakeholder debate[5] in the framework of issue group 2 was a "guide for collecting data and comparing benefit and risk aspects of

[5] With the participation of Mr. Martin Moeller, the Öko-Institut was actively involved in the activities of the issue group.

nanoproducts". The guidelines are intended first and foremost to provide a framework for other case-specific stakeholder debates on potential benefits and risks of nanoproducts and to give a first orientation to the benefit and risk aspects of nanotechnological applications in question. These aspects, however, are not assessed against indicators or weighed up against each other, as this assessment should be left to more comprehensive tools (e.g. life-cycle assessment, regulatory risk evaluation) which may be used subsequent to the application of the guidelines. The original objective to produce an indicator-based methodical approach for the assessment of benefit and risk aspects, however, could not be reached. In addition to the methodological difficulties of developing objective, broadly applicable assessments of parameters, constraints on time and resources as well played a significant role in this target shortfall. With a view to the application of the guidelines, however, two interesting tools were drawn up by issue group 2, i.e. a so-called product profile and a list of criteria, which will be briefly presented in the following.

The product profile characterises the final product and the particular nanomaterial used to produce it. For this purpose, available data, such as the information provided by the security data sheet, is assembled by the manufacturer. Moreover, this document contains a definition of the reference product which does not contain nanomaterials with regard to the functionality in question and which is used as a basis of comparison for the analysis of benefit and risk aspects.[6]

The list of criteria which has been drawn up both provides criteria on benefit- as well as on risk-related aspects. Both lists of criteria are divided into five categories, i.e. "environment", "consumers", "workers", "society" and "company". In each category, up to another six different criteria are listed, some of which are further divided into subcriteria. This document which is available online in the form of an Excel file is not exhaustive, but rather represents various aspects identified as important by the stakeholders in the scope of issue group 2.

Within the five categories in the list of criteria for benefit-related aspects, a number of "core" criteria are listed prominently. Responding to these core criteria is mandatory for all users.

The core criteria are in detail (cf. BMU 2011):

<u>Benefits for the environment</u>

- Reduced resource use: energy
- Reduced resource use: water
- Reduced resource use: raw materials
- Prevention of greenhouse gas emissions
- Reduced emissions of pollutants

[6] Cf. final report of issue group 2 of the NanoCommission, Guidelines for Collecting Data and Comparing Benefit and Risk Aspects of Nanoproducts, available online at: http://www.bmu.de/files/english/pdf/application/pdf/nano_finalreport2_bf.pdf

- Reduced waste volume and hazard

Benefits for consumers

- Products with improved functionality
- Products with improved safety in use (including protection from disease)
- Consumers benefit from improved cost-benefit ratio for products

Benefits for workers

- Advantages resulting from simpler of safer handling
- Health protection in the workplace (risk management)

Benefits for society

- Lower costs for protecting health and the environment
- New skilled job opportunities, job security
- Better product performance; improved export opportunities, improved market position and competitive edge

Benefits for companies

- Creation of new markets, enhanced competitiveness
- Improved product quality and performance
- Reduced costs, e.g. by optimising production processes
- Raised work and process safety

The guidelines developed are structured and documented in a way so that they can be used by different user or stakeholder groups. These are (BMU 2011):

- Companies / product development: for preliminary assessment of benefit and risk aspects of new products
- Companies / marketing: for transparent communication of the benefit and risk aspects of nanoproducts
- Public authorities: for assessing products for compliance checking or licensing purposes, and for the granting of funding for research and development projects
- NGOs: as a basis for making positive or negative recommendations regarding nanoproducts and for communicating with companies, public authorities, the media and the general public.

The criteria developed were tested using five example products while the guidelines were being developed. These examples included products already on the market such as glass cleaning products, PET bottles, awning fabrics, products in development (textile cleaning) and materials in the very early stages of development (wind turbine rotor blades made from CNT containing materials). Only in two of the five example cases it was possible to fully apply the list of criteria developed by issue group 2 and to work through in full the results for publication. These were awning fabric incorporating nanomaterial and PET bottles with nano-scale titanium nitride. The practise application of the tool showed that in principle the list of criteria is an appropriate means of obtaining a qualitative or overview-like comparison of benefit- and risk-related aspects. Hence it was possible within a reasonable timeframe to obtain relatively comprehensive, conclusive and clear statements on the underlying criteria. However, the final report of the NanoCommission's issue group 2 also pointed out that the achieved results could only be "a first step in assessing the potential benefits and risks of nanoproducts" … and "need to be more thoroughly tested and, if possible, quantified". Furthermore, it is recommended to integrate the results of the project "Sustainability Check for Nanoproducts" into the guidelines or to use the guidelines as a "preliminary step" for the Nano-Sustainability Check (BMU 2011).

4.4 Further Preliminary Work

Studies on sustainability aspects of nanotechnologies which have already been commissioned by the German Federal Environment Agency (UBA) in the past were identified as further relevant preliminary work. Other important approaches to be linked with the methodical procedure concerning the Nano-Sustainability Check are the Swiss precautionary matrix and the self-evaluation tool "NanoMeter". These preliminary works are introduced in the following subsections.

4.4.1 Studies on Sustainability Aspects of Nanotechnologies Commissioned by the Federal Environment Agency (UBA)

In 2009, two studies on the relevance of nanotechnologies for the area of environmental protection / pollution were completed, having been commissioned by the Federal Environment Agency (UBA).

In the study "Environmental Relief Effects of Nanotechnological Processes and Products" (Steinfeld 2010), the environmental and sustainability opportunities and risks associated with nanotechnologies were to be identified and – as far as possible – quantified. Environmental relief potentials were understood here to include not only environmental engineering in the narrower sense, but also and specifically relief potentials based on improvement in the general production processes due to nanotechnological methods. To this end, a screening of nanotechnological applications was carried out first. With respect to essential potentials for environmental relief, but also, as the case may be, to unintended environmental burdens, an initial qualitative assessment was performed in a second step building on the screening. Then, an in-depth life-cycle analysis and assessment of selected processes or products was carried out on the basis of four example cases. Finally, an appraisal of employment potentials was conducted supplemental to the environmental assessment.

For the assessment of environmental relief effects within the scope of the in-depth analysis, a life-cycle approach was initially taken, whereby various methodical problems associated with a comprehensive assessment of newly emerging nanotech processes and products were already identified. The modelling was carried out by means of the LCA software Umberto, based on the method of the Institute of Environmental Sciences of Leiden University (CML), the major impact categories encompassing abiotic resource use, the greenhouse effect, acidification, eutrophication (overfertilisation), ozone depletion and the formation of photochemical oxidants (summer smog). In addition to this methodology, specific risk aspects of dealing with nanomaterials were addressed within the framework of a 'concern analysis' utilising specific relief and concern criteria established by the 'Risks and Safety Research' Work Group within the framework of the German NanoCommission, under the direction of the Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety.

The case examples under investigation were:

- the manufacture of solderable surface finishes on printed circuit boards,
- carbon nanotube applications for foils in the semiconductor industry,
- lithium-ion batteries for energy storage
- modification of processing properties of polybutylene terephthalate (PBT) plastics

Overall, it was concluded that nanotech applications neither intrinsically nor exclusively can be associated with the potential for a large degree of environmental relief. Nevertheless, for the majority of the application contexts, potentials for more or less significant environmental relief could be ascertained using the chosen methodology based on a comparative assessment of functionalities.

For the manufacture of solderable surface finishes by means of a nanotechnical process, the latter performed four to twenty times better than the equivalent conventional processes in all environmental effect categories. When compared to certain processes, the values even decreased by a factor of up to 390. The concern analysis conducted to accompany the LCA revealed a minimal level of concern for the nanotech process. By contrast, saving potentials achieved for nanotube applications were lower, ranging in the two-digit percent region. These savings are even counteracted by evidence for concern in the area of 'free' carbon nanotubes. As for the use of lithium-ion batteries in public transport, no breakthrough was anticipated to take place on the basis of existing technologies. Only the future variant model demonstrated a difference in environmental impact which was 20% less than the conventional diesel city bus. This case study, however, illustrates the high degree of uncertainty related to the quantitative assessment of those technologies that are still in development. In the fourth case study, energy savings of approx. 9% were achieved by improvements in the manufacturing process of technical plastics. This saving also led to a number of corresponding improvements in other environmental aspects.

As a result of the final examination of employment effects carried out for nanotechnologies, it was found that nanotechnology firms have positive expectations for development. This, however, would not necessarily involve the creation of new jobs. Due to the characteristics of nanotechnologies being classified as an "enabling technology"[7], the improvement of competitiveness and thus a preservation or a strengthening of already existing employment relationships is more likely than new independent "nano-jobs" that are expected to be created only to a limited extent.

The study "Applications of Nanomaterials in Environmental Protection" [Martens 2010] aimed at a qualitative and, if possible, quantitative presentation of benefits and risks of nanotechnological products and procedures in the area of environmental protection, focussing on the water and air sectors. As a first step, an inventory analysis on research and development approaches and of products already on the market was carried out in the scope of the study. On this basis, an LCA was made to review two case studies – the solar treatment of water contaminated with tetrachloroethylene and a combination filter for passenger cars.

As part of the stocktaking process, approaches for filtration / separation, the functionalisation of surfaces, the sorption of nanocatalysts and nanoreagents were identified as important technological fields for the water sector. Technologies already being applied were exemplified in particular by nanotechnological products in drinking and waste water treatment and groundwater remediation. Apart from the technological fields of filtration / separation and nanocatalysts, especially automotive catalytic converters were considered for the air sector.

Areas specified as nanotechnological products which are already applicable today were automotive catalyst converters, air filters and applications for the removal of air pollutants. On the whole, a selection of nearly forty German companies with products / procedures in the field of nanotechnology and environment was identified.

Subsequent to the stocktaking, in accordance with ISO 14040 and 14044, an LCA was carried out for two specific products, in order to obtain an assessment of the benefits and risks associated with nanotechnological products and processes in the field of environmental protection. In a first phase, the material inventories were investigated throughout the life cycle of a product. Afterwards, potential environmental impacts were determined by allocating the life-cycle inventories to the major impact categories and calculating aggregated values for these categories. In a final phase, the insights gained were discussed and evaluated in terms of the natural resources "Impact on human health", "Ecosystem quality" and

[7] A "(key) enabling technology" is a technology which is connected with high research and development expenses, rapid innovation cycles and a high level of capital investment. A key technology enables innovations in procedures, goods or services in all economic areas and is thus relevant at system level (cf. EU Commission 2009).

"Resources", mainly on the basis of the Eco-indicator 99 assessment method, but also by means of the CML method.

Case study 1 investigated the purification of water contaminated with tetrachloroethylene by a semi-conductor photo-catalysis procedure using nanoscale titanium dioxide in comparison with a conventional photo-Fenton process using ferrous compounds with hydrogen peroxide. The analysis concentrated on material and energy requirements as well as on the chemicals used with consideration of the upstream chains. While, in a (small) batch system, for both approaches the environmental impact under the different impact categories was of approximately equal height, there is evidence for a shift in the impact categories after many years of continuous application. For long-term operation, under the given boundary conditions, resource consumption dominates the overall assessment for the production of nanoscale titanium dioxide, the nanotechnological process thus having a higher environmental impact than the conventional procedure.

In case study 2, the supply air filtration of a passenger car using a nanofiber-coated filter was compared with a conventional combination filter. The analysis focused on production and the use phase. For only one filter, only extremely small differences were found in terms of fuel savings potential and a corresponding reduction in CO_2 emissions. Due to potential scaling effects (high number of substitutable passenger car filters), a savings effect that is likely to be relevant was nevertheless identified as a result of the nanotechnological application. The comparison of the environmental impacts on the considered natural resources, however, only revealed marginal differences, the outcome of this case study thus showing a positive performance for the nanotechnology-based products.

4.4.2 Swiss Precautionary Matrix

The Swiss "Precautionary Matrix" addresses stakeholders from industry, trade, authorities, insurance companies and research laboratories dealing with processes and products based on synthetic nanomaterials. The precautionary matrix which is publicly available in the form of an Excel tool helps stakeholders to investigate products and applications involving synthetic nanomaterials relative to the risk potentials entailed for workers, consumers and the environment, thus ensuring early detection of a need for precautionary action. Hence, the precautionary matrix boosts the self-responsibility of industry and trade thus enabling them to identify the risk potential and the precautionary need for human health and the environment throughout the entire life cycle of nanomaterials (cf. Figure 2).

In 2008, the Swiss Federal Office of Public Health (FOPH) and the Federal Office for the Environment (FOEN) commissioned development of the tool which, after an initial test period, was made accessible to the public in 2009. The precautionary matric is continually being developed further; the most recent version V2_1_d.xls (status as of July 2011), together with more detailed information, is presented in four languages[8] on the Internet[9]:

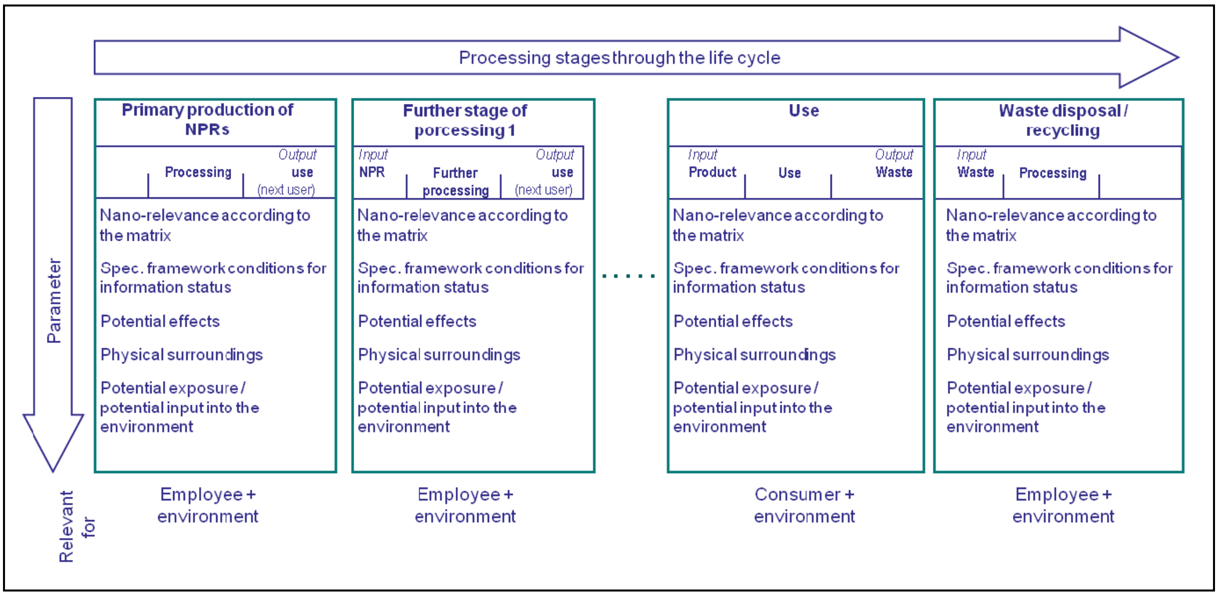

Figure 2: The parameters of the precautionary matrix throughout the life cycle (from Höck et al. 2011)

In the precautionary matrix, it is assumed that nano-specific risks only arise if synthetic nanomaterials are released which are on the nanoscale in at least two dimensions. The data therefore refer to a certain type of nanomaterial in clearly defined surroundings. If the physical surroundings (i.e. solvent, matrix / substrate, state of aggregation etc.) or the respective conditions of use change, a new precautionary matrix has to be filled in.

The precautionary matrix is based on a limited number of evaluation parameters:

- The **specific framework conditions** cover, on the one hand, the order of size of the primary particles, the possible formation of agglomerations and the possible deagglomeration under physiological and environmental conditions. On the other hand, they help to assess the level of information on the origin of the starting materials and on the future life cycle of the nanomaterials.
- The **potential effect** of nanomaterials is estimated by means of the parameters reactivity (redox activity and / or catalytic activity) and stability (half-life in the body and in the environment).
- The **potential exposure** of human beings (workers and consumers) is identified via information on the physical surroundings of nanoparticles (air, liquid media or solid

8 German, English, French and Italian.

9 Cf. http://www.bag.admin.ch/themen/chemikalien/00228/00510/05626/index.html.

matrix) as well as on the volume of nanomaterials (up to 1.2 mg, 1.2 – 12 mg, more than 12 mg) with which those people come into contact, and the frequency at which this occurs (monthly, weekly, daily). Relating to the potential exposition of workers, the "worst case" is queried in terms of the possible volume of nanomaterials with which a worker comes into contact in the "worst case" (up to 12 mg, 12 – 120 mg, more than 120 mg).

As regards the estimation of the input into the environment, a distinction is made between production and use phase; volumes of up to 5 kg, 5 – 500 kg, more than 500 kg can be selected. During the production phase (including manufacture, processing, packaging, transport and disposal), the volume of nanomaterials which is released into the environment via waste water, exhaust air or unspecific waste disposal is being assessed. For the use phase, the volume of nanomaterials in utility products per year with and without specific waste disposal is queried. Finally, the environmental inputs via a specific means of waste disposal or recycling after use are evaluated considering the quantities of nanomaterials which are disposed of per year.

On the basis of the parameters described above, the matrix assesses the potential risk or the precautionary need for workers, consumers and the environment at each predefined step in the life cycle of a product. The evaluation parameters are predetermined, providing the specified information for selection. As regards the query for stability (half-life) of nanomaterials in the environment, for instance, the possible responses "hours", "days / weeks" and "months" are options provided in the selection menu. These data are combined with scores (in the case of low stability = 1, medium = 5 und high = 9). These scores will be used in further calculations on the precautionary need. The calculations are described in detail in the "Guidelines on the Precautionary Matrix for Synthetic Nanomaterials" (Höck et al. 2011).

According to the individual scores, a classification into two classes is carried out (Höck et al. 2011): For **class A** (0-20 scores), the nano-specific need for action associated with the considered materials, products and applications can be rated as low even without further clarification. For **class B** (>20 scores), nano-specific action is needed. Existing measures should be reviewed or new measures be evaluated. Further clarification and, if necessary, measures to reduce the risk associated with development, manufacturing, use and disposal should be implemented in the interests of precaution (Höck et al. 2011).

High scores and a classification into class B may also result from a lack of knowledge and the consequent precautionary high scores. In this case, high scores indicate that there is a great need for knowledge procurement, additional explanations, evaluation of the existing knowledge and possibly of targeted measures.

4.4.3 The Self-Evaluation Tool "NanoMeter"

The NanoMeter is an internet-based **screening tool** for the assessment of applications involving nanomaterials, which are currently under development, addressing researchers and developers. The purpose of the NanoMeter is to highlight relevant aspects in order to enhance public acceptance and thus to support market success of the nano application under development.

The NanoMeter was developed in the scope of the project 'observatoryNANO' as a support action funded under the 7th European Framework Programme for Research from 2008 to 2012, and headed by the British "Institute of Nanotechnology". At the European level, a number of additional partners are involved in the project.[10] The NanoMeter is available on the Internet at the following address: http://www.observatorynano.eu/project/questionnaire/nanometer/.[11]

By means of the NanoMeter, the researchers' and developers' assessment of the future nano application is queried in terms of six aspects:

- Environment, health and safety (EHS),
- Resource and energy requirements,
- User benefits,
- Benefits and risks for society,
- Product responsibility and
- Commitment to stakeholder dialogues.

The questions are answered by ticking the relevant box, while the estimations are carried out **in qualitative terms only**. By the first question in the field of "Environment, health and safety", for instance, the user is queried about his estimation of human exposure to unbound nanostructured materials during production, use and disposal of that application. The options provided for selection by ticking are: "high", "medium", "low", "nanostructured materials can under no circumstances be released" or "not applicable".

Some questions refer to the comparison to the conventional product without nanostructured materials (reference product). As regards the disposal issue, the user is asked for his assessment, whether, in comparison to the conventional application which does not involve

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[10] The European partners of the obervatoryNANO project are: VDI Technologiezentrum GmbH, Germany; Commissariat à l'énergie, France; Institute of Occupational Medicine, Great Britain; triple innova, Germany; Spinverse, Finland; Bax & Willems Consulting Venturing (B&W), Spain; National Institute for Public Health and the Environment (RIVM), the Netherlands; Technical University of Darmstadt, Germany; AIRI/Nanotec IT, Italy; Nano and Micro Technology Consulting (NMTC), Germany; Swiss Federal Laboratories for Materials Testing and Research (EMPA), Switzerland; Nanoethics Centre, University of Aarhus, Denmark; UNU-MERIT, the Netherlands; Technology Centre AS CR (TCASCR), Czech Republic.

[11] This information is exclusively available in English.

any nanostructured materials, the use of nanostructured materials fosters, does not affect or diminishes[12] waste treatment, whether recovery is not possible with current technology or whether the question is not applicable.

Furthermore, the degree of certainty of the selected options has to be specified for all answers, i.e., whether the user is confident about his information, accordingly qualifying it as “very sure”, “fairly sure” or “not sure”.

Finally, the responses are summarised in a table. The answers thereby have to be entered as a round-shaped mark on a four-stage scale between risk for a market success and opportunities, a high human exposure, for example, thus being represented as a threat, while a low exposure will be depicted as an opportunity. Depending on the certainty of the self-assessment, the round-shaped markings will be filled in to a greater or lesser extent.

This mode of presentation helps to identify knowledge gaps. If quite a lot of questions could only be answered with low certainty, it is recommended to seek the advice of internal or external experts (such as the partners in the supply chain) regarding these issues. As regards those replies that have been allocated to a threat, it is recommended to identify those aspects which are the most critical to the relevant actors and to elaborate on them in the scope of the development team. Replies that have revealed a benefit are to be verified and may be used to gain a decisive edge on the market. In addition to the separate evaluation of benefit and risk aspects, users are encouraged to investigate the integrated risk / benefit ratio for different stakeholders.

5 Basic Principles of the Nano-Sustainability Check

Against the background of the goal setting that has been adopted and of the methodological connecting factors, the following section explains the basic principles of the Nano-Sustainability Check. Based on the general concept of sustainable development (see section 5.1) and the consistent application of the life-cycle approach (see section 5.2), a core idea of this instrument is to provide a universal approach for analysing sustainability aspects in nano-specific applications (see section 5.3). Other key elements are the comparative analysis, i.e. the analysis in comparison to a reference product (see section 5.4), and a timely anchorage in the development process (see section 5.5). Furthermore, the integration of the precautionary principle (see section 5.6) and the resulting consideration of hazardous incident (see section 5.7) are important characteristics of the Nano-Sustainability Check.

5.1 Sustainable Development as a General Concept

As is evident from title and goal setting, the focus of the Nano-Sustainability Check is on the concept of sustainable development. According to the recommendations of the 13th German

[12] For instance with regard to reusability, recyclability, degradability in landfill sites or by incineration.

Bundestag's Enquete Commission for "Protection of People and the Environment", the term "sustainability" refers to an integrated consideration of three dimensions:

- the environmental dimension,
- the economic dimension and
- the social dimension.

In this respect, it is essential that the interdependencies and interactions between the three dimensions and the objectives are identified and respected. This, however, is not a question of combining three adjacent pillars, but of developing a three-dimensional perspective from experiences gained in everyday practice.

"Since the World Conference on Environment and Development in Rio de Janeiro, at least one thing has become clear: all economic activities and thus welfare in the traditional sense are subject to environmental viability. It equally became clear that even ecological goals (...) (can) hardly be realised when the material conditions make it difficult for people to take into consideration environmental goals" (Enquete Commission 1998).

Hence, sustainable development can only be progressively achieved within the context of evolutionary, socio-political concretisation and decision-making processes in which the different perspectives and interests of individuals and social groups are matched.

Due to the outstanding importance of the environmental viability and for the purpose of a target-oriented approach, the Nano-Sustainability Check requires a focus on aspects of environmental and climate protection and special attention to be given to their related issues. This priority, however, does not mean that either the economic or the social dimension of sustainability shall be disregarded or ignored. These aspects rather have to be represented by a sufficient number of indicators within the analysis grid.

5.2 Application of the Life-Cycle Approach

Basically, industrial systems are characterised by processes and activities which complexly intersect and that are closely related to each other. Therefore, a holistic approach is required to adequately assess the opportunities and risks associated with industrial products.

The life-cycle approach is such a kind of holistic approach for the assessment of ecological, economic and social aspects of a product, a process or a service. It has been derived from the methodical concept of product life-cycle assessment (LCA) and represents one of the core aspects of PROSA (see section 4.1), presuming that each life cycle of a product or service starts with the extraction and processing of raw materials, is followed by further processing, transport and use, and finally ends up with waste treatment. By virtue of the aspects taken into account, the life-cycle approach is also known as cradle-to-grave approach. The use of the life-cycle approach allows identification of the most important (positive as well as negative) impacts of a product system.

In particular, this approach helps to detect, where relevant, existing conflicts and shifting problems, i.e. problems that are shifting between the individual life-cycle phases (such as the environmental pollution being transferred from the manufacture to the use phase) and between different environmental aspects or media (for example, CO_2 emissions in the air and acidifying substances in water and soil).

Within this general approach, the following three perspectives are particularly relevant:[13]

- location-based perspective (within the "gate")

At this level, the life-cycle approach focuses on the evaluation of alternative materials or the modification of processes, especially aiming at reducing the energy and resource consumption as well as the exposition of workers and the environment.

- upstream perspective (towards “cradle”)

The focus of the life-cycle approach in the upstream perspective lies in the evaluation and, where relevant, in the optimisation of supply chain management, directing particular attention to reducing the “ecological rucksacks” of substances and energy used.

- downstream perspective (“gate to grave”)

As regards the downstream perspective, the analysis focuses on optimising the use phase (through e.g. reduction of energy requirements, prolongation of product lifetime, reduction of consumer exposure) and on a systematic evaluation of the processes at the end of the life cycle (such as wastewater treatment, recycling, waste incineration).

Within the context of the debate on nanomaterials, the focus up to now has rather been on their production and application. Experience in many other areas, however, has shown that the question of safe recycling and disposal is gaining in importance as substances are used on a growing scale. It is not sufficient to only evaluate the use phase of nanotechnology applications. Downstream processes, in particular, must also be considered. Therefore, the analysis grid should explore, for example, whether the existing waste disposal systems are able to identify and safely treat nanomaterials (cf. Möller et al. 2010).

5.3 Universal Approach for a Nano-Specific Analysis

From the point of view of science and technology, nanomaterials do not represent a homogeneous substance group. These materials differ strongly from one another in their physical and structural properties. In terms of their chemical composition and their potential for chemical and bio-chemical reactions, too, these substances differ widely. Therefore, a case-spe-

[13] Cf. Socolof, M. L.; Life-cycle Assessment and Life-cycle Thinking, Performance Track Teleseminar, www.epa.gov/perftrac/LCA%20teleseminar-1-26-05.ppt.

cific consideration shall be based on those conditions prevailing in the sustainability analysis, which are relevant to a specific nanomaterial in a specific application. Transferring specific findings on one nano material indiscriminately to another is contrary to a well-founded scientific approach.

Despite the need for a case-specific consideration, a general approach for a self-evaluation tool should be made available by means of the analysis grid. For this purpose, it is necessary to cover all relevant aspects of sustainability associated with the underlying indicators and criteria. In developing the analysis grid along the life cycle of nanotechnology-based products, the most important interactions with the natural environment, but also with the economic and social fabric have to be considered in order to conform to the concept of a sustainable development. The view that has been adopted will ensure that the identified indicators and criteria will take into account those sustainability aspects which are particularly relevant to nano-technological developments, thus going beyond an overall technology assessment in the general sense. Taking an overall view encompassing all aspects of sustainability relevant to nanoproducts will also mean that different indicators in a particular case will not be relevant or can be regarded as indifferent in view of the comparative study.

In order to keep the efforts in applying the analysis grid within a manageable range, it is essential to develop standardised indicators with clearly defined examination criteria and an unambiguous description of the corresponding data collection procedure. In this context, guidelines for data collection and analysis are needed, including both a description of the methodical principles and a step-by-step guide for data collection, thus providing the basis for quantifying sustainability aspects as much as possible. Even for aspects where, due to complexity and insufficient data, accurate quantification cannot be made, uniform criteria and guiding questions will serve as a basis for a semi-quantitative analysis to be carried out.

For further simplification and standardisation of data collection, the analysis grid furthermore requires provision of electrical tools including input masks for the data elaborated and an automatic calculation of indicator results.

5.4 Assessment by Comparison with a Reference Product

One of the basic principles of Nano-Sustainability Check is the finding that there is no absolute standard by which an ecological or sustainable product could be appropriately defined. Hence, reliable conclusions about the sustainability of a product can only be drawn in the context of an examination of (a) certain function(s). This requires a detailed consideration of the various benefit aspects of the product. Moreover, this principle implies a comparative view of the nanotechnology-based product relative to an already available product.

As the Nano-Sustainability Check shall elucidate those aspects of sustainability that result particularly from the use of nanomaterials or nanotechnologies in the sense of an “enabling technology", the reference product must be a product which, with regard to the investigated functionality (see functional unit, section 6.2.2), is produced without using any nanomaterials.

5.5 Timely Anchorage in the Development Process

The objective of the Nano-Sustainability Check is to reveal the strengths, weaknesses, opportunities and threats associated with a specific nanoproduct. Applying a development accompanying approach, it aims to open up new opportunities to optimally use existing chances, to spot risks at an early stage and to reduce them as much as possible. Taking a purely descriptive analysis without the possibility to influence the actual product development would only contribute to increased sustainability to a very small extent. With regard to the temporal anchoring of the analysis, this objective will result in a stress field: if the analysis sets in at too early a stage in the development process, not all opportunities and risks will be identifiable or adequately quantifiable. If the starting point, however, is fixed at too late a stage in the development process, there is no adequate scope for adjustment. Such a view would only have an affirmative character and thus contradicts an important core idea of the SWOT methodology (see section 4.2).

For this reason, the Nano-Sustainability Check should primarily address products which will shortly be launched on the market or are just being launched now. At this point, on the one hand, many framework conditions in the life cycle of the product (such as resource consumptions, production processes, specific characteristics of the use of the product, et cetera) have been determined with sufficient accuracy and a sound database is available in order to quantify sustainability issues to the greatest extent possible. On the other hand, the product is not yet as well-established in the market that there would be no scope for further product development or optimisation.

Generally, however, evaluation could commence already at a relatively early stage of product development. At this stage, it will necessarily be of a more qualitative nature and therefore is likely to prove more effective in considering key aspects (such as recycling issues) that have to be taken into account, at an early stage. As soon as the product design takes more concrete shape, the analysis can proceed in an iterative way, beginning to refine and precisely quantify the relevant issues.

5.6 Integration of the Precautionary Principle

In the context of the chosen approach, i.e. the self-evaluation tool that is to be applied in the development process of nanotechnology products, the question immediately arises of how to deal with gaps in knowledge or unreliable information and assumptions. As described in the previous section, databases are subject to greater uncertainty, the earlier the analysis grid is used in the development process. Hence, the precautionary principle will have to be adequately reflected in the underlying analysis grid and in the indicators. With regard to the analysis grid and specific indicators, it has to be taken into account whether there is first scientific evidence of serious or irreversible damage to humans or the environment that may be caused by use of the materials (nanomaterials). If, moreover, a hypothesis with a plausible scientific explanation on the potential risk of damage that may occur is put forward, this should also result in preventive action. The integration of the precautionary principle is guided by the considerations which have been set out in numerous judgments by the European Court of Justice (ECJ) on the application of the precautionary principle by the legislator.[14] Accordingly, the precautionary principle in practice is particularly applicable in cases where an objective scientific evaluation gives cause for concern that the potential risks to the environment and the health of humans, animals or plants may be unacceptable or incompatible with a sufficiently high level of protection.[15] Hence, if there is a risk of irreversible and severe damage to the health of humans, animals, plants or the environment and if the cause-effect relationship or the scope of the risks of a product or process has not yet been proven, this cannot be claimed to be the reason for the delay in taking appropriate measures.[16]

5.7 Consideration of Hazardous incidents

For nanomaterials, a general risk assessment and thus the fixing of reasonable limits to protect people and the environment are generally not possible yet. In the context of existing approaches for risk assessment, such as the "Precautionary Matrix for Synthetic Nanomaterials" (Höck et al. 2011), risk potentials of synthetic nanomaterials and their applications are identified for humans and the environment. Furthermore, provisioning requirements for workers, consumers and the environment are evaluated. So far, however, the impacts of potentially hazardous incidents have been explicitly excluded from consideration.

In the last few decades, however, the question of how to avoid and master hazardous incidents in production and in the processing of chemicals has steadily grown in importance. In Germany, for example, the corresponding regulations are contained in the Hazardous Incident Ordinance. A systematic debate on the possibility of hazardous incident associated with nanomaterials, however, has virtually been non-existent to date.

With regard to the possibility of such incidents, the European Commission has already confirmed the fundamental suitability of the Hazardous Incident Ordinance to also take into account nanomaterials. In view of the “implementation of legislation”, the Commission at the

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14 Cf. ECJ, Case T-13/99 (Pfizer Animal Health v. Council), 2002, ECR II-3305, para. 143, for example

15 Communication from the Commission on the application of the precautionary principle COM(2000)(1) of 2.2.2000, in the following: Commission Communication.

16 The ECJ sets out the prerequisites for the application of the precautionary principle in: EuGH, Rs. T-13/99 (Pfizer Animal Health v. Council), 2002, ECR II-3305, para. 143. According to the Commission Communication, reference as above, p. 3, the precautionary principle is to be recoursed to “specifically where preliminary objective scientific evaluation indicates that there are reasonable grounds for concern that the potentially dangerous effects on the environment, human, animal or plant health may be inconsistent with the high level of protection chosen for the Commission”.

same time points out, however, that "currently, ... the scientific basis that is needed to thoroughly understand all properties and hazards associated with nanomaterials is only insufficiently available" (cf. European Commission, 2008). Moreover, the Harzardous Incident Ordinance does not explicitly take into account nanomaterials.

However, it has hitherto not been systematically evaluated whether these provisions sufficiently cover the behaviour and effects of nanomaterials in case of hazardous incidents. In this context, it has to be clarified, among other things, how likely it is that such particles may be released as a result of a hazardous incident. As a result, a realistic picture should be drawn up, depicting the nature of incidents that might occur and the consequences of released nanoparticles on workers, the population or the environment.

Against this background and within the scope of the underlying analysis grid, it is necessary not only to consider the production and processing of nanomaterials during normal operation, but also the known possible effects with view to their relevance in the case of hazardous incidents, and to record and evaluate them by appropriate criteria.

6 Characterisation of the Analysis Grid

This section presents the analysis grid for the systematic analysis of sustainability aspects of nanotechnology products and applications developed within the framework of the project. First, the objects of investigation considered within the Nano-Sustainability Check will be defined (see section 6.1) and relevant aspects of establishing the system boundaries of the underlying process chain (see section 6.2) will be outlined. Subsequently, section 6.3 will depict the key indicators used and describe their methodological embedding and allocation. Section 6.4 will describe in detail the key indicators used within the analysis of strengths and weaknesses. Then, section 6.5 will give a detailed description of the key indicators of the opportunities and threats analysis. Section 6.6 finally contains the cornerstones concerning the evaluation of the key indicators, while section 6.7 focusses on the cooperation in the development and testing of the analysis grid.

6.1 Definition of the Objects of Investigation

6.1.1 Nanomaterials

Several proposals on the definition of nanomaterials have already been drawn up in the past, both at international and at national level as well as by different stakeholders (such as standardisation bodies, scientific institutions, ministries and authorities or environmental organisations).

At present, the cosmetics directive is the only piece of legislation that contains a legally binding definition of nanomaterials at EU level. Apart from that, there are no other legally binding definitions for nanomaterials in the EU or Germany.

Against this background, nanomaterials – for the purpose of the Nano-Sustainability Check – are defined as follows:

> *"Nanomaterials are deliberately engineered materials which have at least one dimension in the order between 0.5 nm and 200 nm (primary nanoparticles), and agglomerates and aggregates derived from such materials."*

The lower limit chosen for the spectrum of nanomaterials was a value of 0.5 nm, which is based on the minimum hitherto used, "in the order of 1 nm", while being more precise. It was necessary to expand the spectrum to include sizes below 1.0 nm because some of the nanomaterials that have been widely discussed in the public in terms of their sustainability fall within this size range. The diameter of a C60 fullerene, for example, is 0.7 nm.

The upper limit of the spectrum has been set at 200 nm. As nano-specific effects in the physico-chemical properties of the substances under investigation can neither be ruled out for sizes exceeding the order of 100 nm, the value of 200 nm was chosen in the sense of a moderate safety margin.[17]

6.1.2 Nanoproduct

EU-wide definitions introduced through REACH can be drawn upon to define the term "nanoproduct"[18].

In line with different potential objects of investigation, the term "nanoproduct" should be defined as a generic term for:

- nanomaterials
- mixtures containing nanomaterials, as well as
- semi-finished and finished products containing nanomaterials.

The definition of the term “nanomaterial” is based on the proposed definition as set out in the preceding section.

In the case of the term “mixture”, the definition in Article 3 (2) of REACH is applied, according to which a mixture means

“a mixture or solution composed of two or more substances.”

By adopting definitions from REACH, we are making use of provisions already introduced and binding throughout Europe, and which are also familiar to the addressees of the legislation in the context of exports and imports.

The same applies to defining semi-finished and finished products containing nanomaterials. For this we have made use of the concept of “article” set out in Article 3 (3) of REACH. Under REACH, “article” covers both finished and semi-finished products, although this could make it

[17] Cf. (Hermann / Möller 2010).

[18] Regulation (EC) No 1907/2006 on the Registration, Evaluation, Authorisation and Restriction of chemicals

difficult to distinguish clearly between substance, mixture and article. In accordance with Article 3 (3) of REACH, for the purposes of REACH, “article” means “an object which during production is given a special shape, surface or design which determines its function to a greater degree than does its chemical composition.”

In the light of these considerations, we propose the following definition of the term “nano-product” for the purposes of the Sustainability Check. “Nanoproducts” cover:

- Nanomaterials within the definition of section 6.1.1,
- Mixtures within the definition of Article 3 (2) REACH containing nanomaterials, and
- Articles within the definition of Article 3 (3) REACH containing nanomaterials within the meaning of section 6.1.1; irrespective of the concentration of the nanomaterial present in the article.

6.1.3 Reference Product

As explained in section 5.4, a comparative consideration to a non-nanotechnological reference product is to be undertaken within the framework of the Nano-Sustainability Check. Regarding the definition of the reference product, referral is made to the report of the Nano-Commission’s issue group 2. The definition for the reference product set out there was elaborated in close coordination with the development of the analysis grid for the Nano-Sustainability Check and drawn up by the principal author of this report. In order to harmonise the methodological foundations between the two instruments as far as possible, the definition of the reference product from the final report of issue group 2 has been adopted unchanged (cf. BMU 2010):

“Essentially, the reference product should be a product in which the functionality under examination is achieved without the use of nanomaterials.”[19] The reason for this is to enable comparison of the nanoproduct with a reference product in order to establish which benefit and risk aspects result specifically from the use of nanomaterials or nanotechnologies.

When selecting a reference product, it is important to ensure that both nanoproduct and reference product have the same basic technical functionality. This principle of functional equivalence is very important, as otherwise we cannot be certain that we are comparing like with like. For this reason, the benefit aspects of the product being assessed should be carefully analysed and identified at the start of the process. Using this as a basis, benefit aspects that constitute basic technical functionalities should then be established and distinguished from those representing additional benefits.

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19 If the reference product has an additional functionality that depends on the use of nanomaterials but this functionality is not relevant to the comparison with the nanoproduct, this does not present a problem. One such example might be nanomaterials that have been used for the same purpose and in the same quantity in both the nanoproduct and the reference product for many years.

If the nanoproduct is an entirely new product or has novel properties that could not have been produced hitherto, specification of a reference product with the same basic technical functionality will not be possible in the individual case. In such cases the "next best" reference product must be chosen instead, i.e. a product with a functionality most closely resembling that of the nanoproduct.[20] The choice should be guided by the question of which conventional product the nanoproduct might substitute when it is placed on the market or if demand increases.

Whatever the case may be, it is important to document clearly the assumptions on which the choice of reference product is based and include this as supplementary information in the results of the assessment."

In principle, it would be possible to use the analysis grid under the Nano-Sustainability Check to carry out comparisons between two or more nanoproducts. It would be interesting, for example, to explore the relative advantages of using a different or new type of nanomaterial compared to the material hitherto used. This is another issue where the developed key indicators can be used. This line of enquiry, however, is not the focus of the "Nano-Sustainability Check" project and is therefore not pursued here.

6.2 Defining the System Boundaries

By selecting the system boundaries, the modules which have to be taken into account are defined with a view to determining the key indicators. Modules in turn present such processes, activities or aspects of the product system under investigation, for which data are collected.

In principle, the Nano-Sustainability Check always requires to analyse the entire life cycle of the investigated nanoproducts from the extraction of raw materials to waste treatment (cf. section 5.1). With an emphasis on quantifiable aspects relating to environmental and climate protection, however, simplifications have to be used in order to reduce complexity and due to time and resources constraints.

After an introductory characterisation of the life-cycle approach, the next section presents a range of possible simplifications. The specific simplifications made for each key indicator are being addressed in the relevant guidelines[21] for the determination of the key indicators.

6.2.1 Definition of the Product System

Possible simplifications of an entire life-cycle approach can be obtained by blanking out one or more of the mentioned perspectives or to address them only cursorily. Adopting such an

[20] Depending on the product being assessed, there is, however, a "zero option" that may be adopted in extreme cases for the reference product if the functionality in question can only be achieved by using the application of nanotechnology.

[21] The individual guidelines are included in the annex to this final report.

approach, it is necessary, however, to ensure that all aspects relevant for the key indicator will nevertheless be taken into account and that the aforementioned shifting of the problem from one life-cycle stage to another can be excluded.

In this context, it is recommended both for the nanoproduct as well as for the reference product to prepare a schematic diagram of the product system showing all relevant processes, material and energy flows, as well as the interactions between the processes (see the following figure).

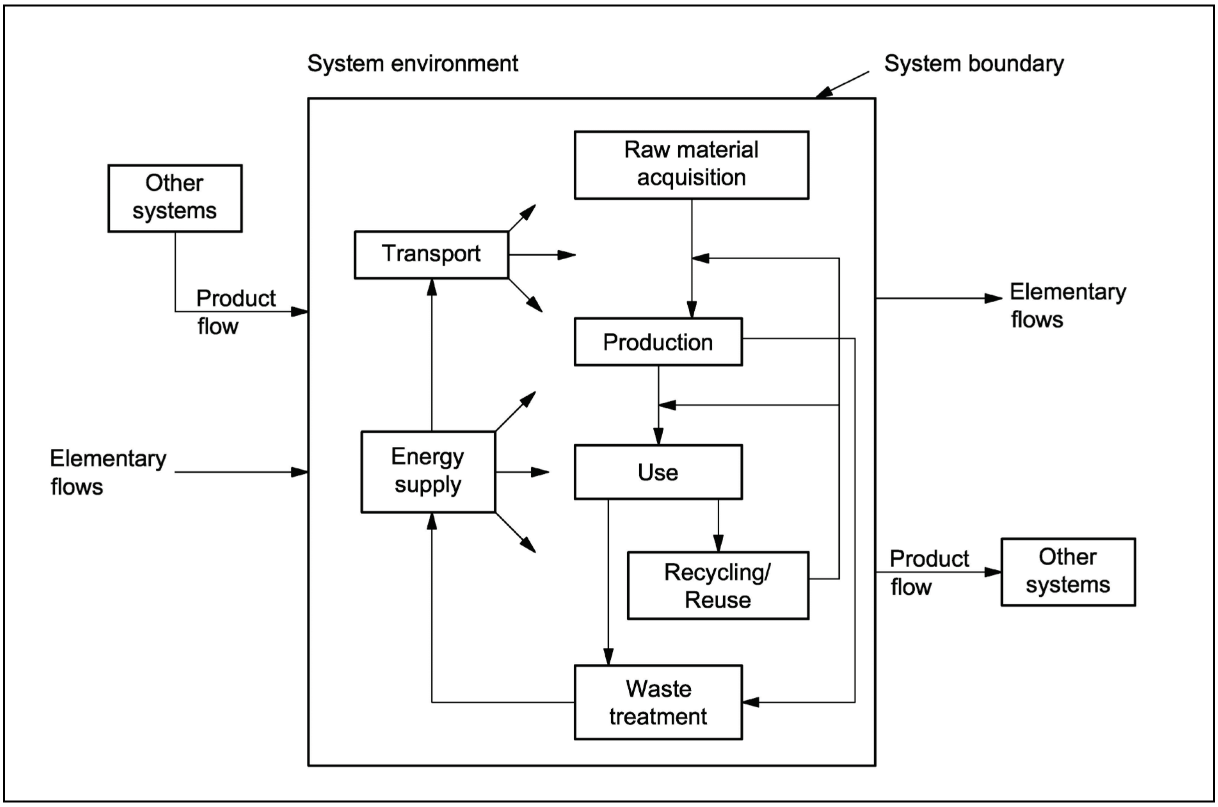

Figure 3: Example for System Boundaries of a Product System (ISO 14040)

The system boundaries for the nanoproduct and the reference product must be selected in such a way that all processes, material and energy flows and aspects that are relevant for providing the functionality (see section 6.2.2) of the product system and for a fair comparison between the two options are within the system boundaries of the investigation. The examination should inter alia cover energy savings made throughout the use phase resulting from certain product components, as well as any additional expenses or emissions produced throughout the waste treatment process.

6.2.2 Functionality and Functional Unit

When comparing the nanoproduct with the reference product, it should be noted that the two alternatives have the same technical functionality. This principle of functional equivalence is very important, as otherwise alternatives will be examined and evaluated that are not comparable. For this reason, the benefit aspects of the investigated products should be exactly analysed and identified at the beginning of the examination. On the basis of this investigation it has to be determined which benefit aspects involve basic technical functionalities and which rather represent an additional benefit.

Finally, the identification of the basic common functionality of the objects that are to be compared forms the basis for identifying the functional unit. The functional unit represents the quantified benefits, which has the same validity for both the nanoproduct and the reference product and which should be expressed by physical variables (for example 1000 kg of final product, 1000 m² of treated surface). This parameter serves as comparison unit of the investigation and as a reference for all results of the key indicators.

6.3 Methodically Embedding and Allocating the Key Indicators

The key indicators used in the Nano-Sustainability Check are methodically embedded in the "SWOT analysis" originally developed for business and industry. The basics of SWOT were already explained in section 4.2. For the purposes of the Nano-Sustainability Check, the SWOT method has been adapted. Thus, the analysis of strengths and weaknesses in the sense of the Nano-Sustainability Check refers to the inherent properties and potentials of the product in terms of CO_2 reduction and toxicology, for example, while the analysis of opportunities and threats is concerned with external (environmental, economic, legal and societal) framework conditions. These include implications as obstacles due to legal provisions (for example product realisation is not carried out because of unclear legal situation concerning liability) or lack of recyclability, resource availability, employment situation / employment effects as well as social value concepts and megatrends.

The following indicators are part of the strengths / weaknesses analysis:

- product carbon footprint
- energy efficiency
- workplace exposure
- user benefits
- life-cycle costs
- risk estimation for men and environment
- hazardous incident analysis
- symbolic benefits

The opportunity / threats analysis is implemented on the basis of the following indicators:

- employment effects
- societal benefits
- legal framework and research funding
- recyclability
- resource availability
- risk perception

Within these two groups, the allocation of the key indicators is carried out depending on the result of the comparison between nano- and reference product. If, for example, the nanoproduct performs better than the reference product being compared in terms of the product carbon footprint, this key indicator represents a strength. If, by contrast, it is shown that there are disadvantages relating to recyclability, for example, there is a threat according to this key indicator.

The following table exemplarily represents the allocation of the key indicators in a hypothetical case study:

Table 4: Exemplary SWOT matrix for a hypothetical case study with allocation to the key indicators strengths, weaknesses, opportunities and threats.

Strengths	**Weaknesses**
Producrt Carbon Footprint Energy Efficiency User benefits Risk Estimation for Men and Environment Incident Aspects Symbolic benefits	Workplace Exposure Life-cycle Costs
Opportunities	**Threats**
Employment effects Societal benefits Legal framework and research funding Resource availability	Recyclability Risk Perception

6.4 Detailed Description of the Strengths / Weaknesses Analysis

In the following, the key indicators used in the analysis of strengths and weaknesses are characterised. More background information as well as a detailed guide to the compilation of the key indicators is available in the particular guidelines, which were developed for each key indicator within the framework of the project. These guidelines are annexed to this report.

6.4.1 Product Carbon Footprint

Given the promising potentials and approaches offered by new nanotechnology developments to the existing climate protection goals (cf. section 2), the key indicator "Product Carbon Footprint" is particularly important in the context of the Nano-Sustainability Check. This key indicator is a quantitative parameter, which reflects the greenhouse gas potential of the nanoproduct as compared to the reference product of equivalent functionality. The greenhouse gas potential refers to the overall balance of all climate-relevant emissions along the entire life cycle of a product in a defined application and based on a defined usable unit (functional unit).[22] Greenhouse gas emissions in the sense of this definition are all those gaseous substances, for which the Intergovernmental Panel on Climate Change IPCC has defined a coefficient used to indicate the global warming potential (GWP). The life cycle of the objects that are compared covers the entire value-added chain from manufacture and transportation of raw materials over production and distribution to use, subsequent usage and disposal. With regard to the basic approach, we refer to (ISO 14040). Additional information on the methodological approach is available in (PAS 2050).

The evaluation for the key indicator "Product Carbon Footprint" is equivalent to the impact assessment of a life-cycle analysis, while restricting the determination to the impact category of global warming potential. In this step, the actual Life-Cycle Inventory (LCI) data identified in the framework of data collection are classified[23] and characterised[24] as well as aggregated to the key indicator. In addition to the absolute representation of the product carbon footprint (if available), the relative CO_2 savings identified for the nanoproduct as compared to the reference product are depicted. Thus, the determination of the product carbon footprint leads to the following results:

1. **Absolute product carbon footprint** of the nanoproduct and of the reference product relative to the functional unit; the unit of this parameter is indicated as "kg CO_2 equivalents" (abbreviated: kg CO_2e).
2. **Relative CO_2 savings** in the formula of "1/x", wherein "1" is the product carbon footprint of the nanoproduct and "X" the CO_2e savings that can be achieved by the nanoproduct throughout its life cycle as compared to the reference product. This size is dimensionless.

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[22] Cf. / Hochfeld; Memorandum Product Carbon Footprint, Berlin 2009

[23] Classification means assigning the LCI results to the selected impact categories (cf. ISO 14040).

[24] Charakterisation refers to the conversion of the assigned LCI results into the common unit of the impact indicator. For this purpose, characterising factors are used having been derived from a characterisation model (cf. ISO 14040).

Provided that sufficient data is available, an extrapolation on the CO_2e savings is desirable as well. These projections ("voluntary exercise") should be made on the basis of the CO_2e savings per functional unit and in relation to the global potential (using current market data). The unit used to express this parameter is "kilograms of CO_2 equivalents" (abbreviated: kg CO2e). If desired by the respective companies, an attempt can be made to provide an outlook on the market as well.

Within the framework of the Nano-Sustainability Check, the Excel tool of the "Product Carbon Footprint" offers assistance in determining the key indicator of "Product Carbon Footprint", mainly by providing LCI data for selection and use in some critical processes and by carrying out the required calculation steps for aggregating the LCI data. Although all steps necessary to determine the key indicator can be taken by using this tool, it always should be used together with the related guidelines.

6.4.2 Energy Efficiency

The key indicator "Energy efficiency" represents a quantitative parameter expressing the cumulative energy input of the nanoproduct in comparison to the reference product of equivalent functionality and relative to a defined usable unit (functional unit). The cumulative energy demand (CED) represents the sum of all primary energy inputs made in the course of the life cycle of a nanoproduct or a reference product, including the energy for manufacturing the materials.

The life cycle of the objects that are compared covers the entire value-chain from manufacture and transportation of raw materials and intermediate products over production and distribution to use, subsequent usage and disposal.

According to the economic minimum principle, maximisation of the energy efficiency means that the functional unit is realised in a way that requires minimal energy input.

The individual primary energy contents have to be determined for all total amounts of energy, energy sources, substances, services and transports identified and relevant within the boundaries of the system. The specific CED data needed to that end (such as the MJ primary energy / kWh electricity) can be drawn from corresponding databases, such as GEMIS[25].

Depending on the source of resources, the identified primary energy contents are assigned to one of the following three components of cumulative energy demand:

- $CED_{non\text{-}renewable}$: total cumulated energy requirement from fossil and nuclear sources;
- $CED_{renewable}$: total cumulated energy requirement from renewable sources and
- CED_{others}: total cumulated energy requirement of residues used as energy (such as waste).

25 GEMIS is a publicly available database for energy systems, substances and services, available online at www.gemis.de.

In terms of resources, total CED (that is the sum of the total cumulated energy demand, regardless of the respective energy sources) does not reflect any shortage, especially since significant shares of renewable and recycled energy may be contained herein. Within the scope of the objective selected, $CED_{non\text{-}renewable}$ will thus be used for determining the energy efficiency. In addition to an absolute representation of the energy efficiency, the energy savings from the nanoproduct as compared to the reference product (where these exist) should be communicated as well. Hence, determination of the energy efficiency will lead to the following two results:

1. **Absolute energy efficiency** of the nanoproduct and the reference product related to the functional unit; the unit of this parameter is indicated as “megajoules” (abbreviated: MJ).
2. **Energy savings** in the formula “1/X”, wherein “1” is the energy efficiency of the nanoproduct and “X” the energy savings that can be achieved by the nanoproduct throughout its life cycle as compared to the reference product. This size is dimensionless.

Provided that sufficient data is available, an extrapolation on the energy efficiency is desirable as well. These projections (“voluntary exercise”) should be made on the basis of the energy savings per functional unit and in relation to the global potential (using current market data). The unit used to express this parameter is “megajoule” (abbreviated: MJ). If desired by the respective companies, an attempt can be made to provide an outlook on the market as well.

Analogous to the Excel tool for the “Product Carbon footprint”, the Excel tool “Energy efficiency” offers assistance in determining the key indicator “Energy efficiency”, mainly by providing LCI data for selection and use in some critical processes and by carrying out the required calculation steps for aggregating the LCI data.

6.4.3 Workplace Exposure

Within the scope of the key indicator “Workplace exposure” it is analysed, whether the relative efforts that need to be made for the protection of workers and/or as precautionary measures when producing a nanoproduct are higher, comparable or less burdensome than that required for the production of a reference product. The efforts and related costs depend on the results of the risk assessment, namely the risk potential and, in particular, on the protection and monitoring measures derived therefrom, while the costs incurred are related to the overall costs for construction and operation of the respective facilities, and therefore have to be considered accordingly.

As an estimate of the expenditure for health and safety measures in terms of absolute costs is generally difficult, a semi-quantitative evaluation will be made.

A key factor in the analysis is the effort required for the necessary protection and monitoring measures, which has to be estimated by means of some key questions in the following areas:

- technical measures;
- organisational measures;
- personal protective equipment;
- surveillance measures.

In the area of technical measures, for example, the following aspects are considered:

- expenses / costs for the substitution of hazardous substances and materials by less hazardous ones;
- expenses / costs for the substitution of procedures / works steps by less hazardous ones;
- expenses / costs for the use of closed and/or encapsulated systems and parts of systems;
- expenses / costs of setting up and operating stationary extraction systems with subsequent treatment of exhaust air.

As a result, a value between -3 and +3 will be determined and documented, a zero being equivalent to the “workplace exposure” of the reference product, a positive value indicating an edge over the reference product and a negative value a corresponding disadvantage. Each estimate made must be justified.

6.4.4 User benefits

The key indicator “User benefits” specifies whether, in addition to the defined functional unit, further differences concerning the product benefits can be identified for the product under study. The given end product being defined by the functional unit constitutes the reference point for discussing the benefit aspects. With regard to this indicator, the following key criteria should be discussed in any case:

- What is the added value provided by the nanoproduct?
- What is the durability of the nanoproduct as compared to the reference product?
- Are there any differences in reliability of the function?
- Are there any differences with regard to product safety?
- Are there any differences concerning the maintainability of the product?
- To which extent does the nanoproduct meet the customers’ requirements as compared to its reference product?
- Are there any differences in convenience for the customer?
- Is there some good customer information made available to the user?

Other criteria may be supplemented on a product-specific basis.

In order to analyse the individual criteria, recourse should be made to standardised methods for measuring and/or quality assurance systems, wherever possible. If there are any national or international standards or guidelines (for example concerning durability or reliability) corresponding to individual criteria, reference should be made to these regulations. In individual cases where there is no such data available (yet), an assessment can be made on the basis of a concise qualitative description. This has to be disclosed accordingly.

The presentation elaborated by the respective company on the aforementioned individual criteria is finally subjected to a semi-quantitative overall assessment. To this end, there is a need for both a consideration of the individual criteria relating to the nanoproduct as compared to the defined reference product, and a product-specific weighting of the individual criteria as well.

On the basis of a qualitative description and/or a delineation which already contains a quantitative description of the individual examination criteria, a quantitative classification of the criterion under review, based on a scale from -3 to 3, is carried out by the company. At a value of zero, the respective benefit aspect of the nanoproduct is equivalent to that of the reference product, while positive values indicate an edge over the reference product (slight advantage, advantage, significant advantage) and negative values correspondingly imply disadvantages.

For this indicator, we additionally recommend a weighting of the various criteria under analysis. In doing so, equal weight should initially be given to all criteria, assuming a numeric value of 1. If, however, the company has found that special importance should be attached to individual criteria relating to the analysed nanoproduct, this relevance can be taken into account by adapting the weighting of the appropriate criterion. A modified weighting requires a justification to be given for each specific product and criterion. It may either be assumed that the criterion is not relevant for the investigated product (then, further consideration of this criterion is not necessary), or that the criterion has great importance for the specific product (in this case, the weighting factor can be doubled).

For the purpose of evaluating the key indicator “user benefits”, the Excel tool “Nano Benegrade” is available, which enables determination of all key indicators relating to the aspects of utility.

6.4.5 Life-Cycle Costing

Life-cycle costing is generally defined as the calculation and assessment of all costs (expressed in euros and based on the functional unit) which are connected with a certain product and are directly covered by one or more actors in the life cycle of this product (cf. Hunkeler et al. 2008). Such a calculation (in contrast to an isolated view of the purchase or investment price) is especially useful if a relevant share of costs incurs during the use or end-of-life phase of the analysed product.

For various applications, the methodological basis for the implementation of life-cycle costing is laid down in different international and national standards and directives (cf. ISO 15663-2: 2001, for example). Some aspects are also covered by conventional methods of investment costing.

As the Nano-Sustainability Check focusses on sustainability aspects associated with nano-technological applications, we do not recommend a life-cycle costing from the developers' viewpoint, but rather from the consumer's perspective. Depending on the investigated case study, consumers may be the end consumers or customers from the B2B[26] sector.

With regard to the individual cost elements, it is important to know when they accrue. Future costs, for example, are generally rated lower than current costs.[27] With respect to the point in time when they incurred, all costs have to be accrued accordingly, i.e. accumulated or discounted. The discount rate should be set with a view to reflecting the real-life situation as exactly as possible. Hence, the valuation of costs according to the time factor may only be waived on the grounds that no further costs are incurred during the use phase or at the time of disposal, or that the costs resulting therefrom are comparatively low in comparison to other cost factors.

A calculation of the life-cycle costs taking into account discounting is done by using the present value or the annuity method. From both methods, the best-performing alternative is the method presenting the lowest value, i.e. the one with the lowest net present value or the lowest annuity. The results, however, can differ, depending on whether or not the examined alternatives have the same useful life:

- If nanoproduct and reference product have the same useful life, the results obtained will be the same regardless of the methods used – both methods thus will show the lowest value for the same alternative. The absolute results obtained, however, will be different.
- If nanoproduct and reference product (partly) have useful lives differing from each other, the annuity method will produce more meaningful results, if it can be assumed that a reinvestment will be made after the end of the useful life. The aspect that the period of service or useful life may vary between the two objects that are being compared, may become particularly relevant within the scope of the Nano-Sustainability Check: on the one hand, it may be that the nanoproduct (due to a surface finishing, for example) has a longer service life than the reference product; the reverse situation, of course, is possible as well, if the nanoproduct has a shorter lifespan, prematurely losing its functionality (resulting from wear and tear, for example).

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26 business-to-business sector

27 This is due to the fact that money that must be raised immediately, cannot be invested in one form or another (i.e. profitably), or otherwise has to be taken out as a loan for which interest has to be paid.

An Excel tool which is available can be used to automatically calculate discounting and present values (or annuities) for both nano- and reference product.

6.4.6 Risk Estimation for Men and Environment

The key indicator "Risk estimation for men and environment" analyses whether the use of the nanomaterials or nano-containing products under study can result in a risk to human health or the environment. Furthermore, it is investigated whether the use of the nanoproduct or nanomaterial leads to the prevention of substances which are hazardous to health and the environment, so that relief potentials can be attributed to the nanoproduct / nanomaterial as compared to the nano-free reference product in terms of protecting health and the environment.

When carrying out an assessment of the risks to human beings and the environmental sphere, a semi-quantitative determination in accordance with the precautionary matrix for synthetic nanomaterials of the Swiss Federal Office of Public Health (cf. Höck et al. 2011) should be done. On the basis of a limited number of parameters for analysis, the risk potentials for workers, consumers and the environment are assessed and presented in the form of a numeric value which allows an allocation to various (risk) classes. Hence, a need for precautionary measures may be derived from this classification.

The precautionary need is represented in relation to the potential effect and/or hazardous potential on the one hand and the potential exposure of humans or inputs into the environment on the other:

- The potential effect or hazardous potential is estimated on the basis of the parameters reactivity and stability of the nanomaterials.
- The probability and the degree of exposure (= potential exposure) of humans (workers and consumers) are determined through data on the physical surroundings of nanoparticles (i.e. air, liquid media or solid matrix), as well as the extent and frequency of contact with these nanoparticles.
- The potential entry into the environment via exhaust air, waste water or (un)specific disposal in the course of production and use phase is determined through data on the amount of disposed nanoparticles or the overall amount of nanoparticles contained in consumer products that are placed on the market.

In addition to the parameters relating to potential effects and exposure, parameters for "specific framework conditions" are taken into account as well: On the one hand, these comprise the size of primary particles, the formation of agglomerates and any possible deagglomeration under physiological and ambient conditions. On the other hand, the amount of information available on the origin of the source materials as well as the further life cycle of the nanomaterials will be assessed.

If the reference product contains any hazardous substances, the use of which could be avoided or substituted by use of a nanoproduct or nanomaterials, such a prevention or substitution of hazardous substances will be assessed and qualitatively described by introducing a supplementary indicator.

Classification is a means to identify the specific precautionary need for action, resulting in the allocation into the Nano-Swot matrix:

- **Class A**: The nano-specific need for action can be rated as low, even without further clarification.
- **Class B**: It cannot be excluded that there are nano-specific risks. Further clarification regarding the risk potential and, if necessary, measures to reduce the risk associated with development, manufacturing, use and disposal implemented in the interests of precaution should be undertaken.

If, within the scope of the analysis, the assessment concludes that there is a precautionary need (allocation into class B), this key indicator, within the framework of the Nano-Swot matrix, is to be assigned to the weaknesses. Otherwise it would have to be considered as belonging to the strengths.

6.4.7 Incident Aspects

The key indicator "Incident aspects" is a semi-quantitative method for evaluating the potential of hazardous incidents during the manufacture of the nanoproduct. Pursuant to the Hazardous Incident Ordinance, a "hazardous incident" is considered to be an occurrence such as a major emission, fire or explosion, resulting from a disturbance of the specified normal operation and leading to a serious danger within or outside the operational area or the plant.

To a significant extent, the method is based on studies already carried out within the scope of the indicator "Risk estimation for men and environment". The "Precautionary matrix for synthetic nanomaterials" provided a starting point for evaluating the hazardous incident potential, underlying the indicator "Risk evaluation for humans and the environment" as well. Within the framework of the investigated indicator, there are, however, disparities as regards determining the potential exposure of humans in respect of hazardous incidents. A distinction is drawn between workers and the population. The impact on the environment is not being considered yet, since it is assumed that a rare accident-related release of nanomaterials into the environment involves a rather small amount of substances being released compared to a(n) (uncontrolled) release via the products / waste streams.

The evaluation for the key indicator "Incident aspects" orients itself on the approach taken in the precautionary matrix for synthetic nanomaterials, yet it is complemented or modified by hazardous incident-specific aspects. The probability and the degree of exposure of humans (workers and population), for example, are determined through data on the physical surroundings of nanoparticles (i.e. air, liquid media or solid matrix), as well as other parameters (conditions inducing hazardous incidents, mass affected, number of workers concerned, release, distance to the population). With regard to the approach taken, we refer to the corresponding guidelines for capacity reasons. Assessment is carried out using the Excel tool "Hazardous incident grid", the result being a score value. According to the approach adopted in the "Precautionary matrix for synthetic nanomaterials", classification into class A is performed for scores up to and including 20. Other scores will result in a class B allocation:

- **Class A**: The nano-specific risks can be rated as low, even without further clarification.
- **Class B**: It cannot be excluded that there are risks related to hazardous incidents. Further clarification regarding the risk potential and, if necessary, measures to reduce the risk should be undertaken in the interests of precaution.

If, within the scope of the analysis, the assessment concludes that there is a precautionary need (allocation into class B), this key indicator, within the framework of the Swot analysis, is to be assigned to the weaknesses. Otherwise it would have to be considered as belonging to the strengths.

6.4.8 Symbolic Benefits

In the scope of the key indicator "Symbolic benefits" it will be shown for the analysed product, whether, beyond the defined "functional unit", any further distinctions are noticeable in terms of the product benefits, which are not typically measurable or quantifiable. It is recognised that the benefits of a product not only consists in its actual function (user benefits), but that there are often other factors which are decisive for the satisfaction or dissatisfaction with a product. One possible added value can be based on the image of products or companies, thus not providing a practical but rather a symbolic benefit.

The symbolic benefit is transported via the product and its marketing and raises feelings or moods such as prestige, identity creation or pleasure associated with the product. The key criteria that are, in any case, to be discussed for this indicator are as follows:

- Are there any new possibilities being created in the area of product design (external appearance, taste, haptics, acoustics or similar)?
- Does the product help to establish prestige?
- Does the product provide special relish, pleasure, joy, or beneficial experience?

Other criteria may be supplemented on a product-specific basis.

As for the key indicator "User benefits", a semi-quantitative overall assessment in terms of the individual criteria listed above will be performed on the basis of the presentation drawn up by the respective company (cf. section 6.4.4, details on the approach, see there). The final evaluation as well will be carried out using the Excel tool "Nano Benegrade".

6.5 Detailed Description of the Key Indicators Opportunities / Threat Analysis

The following section describes the key indicators used in the analysis of opportunities and threats. As already mentioned in the context of the key indicators as part of the analysis of strengths and weaknesses, more background information as well as a detailed guide on how to record these data are contained in the guidelines developed for each key indicator within the scope of the project. These can be found in the annex to this report.

6.5.1 Employment Effects

In the context of the economic and social evaluation of new technologies or new products / services, the creation of new jobs while safeguarding existing ones (positive impact on employment) is an indicator of prime importance. A primary concern in this regard is often the creation or the safeguarding of so-called direct and indirect jobs, the monetary payments (such as for wages, investments, etc.) of which, by means of a multiplicative process, can be linked to the economic development of technology or the product / service itself.

Within the scope of the sustainability assessment of nanoproducts, the determination of the impact on employment as a key indicator is limited to direct employment effects and only takes into account the gross effects[28], while indirect effects and net effects[29] are not taken into consideration.

The key indicator “Employment effects” is a quantitative indicator, which describes the number of permanent staff involved in activities connected with a nanoproduct and the reference product in relation to one functional unit of the nanoproduct. A census must be taken on the number of workers working for a company / corporate group, which are exclusively or at least primarily occupied with research and development (R&D), production, marketing, distribution of nanotechnological components and products (nanoproducts). These figures have to be indicated in relation to the functional unit of the specific product. In the manner described above, the indicator also includes the number of permanent staff employed in companies upstream and downstream in the value chain.

It is assumed that data acquisition in the own enterprise will provide a much more precise picture than it can be obtained in the upstream and downstream value-added chains. As regards the own enterprise, the number of all workers that are exclusively or at least primarily occupied with research and development (R&D), production, marketing, distribution across the enterprise or the corporate group has to be recorded. In cases, where workers are not only entrusted with the production or development of nanoproducts, but also produce other

[28] This should be taken to mean all forms of employment related to the manufacture of the nanoproduct.

[29] In contrast to the gross effect, the net effect takes into account that the use of nanotechnologies may induce replacement of other technologies and products, which could result in job losses elsewhere in a company or in the value added chain.

products, for example in different production cycles, they will nevertheless be registered, if the activities they carry out in connection with the investigated nanoproduct make up more than half of their working time. The number of workers has to be related to the functional unit of the manufactured product, as may be one ton or one piece of the nanoproduct produced.

In addition to estimating the absolute employment in a company or group, the mementum of the employment trend is of great interest, too, in order to make forecasts about the future development of the jobs depending on nanotechnology. In this respect, both the developments that have already taken place in the past as well as the potential prospects for the future are of interest.

"Employment effects" must be classified into the area of "opportunities", provided that the net employment (measured in full-time positions per functional unit) remained unchanged or increased during the investigation period. An opportunity is deemed to exist if there is high employment in a (new) business segment at the beginning of the investigation period, before declining again, however, as it is possible in pure research enterprises that are dealing with nanoproducts without subsequently marketing these products. Otherwise, the indicator should be allocated to the field of "threats" in the context of the SWOT analysis.

6.5.2 Societal Benefits

The key indicator "Societal benefits" analyses whether the product under review has a significant impact on a socially relevant area. The observation shall primarily focus on those aspects that can be attributed to the use of nanomaterials and nanotechnologies as an "enabling technology". In this context, the following criteria must be considered:

- Fighting poverty, hunger and malnutrition,
- Promotion of health,
- Promotion of education and information,
- Promotion of economic stability,
- Protection of scarce resources,
- Miscellaneous environmental relief effects
- Paying attention to generational equity and demographic change,
- Peace promotion and non-violence.

Other criteria may be supplemented on a product-specific basis.

The presentation elaborated by the respective company on the aforementioned individual criteria is finally subjected to a semi-quantitative overall assessment. To this end, there is a need for both an analysis of the effects of the nanotechnology product as compared to the defined reference product, and a product-specific weighting of the individual criteria as well.

On the basis of a qualitative description of the key indicators, a provisional quantitative classification of the individual criteria, based on a scale from -3 to 3, is carried out by the company. At a value of zero, the societal benefit of the nanoproduct is equivalent to that of the reference product, while positive values indicate an edge over the reference product (slight advantage, advantage, significant advantage) and negative values correspondingly imply disadvantages.

For this indicator, we additionally recommend a weighting of the various criteria under analysis. In doing so, equal weight should initially be given to all criteria, assuming a numeric value of 1. If, however, the company has found that special importance should be attached to individual criteria relating to the analysed nanoproduct, this relevance can be taken into account by adapting the weighting of the appropriate criterion. A modified weighting requires a justification to be given for each specific product and criterion. It may either be assumed that the criterion is not relevant for the investigated product (then, further consideration of this criterion is not necessary), or that the criterion has great importance for the specific product (in this case, the weighting factor can be doubled).

6.5.3 Legal Framework and Research Funding

The key indicator "Legal framework and research funding" shall provide information on the support conditions for the investigated nanoproduct in the national and European context. It is to determine whether the nanoproduct under study already has access to favourable support conditions or to identify any shortcomings which might exist with respect to such conditions for nanoproducts.

The key indicator mainly describes the eligibility conditions for a specific nanoproduct in the following three areas:

- Company-own research funding, development and application of the investigated nanoproduct;
- Funding under state government programmes in Germany and the EU for the research, development and application of the investigated nanoproduct;
- Legal framework conditions for research, development and manufacture of nanoproducts in Germany.

The evaluation is to be carried out separately for each of the aforementioned areas. It should contain a verbal report describing the development of the specific nanoproduct over the last five years (here: 2005 to 2010) and presenting arguments and evidence in favour of the product. Within the scope of the "legal framework conditions", for example, the central questions that should be discussed are as follows:

- How do you currently view the legal framework conditions for research, development and production of your nanoproduct in your country?
- How have the legal framework conditions for research and development as well as for the production of the nanoproduct been developed between 2005 and 2010 in your country?

- In your view, what are the most serious obstacles to research, development and the production of the nanoproduct in your country, owing to shortcomings in the legal framework conditions?
- As regards the following points:
  - Standardisation of testing methods for the description of nanomaterials;
  - Regulatory approvals and requirements applying to research and the production process;
  - Manufacturer's liability (contractual security in the manufacturing chain) as well as
  - Environmental liability and producer liability,

  do you consider the conditions for the nanoproduct to be better or worse than those prevailing for the reference product that does not contain any nanomaterials, and which are the differences (if any)?

A justification for the development (positive, unchanged, or negative) should always be provided. The qualitative statements should as far as possible be backed with quantitative information, for example with regard to the funding amount or the weight assigned to sustainability issues when support is granted in the scope of a special programme.

The company, in an overall conclusion, will then assess whether and why the regulatory framework conditions and the research funds dedicated to the promotion of the nanoproduct, from their own perspective, are to be viewed as an opportunity or a threat, providing arguments and evidence relating to the product.

6.5.4 Recyclability

Based on the key indicator "Recyclability", it will be examined whether there are any differences between the nano- and the reference product with regard to certain properties and/or constituents or whether such distinctions which could impede a high-quality disposal or even make it impossible can be expected. In this context, a semi-quantitative determination will be conducted. On the basis of the following key questions, this examination will specifically address the question whether a product / waste has properties that might, for example

- cause problems and/or require a considerable investment of time and effort as regards the separation of other substances / materials contained in the specific product / waste,
- cause problems and/or require a considerable investment of time and effort as regards the separation of the respective product / waste from other products / waste, if such products or wastes have been generated or collected together or cannot be disposed of together (for example recycled),

- raise problems and/or involve a considerable investment of time and effort regarding the safety and health of workers in disposal facilities (for example facilities for the preparation of re-use or recycling, treatment and recycling plants),

and/or contain substances,

- leading to an unwanted accumulation in the new product,
- which need to be captured and separated (as, for health and safety reasons, for example, they should not find their way into the new product, or because they negatively affect the quality of the new product) and involve considerable time and efforts,
- which negatively affect its recycling together with other products / waste, in cases where there are significant quantities of generated waste.

Where, during the usage phase of the nanotechnological product, any waste containing nanomaterials has been generated, such as replacement parts for maintenance or repairing charges, this waste as well as the corresponding waste from the reference product must be included in the analysis.

The individual key questions will not be weighted against each other, since all of them are considered to be of equal importance and significance.

6.5.5 Resource Availability

By the key indicator "Resource availability", we understand secure physical, temporary, financial and technological access to resources which are used for the manufacture of a nanoproduct. The conceptual development of the analysis relating to the examination criteria and thus resource availability is based on the study (Buchert et al. 2009). Hence, examination criteria are as follows:

- supply risks;
- growing demand and
- recycling restrictions.

For each of the aforementioned criteria, subcriteria are being defined, which eventually form the basis for a semi-quantitative view. As regards supply risks, for example, the following aspects are to be considered:

- Regional concentration of mining
  - 90 % share of global production in 3 countries
  - 90 % share of global production in 4-6 countries
  - 90 % share of global production in a number of countries
- Physical shortage (reserves in relation to global demand)
  - Global reserves distinctly smaller than global demand
  - Global reserves exactly meet the global demand

  - Global reserves clearly exceed the global demand
- Temporary shortage (time lag between production and demand)
  - Current production lower than the global demand
  - Current production satisfies major part of global demand
  - Current production completely satisfies the global demand
- Structural or technical shortage (the resource is only a small by-product and there are significant inefficiencies with regard to excavations, production and processing)
  - Large inefficiencies with regard to excavations, production and processing
  - Minor inefficiencies with regard to excavations, production and processing
  - Excavations, production and processing are largely efficient

As part of the analysis, the individual subcriteria related to supply risks, growing demand and recycling restrictions, are classified into the categories "high" (3), "medium" (2) and "low" (1). If availability of a resource is particularly critical for one aspect, it will be assessed with a "high" valence and will be rated as a "3". If, for example, the regional concentration of a resource is greater than 90% in less than three countries, the criterion of "Regional concentration of mining" is assigned to the valence "high" and the rating "3".

As regards recycling restrictions, the analysis will only be performed if the assessment confirms the existence of a critical situation for the subcriteria "Supply risks" and "Growing demand". In the case of resources for which there is a lack of pressure to address the problem, this is due to the fact that the appropriate infrastructure for recycling in most cases will not be established for such subcriteria (sand, for example) and, from this point of view, the product would score badly from the very beginning.

In order to obtain the overall classification, the results of the individual subcriteria are finally added up to a total score. In many cases, several resources have to be examined per nanoproduct in terms of their critical availability. In such cases, the resource with the highest score will be taken as a basis for the evaluation.

Eventually, inclusion of the key indicator into the Nano-SWOT Matrix will be conducted as follows:

- In cases where the overall rating for both the nano- as well as the reference product will be the same (for example "critical"), the key indicator will be viewed as being indifferent.
- Given that the overall classification identifies a lower risk for the nanoproduct than for the reference product (for example "less critical" versus "critical"), the key indicator "Resource availability" is to be regarded as an opportunity.

- If, however, the overall classification reveals a lower risk for the reference product than for the nanoproduct (for example “less critical” versus “critical”), the key indicator “Resource availability” has be considered as a threat.

6.5.6 Risk Perception

Risk perception and acceptance of a technology is essential for the confidence of business customers, professional users, as well as private consumers in a product and its manufacturer, whilst also being a determining factor for the opportunities and threats in the context of marketing a nanoproduct. This applies all the more as the development of nanotechnologies in Germany is still in its early stages, in which acceptance can rapidly change, depending in essence on whether the product will be accepted and bought by the customer or not (VZBV 2008). Within the scope of a sustainability check of products, this is a relevant issue, since only if a product can assert itself in the market, the opportunities that may be associated with a product in terms of the various sustainability aspects can actually materialise.

Using the key indicator “Risk perception”, four aspects relating to the company-internal treatment of risk perception are investigated. These include:

- Company-internal assessment of the nanoproduct’s potential risks;
- Analysis of the product environment;
- Risk management and
- Risk communication.

On the basis of a qualitative approach, it is to be determined how the company's own perception of the risk potential in a given product environment correlates with risk management and risk communication. For the purpose of the indicator “Risk perception”, the analysis will not be grounded on a purely technical and scientific definition, but presume a complex understanding of the risk concept which follows the three-level model of Haller (Haller 1995; Grobe, 2004). According to this model, risk perception and risk communication basically occur on three different levels (scientific / technical analysis of the risk, psychology of risk and sociology of risk), each level being based on a specific logic and generating its own objectivity.

For this indicator, the consideration of internal and external risk perception is carried out in two separate domains:

- Risk assessment;
- Risk management and risk communication in the context of the product environment.

The analysis is initially conducted separately for each domain.

In the first domain – risk assessment – criteria will be used to determine how the human and ecotoxicological risk is to be viewed from a technical / scientific point of view. Furthermore, it is necessary to determine whether there is a reason for the company to actively pursue risk communication. The potential reasons lie above all in well-known risks on the technical / scientific level or in the fact that wide degrees of uncertainty have been identified with regard to certain risks. This evaluation shall be made on the basis of the classification into the classes A or B as for the key indicators “Risk estimation for men and environment” and “Incident aspects”.

On this basis, the risk management measures taken and the risk communication pursued are to be assessed within the scope of the second domain. Besides, it needs to be clarified whether these activities are an appropriate response to the evaluated risk. It should be noted, however, that risk communication measures may depend on the size of the company. These risk communication measures shall be correlated to the “product environment”. The company’s views concerning the product environment should be described. It must also be stated whether the company is able to actively influence product perception or whether it has to restrict itself to a reactive position, only monitoring the development of the product environment. Hence, risk perception and acceptance of a product may be substantially influenced by negative events associated with other products belonging to the same or even another product class, on which the company has only a limited influence.

Taking an overall view highlighting the two aforementioned domains, it is to be concluded whether the aspects of the internal and external risk perception, from the company’s point of view, present themselves as an opportunity or a threat with regard to the product. It can thus be distinguished between the following four basic combinations which, within the framework of the SWOT analysis, should be classified as follows:

- The company-internal assessment comes to the conclusion, that there are only low nano-specific risks requiring no risk management or risk communication measures at all or only a few of these measures to be taken. In such a case, the indicator should be considered as an indifferent one.
- Although the company-internal assessment comes to the conclusion that nano-specific risks cannot be ruled out, these may however be mitigated by risk management and risk communication measures to an appropriate extent. In this case, too, the indicator is indifferent.
- The company-internal assessment comes to the conclusion that there are no or only very low nano-specific risks. Due to its position in the product environment and because of the risk management and risk communication measures taken, the company, however, is in a position to respond adequately to the public risk perception. In this case, the indicator should be considered as an opportunity.
- The company-internal assessment comes to the conclusion that there are some nano-specific risks or that these risks cannot be ruled out altogether, and that no risk management or risk communication measures at all or only inappropriate measures have been taken with view to the product environment. In this case, the indicator should be regarded as a threat.

6.6 Interpretation of the SWOT Matrix

The evaluation of the individual key indicators will be incorporated into an integrated overall assessment establishing the knowledge base on which recommendations for the strategic optimisation of the specific application will finally be drawn up. These recommendations relate both to strengths and weaknesses as well as to opportunities and threats. The aim is to maximise the positive sustainability potential of strengths and opportunities, while at the same minimising the possible rebound effects attributable to weaknesses and threats.

To this end, the following combinations existing in the SWOT matrix will be investigated in a targeted manner, and appropriate measures will be derived from the results:

- Combination of strengths and opportunities: What are the best matches between strengths and opportunities? How can strengths be used to better utilise opportunities?
- Combination of strengths and threats: What strengths have to be selected to counter the respective threats? How can existing strengths be used to avoid the consequences of certain threats?
- Combination of weaknesses and opportunities: How can weaknesses be turned into opportunities? How can weaknesses be turned into strengths?
- Combination of weaknesses and threats: What are the weaknesses of nanotechnological applications, and how can the company be protected against threats or actual damage?

6.7 Cooperation in the Development and the Testing of the Analysis Grid

The development of the analysis grid and its application within the scope of case studies was preceded by an analysis of companies' interest in taking part in a Nano-Sustainability Check pilot application. The associated work was designed as a kind of preliminary study and commenced with a broad-based screening programme, under which, broken down by industry sectors, specific applications offering promising sustainability potentials were considered. The starting point for this venture were results of the NanoDialogue 2006-2008 (BMU 2008) and preliminary studies on the subject carried out by the Federal Environment Agency (UBA) (cf. section 4.4.1).

In a second step, the manufacturers and/or developers of the identified products were directly addressed in the second half of 2009. Besides, the framework conditions and prerequisites for participation in this project were explored. These efforts included presentations that were sometimes held at the companies' premises. The following table provides a selection of the companies invited to participate, specifying the products under consideration:

Table 5: Direct contacting of companies in the context of the analysis of interests (own research)

Company	Product
BASF	*Concrete accelerator (X-SEED)*
Bayer Material Sciences	CNT-based lightweight materials
Costec Technologies / Rewitec	Nanoparticulate silicon dioxide as engine oil additives
Dykerhoff	Cement containing nano-components
Elastogran	Nanofoams for thermal insulation
First Solar	Thin film cells
Evonik	Nano-scale platinum-palladium catalyst for the direct synthesis of hydrogen peroxide
ItN Nanovation	Anti-fouling coatings
KHS Plasmax	PET bottles with a nano-barrier layer
Merck	Photovoltaic materials
Nanogate	*UV protective coating (pro.Glass Barrier 401)*
NTC NanoTech Coatings	Anti-corrosion protective coatings

At the turn of 2009 / 2010, we succeeded in recruiting two highly appropriate case examples, namely the products of BASF and Nanogate which are described in the following sections. The Federal Environment Agency agreed on the selection of the submitted products, the following selection criteria having been taken into account:

- The product must be a "genuine" nanoproduct, i.e. the use of nanomaterials[30] is necessary for production;
- A conventional product or a conventional application with a functionality comparable to that of the nanoproduct must exist on the market, in order to permit the comparative assessment required by the objective;
- That product should be able to survive in a high-volume market so that it can be used as a leverage in terms of sustainable use of resources and with a view to energy efficiency;
- The product should be shortly launched on the market or already being marketed, as it has to be guaranteed that the data being proceeded for manufacture, usage and disposal phase are fully reliable;
- The company must be able to provide sufficient (human) resources for data collection, as well as for the necessary meetings and presentations within the scope of the project.

Following the determination of the case studies, the work on the methodological approach taken in the Nano-Sustainability Check that had been undertaken in the meantime, was completed and, in the spring of 2010, a draft of the analysis grid was presented and dis-

[30] Definition see section 6.1.1.

cussed together with BASF and Nanogate during an internal workshop. In the following six months, the two companies applied the tool and the related guidelines and Excel Tools with the aim of identifying the most appropriate key indicators for the selected case studies. On the basis of the experience gained during this process, guidelines as well as Excel tools have been revised. The adjustments in question concerned first and foremost the user-friendliness of the instrument, which could be further improved by the integration of explanations originating from the guidelines into the specific Excel tools, rendering them accessible in the "online help". In addition, the approach to be taken for the individual analysis steps as well as the definition of the boundaries between the individual key indicators were further specified. In a second joint workshop carried out in autumn 2010, the preliminary results obtained with the key indicators and their incorporation into the SWOT analyses were validated by the Öko-Institut. Moreover, data gaps that had existed with regard to individual key indicators at that time could be filled. The cooperation in the development and testing of the analysis grid was finally concluded in a jointly issued brochure about the principal outcomes of the Nano-Sustainability Check, based on a draft submitted by the Öko-Institut.

7 Results of the Case Study pro.Glass Barrier 401

In the presented case example, the product pro.Glass® Barrier 401 of the company Nanogate Industrial Solutions GmbH will be investigated. The following sections will first describe the product (section 7.1), then present the outcomes of the SWOT analysis (section 7.2) and of the individual key indicators (section 7.3) before discussing them (section 7.4). Finally, strategically oriented aspects of product optimisation will be highlighted (section 7.5).

7.1 Product Description

Pro.Glass barrier 401 is a surface coating for glass which is highly protective against UV-rays. This protective effect is achieved by a deposition of nano-scale zinc oxide. This coating is deposited on the glass through dipping, blanket coating or rinsing of a conventional window glass by means of a solvent-based, single component paint. In order to harden the coating, it is subjected to a thermal curing procedure. As a result of curing, the coating is abrasion-, solvent- and hydrolysis-resistant, highly transparent and optically neutral. Pro.Glass barrier 401 is suitable for shop windows, as well as for museum jars, picture frame glasses and showcases, protecting the respective exhibits against harmful UV rays.

The company Nanogate Industrial Solutions GmbH manufactures the solvent-based paint system, which, for example, is used for preparing the immersion bath needed to perform the coating of the glass. In a sequence of several processing steps, the ready-to-use liquid material is first being adhered to a glass plate by a glass coater. Then, the coated panes will be sent to plants for further processing. In order to ensure the desired functionality by means of the processing process, Nanogate Industrial Solutions GmbH provides nanoscaled zinc oxide particles with a special coating, which will then be embedded into a silicone based hybrid matrix.

The zinc oxide particles are spherical particles having an average diameter D_{50} of approximately 20 nm. The weight of the zinc oxide in the annealed layer amounts to about 30%. The thickness of the annealed layer is 1.5 micrometres on average. Following the coating application and the curing process, the nanomaterial, in chemical terms, is tightly embedded in a surrounding matrix.

For the application of pro.Glass barrier 401 in the scope of this case example, it is assumed that a wet-chemical dip coating of flat glass of 3 mm in diameter will be carried out. To this purpose, an immersion cuvette with about 180 litres of pro.Glass Barrier 401 is used (see following figure), with approximately 15-20 grams of pro.Glass barrier 401 per square metre of flat glass being processed. The time period set for the durability of the immersion cuvette is one year, following which the remaining material in the immersion cuvette will be disposed of.

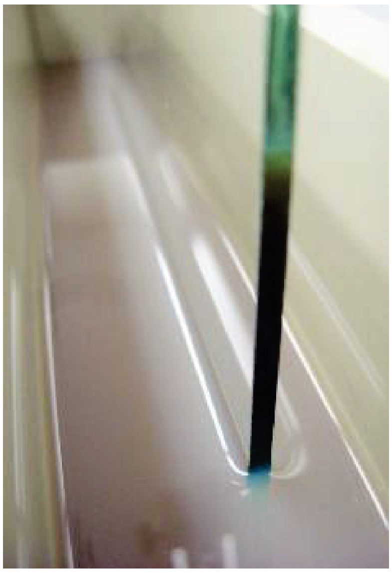

Figure 4: Immersion bath for the deposition of pro.Glass Barrier 401 on a glass pane (Source: Nanogate)

After air extraction at room temperature for a few minutes, the curing process of the layer requires temperatures of approximately 200° C for about 30 minutes. The remaining layer thickness is about 1-2 micrometres.

The basic functionality (significant UV absorption as well as optical neutrality) is characterised by a sharp rise of transmittance from 0.83% at wavelengths of 350 nm to 85.57% at 400 nm (see following figure). In the wavelength range of UV light (approx. 200-380 nm), absorption is about 93%.

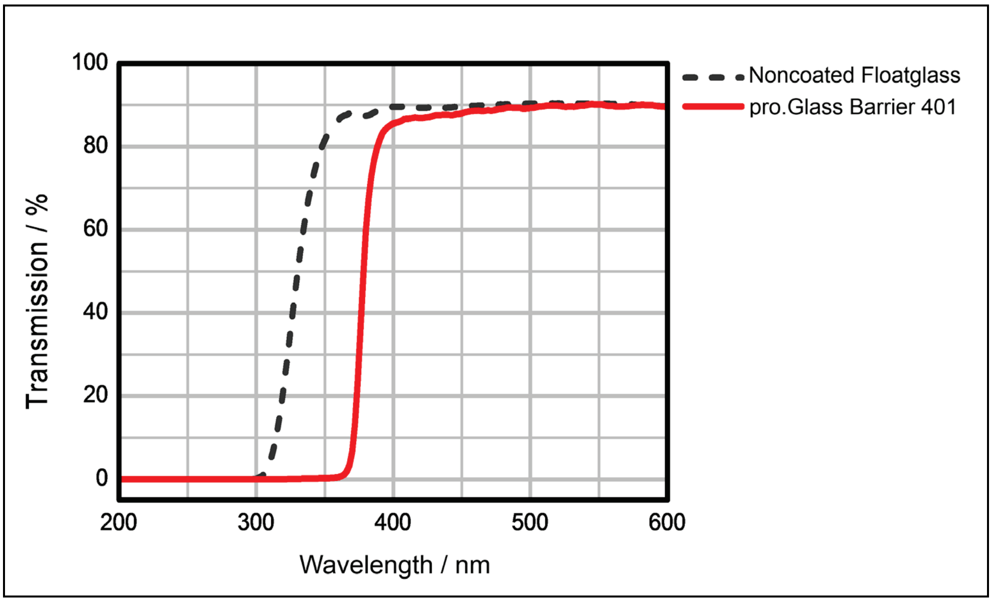

Figure 5: Dependence of transmission behaviour on the wavelength for noncoated glass and on that for glass coated with pro.Glass Barrier 401 (Source: Nanogate)

It should be noted, that the coated pane has a low haze (< 0.3%, on both-side coated glass, measured using the BYK haze-gard) and a minor inherent colouration.

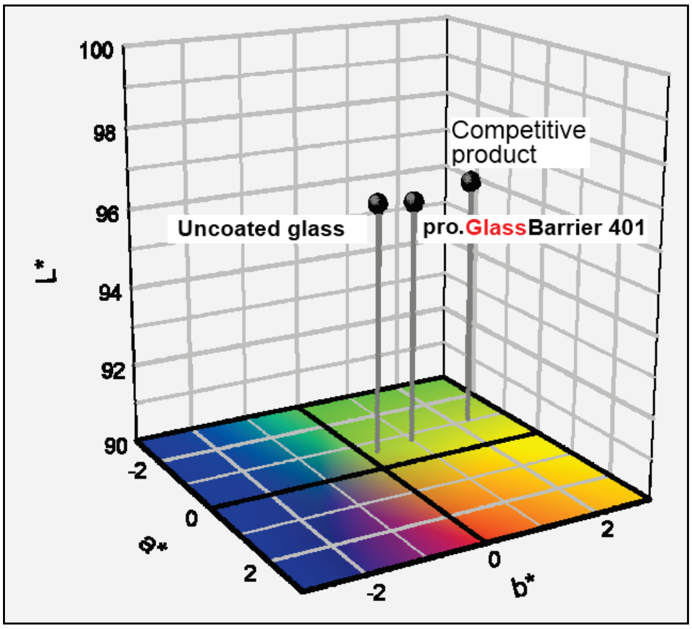

Figure 6: Intrinsic colouration of the coated glass compared to uncoated glass and competitors; colours were measured in the LAB colour space, L*: luminance, a*, b* colour (Source: Nanogate)

As a reference product, a product also exhibiting a high UV protection was selected in order to ensure that the reference product will have the same basic functionality as the one reached by the nanomaterial. Currently, this feature is typically being achieved by using UV absorbers in the coating process. According to the objectives of the Nano-sustainability Check, a comparison with other nanoproducts should, however, be refrained from. A comparison with a “zero option” (uncoated glass pane without UV protection) would not have revealed the specific characteristics of the coated glass pane. Within the scope of the case study, a comparison has therefore been carried out between a nanoproduct, namely flat glass coated with pro.Glass barrier 401, and a reference product using an organic UV absorber (competitive product).

Coating process, thickness and initial properties of the reference product are supposed to be similar to those of pro.Glass barrier 401. In terms of the achieved UV absorption, both products are assumed to have the same quality. There are, however, substantial differences concerning the longer durability of the UV absorption effect provided by the nanoproduct in comparison to the reference product. Tests carried out in order to monitor the change in UV radiation resistance, even after 3000 hours of sunshine, revealed no change of colour or cloudiness. Hence, it may be presumed that the functional durability of Nanogate’s coated glass pane is 1.5 greater compared to that of the reference product. Moreover, the intrinsic colour of the pane coated with pro.Glass Barrier 401 is considered to be less strongly pronounced than that of the reference product.

The functional unit specified on this basis and with view to the following analysis is one square metre of coated flat glass (Optiwhite, thickness 3 mm).

7.2 SWOT Matrix

As regards the nanoproduct, the evaluation that has been carried out identified strengths for the key indicators of “Product Carbon footprint”, “Energy efficiency”, “User benefits”, “Life-cycle costs” and “Symbolic benefits”. The key indicators “Risk estimation for men and environment” and “Incident aspects”, however, were attributed to the area of weaknesses.

Opportunities appeared in the field of risk perception. Threats cannot be identified in the scope of the SWOT analysis.

In terms of the remaining key indicators "Employment effects", "Workplace exposure", "Societal benefits", "Legal framework and research funding", "Recyclability” and "Resource availability" there were no significant differences. Hence, these indicators were classified as indifferent (see following figure).

Figure 7: SWOT matrix with results related to the key indicators within the case study “pro.Glass Barrier 401” (own research)

7.3 Individual Results of the Key Indicators

The following section will present the results of the self-evaluation of pro.Glas Barrier 401 GmbH carried out by the company Nanogate Industrial Solutions GmbH for the individual key indicators of the SWOT analysis. First, the strengths / weaknesses level will be depicted. We then proceed to the level of opportunities / threats.

7.3.1 Strenghts / Weaknesses Analysis

The outcomes of the analysis of strengths and weaknesses are presented in the following section.

Product Carbon Footprint

For a comparison in terms of the product carbon footprint, the production and distribution of 1,000 kg of coated flat glass with a thickness of 3 mm was examined by way of derogation from the above defined functional unit. In case of a density of about 2.49 g/cm³, this accounts for an area of about 134 m². Thereby, account has been taken to the fact that the reference product's UV-effective effect proved to have an inferior durability. Thus, instead of 1,000 kg of the nanoproduct, 1,500 kg of the reference product have to be provided in the temporal mean. Furthermore, assuming that production for Germany takes place at a single site, it can be presumed that the average transport distance (for the coating material, the uncoated and the coated glass panes) will be 500 km.

Under these assumptions, the bulk of the CO_2 emissions is accounted for by manufacture and disposal of the flat glass itself, while the coating's contribution to the product carbon footprint ranges in the per mille region, both for the nanoproduct as well as for the reference product.

The overall product carbon footprint of the nanoproduct is much lower than that of the reference product. The reason for the better performance of the nanoproduct is its 50 % longer durability in terms of its UV protective effect, thus saving a corresponding amount of coated glass, while glass replacement becomes necessary where the reference product has been used. The lower curing temperature, too – 200° instead of 450° Celsius – has a positive impact on the product carbon footprint, although the curing process, too, contributes to the overall product carbon footprint, its contribution, however, only accounting for approximately one percent.

This results in a significant reduction of CO_2 emissions, amounting to approximately 33%. Per ton of coated flat glass, 665 kg of CO_2 can be saved by using the nanoproduct. In the global context, however, this does not result in significant CO_2 saving potentials, since it is assumed that only a total of roughly 1,000 tonnes of UV-absorbing glass is produced worldwide.

Energy Efficiency

The boundary conditions assumed for determining energy efficiency were the same as those on the basis of which the determination of the CO_2 footprint was carried out. Also in terms of energy efficiency, the manufacture of nanomaterials (also compared to the organic coating material for the reference product) only plays a minor role, contributing to energy input only in the range of some per mille. Therefore, wide degrees of uncertainties which, in certain cases, need to be assumed with regard to the energy input for the manufacture of the nano-structured zinc oxide, are not able to affect the results, thus not playing a dominant role either. The outcomes are dominated, similar to that of the product carbon footprint indicator, by the longer durability of the UV protection effect provided by the nanoproduct and the resulting lower energy expenditure in the manufacture of flat glass and the recycling of flat glass that has been disposed of.

Also in terms of energy efficiency, significant savings, i.e. roughly 33%, could be achieved.

Workplace Exposure

As regards the analysis of workplace exposure, there was a need to reflect the underlying scenario again, since a clear production scenario cannot be derived from the above defined functional unit alone. In order to be able to evaluate expenditure and costs for the production of the nanoproduct compared to that of the reference product, however, premisses have to be made. The semi-quantitative assessment in the context of this key indicator was based on the assumption of a manufacturing facility with a capacity of 200 kg of pro.Glass Barrier 401 including the necessary resources and the subsequent coating process.

A small disadvantage to Nanogate, as a result of dealing with a powder nanomaterial (before this is available as pro.Glass Barrier 401, i.e. as a liquid nanoproduct), is the manufacture of the nanoproduct in comparison to the reference product with regard to the aspects of “Setting up and operating stationary extraction systems with subsequent treatment of exhaust air”, “Delineating areas where hazardous substances and materials are used”, “Making available personal protective equipment (inhalation masks, protective suits, protective gloves, et cetera)” and an “Increased share of expenses for safety measures and safe working conditions in the overall maintenance and operating costs”, due to a slightly increased overall expenditure that might be required for increased respiratory protection measures or enclosures. On the whole, however, there are only a few issues in terms of which slight differences were revealed as compared to the reference product. Accordingly, the analysis concluded that the investigated indicator was indifferent.

User Benefits

According to Nanogate, the most important factor with regard to user benefits were differences in terms of the nanoproduct’s durability and especially concerning the less pronounced inherent colouration of the coated glass pane in comparison to the reference product. This might become a critical factor in the purchasing decision, as, in addition to the advantage relating to the acquisition costs (see key indicator life-cycle costs), less expenditure is required with regard to the replacement of the glass pane that needs to be carried out at regular intervals. Another customer benefit stressed by Nanogate relates to the area of comfort, as the superior durability of the inorganic coating, in comparison to the organic coating material, makes cleaning of the glass panes much easier.

Life-Cycle Costs

On the basis of data available in the company, the analysis for the key indicator of life-cycle costs must be limited to the pure costs of acquisition. It is not expected, however, that there will be significant differences in the running costs. In general, it is even more likely that potential savings will be achieved due to advantages relating to the cleaning process (see key indicator user benefits). However, there has not been any estimation on the contribution of the maintenance costs in proportion to the cost of acquisition. Hence, it is not possible to predict the relative savings over the entire life cycle.

Differences in the acquisition costs again do not reflect differences in costs based on the coating materials used (organic compound versus nanomaterial), as the latter shall be deemed to cost about the same in terms of the accuracy of the examination. Differences must rather be attributed to the longer durability that may be realised for the glass pane and its coating. In the reference case, a larger quantity of coated glass must consequently be acquired for a defined unit of time, provided that UV absorption is considered to be an essential property of the glass pane, and that an early replacement of the glass is therefore carried out for the reference product. In relation to the reference product, significant savings of approximately 30 % result from the use of the nanoproduct.

Risk Estimation for Men and Environment

With reference to the risk estimation for men and environment, Nanogate first notes that the needed information about the nanomaterials' life cycle is available, if one disregards a certain degree of uncertainty relating to the preceding chains (in the production of nanoparticles).

With regard to potential effects, it is advantageous that the nanoparticles used only have a low stability, which means that they remain in the environment or the human body only for a very short period of time. Opposing this assessment, however, is the classification relating to the redox potential or the catalytic activity of nanoparticles, which has been rated as "medium".

With regard to a potential exposure of workers and the environment it turned out to be unfavourable that, on the other hand, relatively large volumes of nanomaterials (> 120 mg in relation to the individual operation) are handled during the processing of nanoparticles and the preparation of the immersion bath, and that, on the other hand, larger volumes (5-500 kg) of nanomaterials, in particularly of unprocessed nanomaterials (disposal of immersion bath after one year) and/or of the finished product are disposed of at the end of their life cycle via the usual channels of the waste disposal industry.

Hence, the key indicator "Risk estimation for men and environment" has to be classified as belonging to the category of weaknesses. Although the absolute values for the various preventive aspects that had been previously defined proved to be relatively low, the results slightly exceed the defined threshold of 20 in the fields of "Precautionary need for workers" and "Precautionary need for the environment". In this context it should be noted, however, that especially the precautionary need for workers concerns people working in the processing of nanomaterials. The precautionary need for the consumer or, in this case, the end customer (buyer or user of the coated glass pane) falls well below the defined threshold, which is mainly due to the fact that the nanoparticles are firmly embedded in a solid matrix.

Incident aspects

When looking at the incident aspects, boundary conditions prevail, which are basically comparable to those applying to risk estimation for men and environment (medium level of potential impact, with nanoparticles exhibiting a low degree of stability). In considering this key indicator, it is essential to note that, owing to the proportion of the solvent contained in pro.Glass Barrier 401, a substance with a major-accident potential is present in the establishment. In addition, rather high quantities of nanoparticles are handled as a result of batch operation (preparation of an immersion bath in relatively large quantities).

In terms of the final outcome, the key indicator “Incident aspects” is to be assigned to the area of weaknesses. Concerning the parameter “Precautionary need for workers” the result exceeds the defined threshold of 20 thus implying additional risk provision requirements. In contrast to this, however, an increased need for provision has reportedly not been identified for the population.

Symbolic benefits

As for the key indicator “Symbolic benefits”, Nanogate, in terms of design, points to the less pronounced inherent colouration of the coated glass pane in comparison to the reference product. Since the fields of application of UV absorbing glass panes are considered to be the area of shopwindow glass and artificial glass / glass for showcases in particular, the requirement that the intrinsic colouration of the final product is as weak as possible plays an important role, and even may become a critical factor in the ultimate purchasing decision to many users. Therefore, Natogate regards this aspect as a significant advantage in comparison to the reference product, and even considers this issue to be of utmost relevance to the overall result. Because of the use of inorganic nanomaterials, the “modernity” of the product is viewed as an advantage by the company, comparing to the reference product. Within the overall assessment, the indicator “Symbolic benefits” should thus be regarded as a strength.

7.3.2 Opportunities / Threats Analysis

The following section outlines the results of the opportunities / threats analysis:

Employment effects

In the field of “Employment effects”, Nanogate identified a slight increase in employment for the own enterprise over the 2008-2010 period. Contrary to this trend, employment in the upstream and downstream chains stagnated or experienced a slight decline. In absolute terms, however, the estimated employment effects are minimal. In the overall assessment, this key indicator has thus been classified as indifferent.

Societal Benefits

Analysing the key indicator of "Societal benefits", "Promotion of education and information" was the only aspect for which Nanogate could identify slight advantages in comparison to the reference product, which is due to the fact that use of the product promotes better protection and/or a longer durability of products of cultural significance (documents or works of art). Other influencing factors, as compared to the reference product, could not be identified. All in all, the impact of the nanoproduct on this indicator was classified as indifferent.

Legal Framework and Research Funding

Questions concerning research funding only played a negligible role in the development of pro.Glass barrier 401. The chance of receiving public funds for this product or the product class, however, is viewed as rather favourable by Nanogate.

With regard to the legal framework conditions, Nanogate faces a very inhomogeneous environment. Although a basic regulatory framework, namely the Chemicals Act, is in place for the use of nanomaterials, uncertainty remains about assessment methods for evaluating the human toxicology and ecotoxicology of nanoparticulate systems. This gives rise to uncertainty whether in many areas, such as in the field of health and safety requirements, increasingly higher standards will have to be met in the future.

Overall, this inhomogeneous picture resulted in an indifferent indicator.

Recyclability

With a view to recyclability of the glass panes, Nanogate predicts only marginal adverse effects arising from the particular coating materials used (organic coating versus inorganic nanomaterials). Fundamentally, impacts on the recycling infrastructure are conceivable for both coatings. It cannot be ruled out, for example, that, under unfavourable conditions, toxic substances may be released during thermal decomposition of an organic coating. The use of the inorganic nanomaterial, on the other hand, basically implies the possibility of an accumulation during the glass melting process. Given the very low volume of the respective substances, after all, this is not considered as decisive for the recycling process in both cases, the overall result being an indifferent indicator.

Resource Availability

From the perspective of "Resource availability", glass, the nanoparticulate zinc oxide as well as the organic absorber are viewed. High availability of all required resources seems to be adequately ensured, whilst supply risks are relatively low. As, in those circumstances, recycling issues have no relevance for resource availability, they were not further analysed. Overall, no relevant differences were observed between nanoproduct and reference product. Hence, the indicator was assessed as being indifferent.

Risk Perception

In estimating the risk potential in the scope of the risk perception evaluation, Nanogate obtained a favourable outcome from analysis, even though it has been shown that there is an increased precautionary need for the key indicator “Risk perception for men and environment” as well as for the key indicator “Incident aspects”. According to Nanogate, this is due to the fact that the precautionary need relates to those sections of the value added chain, where only professional users or processors are affected. Since the underlying processing methods are to be regarded as state-of-the-art in science and technology, and as the toxicological risk to human health – in the light of the available know-how about the nanomaterial in question – can be classified as low by Nanogate, the company considers these risks to be manageable. Nanogate’s estimation, moreover, is premised on a high degree of probability for an agglomeration of nanoparticles during the disposal of liquid waste, so that the nano-specific risks for the environment may also be regarded as low.

Within the context of risk management, Nanogate, at the same time, has a strong commitment in various fields of research, aimed at resolving outstanding issues relating to the evaluation of human toxicological and ecotoxicological effects of nanomaterials. In addition, recent evidence on the safety of nanomaterials is regularly evaluated with regard to its importance for the company. Finally, Nanogate, in the field of risk communication, is strongly interlinked with various scientific, political and social groups and pursues an approach based on active communication, both with regard to the investigated product as well as regards the general debate on the risks of nanomaterials.

In conclusion, the indicator “Risk perception” is therefore classified as an opportunity.

7.4 Discussion of Results

Pro.Glass barrier 401 is a nanoproduct which optimises the already existing functionality (UV absorption property of a glass coating) of a non-nano product by using a specially developed nanomaterial. Thus, the final product constitutes an evolutionary enhancement of an already existing reference product and, unlike this, offers several functional differences which are reflected in some of the key indicators. On the whole, however, an essentially new functionnality will not be put forward. It is even more unlikely that efforts will be made to advance an an even revolutionary further development of a product. Accordingly, a greater number of indifferent indicators can be attributed to this nanoproduct, while the differences in functionality that have been deliberately provoked, result in a number of strengths relating to the product.

When looking at several key indicators, the improved long-term durability of the nanoproduct’s UV absorption property represents a major influencing factor. This investigation was based on the assumption that the considered functional unit will actually be replaced in time intervals defined according to the durability of the UV-absorbent layer. Only if this is the case, the differences in the durability of the UV-absorbent layer will bring about major advantages in terms of the respective indicators. If, however, the UV-absorbent layer presents an additional customer benefit and therefore may be a strong reason for buying the product, but there is no direct need concerning the use of the end product, namely the coated glass pane, the boundary conditions relating to the time intervals of product replacement are likely to be completely different. In such a case, the picture produced would also be an indifferent one for most of the indicators that have been studied. Hence, the results achieved in this context are applicable only to those cases where the UV-absorbing effect actually constitutes an integral part of the product.

Furthermore, Nanogate also stressed that it should be noted, with reference to an overall interpretation of the various indicators, that diverse players along the value chain will assign a different relevance to the individual key factors. While “Incident aspects”, for example, especially play a role for manufacturers, but not for the end customer, i.e. the purchaser of the coated glass pane, the practical advantages relating to user benefits by contrast have direct relevance to the end customer. Taking this into account, an overall evaluation of the individual factors cannot be done without a detailed consideration of the underlying factors of influence.

7.5 Strategic Optimisation

Concerning Pro.Glass barrier 401, no key indicator was assigned to the category of threats and only two key indicators (Risk estimation for men and environment, incident aspects) to the category of weaknesses. These weaknesses are particularly balanced by the classification of the indicator risk perception to the category of opportunities.

“Risk estimation for men and environment” is classified as a weakness, because in view of workers, rather high quantities of nanomaterials (> 120 mg) in liquid form are handled during the preparation of the immersion bath, while, from an environmental viewpoint, there is no nano-specific disposal of the immersion bath, meaning that there is a rather extensive release of nanoparticles in liquid form (5-500 kg) in the standard routes of disposal and thus, in the worst case, in the environment, too. So far, it is an open question whether and how a retention or agglomeration of nanoparticles takes place during the disposal process and whether a release into the environment must therefore be assumed. Likewise, a specific disposal of the nanoproduct (coated glass) at the end of its life cycle is currently not provided for, the nanoparticles, however, being embedded in a solid matrix at this time.

Concerning the incident aspects, an increased precautionary need applying to the production process of the liquid coating material arises with regard to the protection of workers. The reason for this is that significant amounts of hazardous materials and nanomaterials (>1 kg) of a major-accident potential could be present in the establishment or in the workshops.

In order to turn these weaknesses into strengths or at least into indifferent indicators, the uncertainties prevailing especially with regard to the human and eco-toxicological evaluation, as well as in terms of the disposal of nanomaterials and the nanoproduct, should be addressed. Given Nanogate's longstanding commitment in the field of research into human and ecotoxicological issues, the company is well positioned to meet these challenges, as can be seen from the classification of the indicator of risk perception into the category of opportunities.

Greater clarity is particularly needed on whether disposal of both the immersion bath with nanomaterials in liquid form and of the UV-coated glass as well poses a risk to the environment. In terms of disposing the immersion bath, a rapid agglomeration of the nanoparticles after disposal can be assumed under usual environmental conditions. It remains an open question, however, whether an ecotoxicological hazard potential can thereby be completely ruled out, or whether a separate disposal might possibly become necessary.

Further testing is needed as regards the incorporation of nanoparticles into the coating of the finished nanoproduct. Based on the fact that the materials are firmly embedded in the product matrix, only a small release into the environment might be assumed, at least for the moment. Here, too, however, there still are uncertainties as to whether there could be a remobilisation of nanoparticles when it comes to glass recycling. In order to be able to make more reliable statements on this matter, further research activities are needed. With its participation in various projects on human toxicological and ecotoxicological effects of nanoparticles, Nanogate is actively involved in such activities.

With regard to potential hazards arising from incidents, Nanogate furthermore ensures safe and reliable working on the basis of risk assessments which, in connection with precautions required for safety reasons, are regularly carried out.

Potential for further optimisation might exist in respect of the batch procedure that is being used (comparatively small batch size, reducing the number of potential exposure pathways when preparing the batch). This would also help to reduce the risks of potential major accidents in the course of preparing the immersion bath. In this context, the evaluation of the key indicator "Workplace exposure" plays a relevant role, estimating that some additional expenditure might become necessary for occupational health and safety measures, as compared to the manufacture of the reference product. As an indifferent result was achieved for this key indicator, it is not to be expected that any additional occupational health and safety measures that might need to be taken would lead to a significant deterioration of the overall outcome achieved for the nanoproduct.

8 Results of the Case Study X-SEED

In parallel to the abovementioned case example, product X-SEED® of the company BASF SE was considered. The following sections first describe the product (section 8.1), then depict the results of the SWOT matrix (section 8.2), as well as of the individual key indicators (section 8.3) and subsequently discuss the results achieved (section 8.4). Finally, aspects relating to the strategic optimisation of the product will be addressed (section 8.5).

8.1 Product Description

In the presented case, the nanoproduct under investigation was a prefabricated concrete part that was manufactured by adding the hardening accelerator X-SEED of company BASF SE. The precast concrete component was compared to a conventional product without accelerator.

In order to ensure comparability of nanoproduct and reference product, both alternatives have to provide the same technical functionality. For this purpose, it is necessary to analyse the various aspects of utility for both products, and to specify a basic common functionality (see also section 6.2.2).

First of all, it is necessary to explain how concrete is manufactured and used. According to EN 206-1: 2000, concrete is defined as a building material, produced by mixing cement, coarse and fine aggregates and water (so-called mixing water) with or without the addition of concrete additions (such as “condensers”) and admixtures (such as “limestone meal”).

Concrete is a major mineral building material in the construction industry, which, as fresh concrete mixture, can easily be processed and transported, and by means of which, even so, monolithic components can be produced as a result of hardening.[31] Besides the use of concrete on building sites (filling the formwork), pre-fabricated concrete elements (precast concrete products) play an important role in the later construction of the building. Accordingly, the share of precast concrete products in the total European market is over 20%, in Germany, this share is already at the level of 30%. When manufacturing precast concrete products, (highly) flowable concrete is poured into reusable moulds or formworks, the subsequent processing and hardening occurring under controlled conditions. The parts are then stored until they are delivered to the construction site, and, depending on the stage of advancement of construction, can be delivered onto the site where they are immediately lifted into their final positions in the building structure.

The constituents of concrete and their functions can be described as follows:

- An indispensable component of concrete is cement, the manufacturing of which is responsible for 5% of world-wide CO_2 emissions. [32] According to EN 197-1, five main types of cement can be distinguished:

[31] Cf. Quack, D.: Liu, R.; Ökobilanz Betondecken - Eine vergleichende Analyse von Spannbeton-Fertigdecken mit Halbfertigteildecken und Massivdecken aus Ortbeton, [LCA of concrete floors. Comparative analysis of prestressed precast floors with partially precast floors and cast-in-place concrete floors], p. 23.

[32] Cf. http://www.wbcsdcement.org/pdf/agenda_gr.pdf (as of 15th August 2011).

  - CEM I: Portland cement; The main component of Portland cement is granulated Portland cement clinker;[33]
  - CEM II: Portland composite cement; This consists of various basic components, each of which can be recognised by certain letters in the cement designation;
  - CEM III: blast-furnace cement; main components are Portland cement clinker and granulated blast furnace slag;
  - CEM IV pozzolanic cement[34] and
  - CEM V composite cement.
- aggregates, accounting for 70% of the total concrete volume, are the main component. They are a mixture or cluster of broken or unbroken grains, composed of natural or artificial mineral substances which are cemented to concrete by adding cement as a binding material,
- concrete admixtures are substances added to concrete in small quantities and in a finely divided form (liquid, powdery form, et cetera) to modify certain properties of fresh or hardened concrete by chemical or physical action.
- concrete additives are finely divided materials used in concrete in order to improve certain properties or to achieve special properties. According to EN 206-1/DIN 1045-2, two types of inorganic additives can be distinguished:
  - Type I: nearly inactive additives such as stone powder conforming to EN 12620 or pigments according to EN 12878;
  - Type II: pozzolanic or latent hydraulic additives such as trass conforming to DIN 51043, fly ash conforming to EN 450 or silica fume.

X-SEED, the product under investigation, is a concrete admixture, by use of which in concrete production the rate of early strength development of concrete is increased. As a result, concrete can be released from the moulds two times earlier than without the use of X-SEED. At the same time, no impairments were identified in terms of final strength and durability properties of the concrete; these features proved to be comparable or even enhanced.[35]

[33] Portland cement clinker is primarily composed of calcium silicate. Portland cement consists predominantly of natural raw materials such as limestone, clay, sand and iron ore, which first undergo a burning process at temperatures of 1430° C, resulting in the formation of clinker, and then are ground up with added gypsum to produce the finished cement. In addition to the high energy demand, large quantities of CO_2 are released by the essential calcination of lime.

[34] Natural pozzolans are crushed rock of volcanic origin, trass or sedimentary rock with a specific chemico-mineralogical composition, which are capable of reacting with dissolved calcium hydroxide and of forming compounds that harden extremely well.

[35] Data from BASF SE 2011.

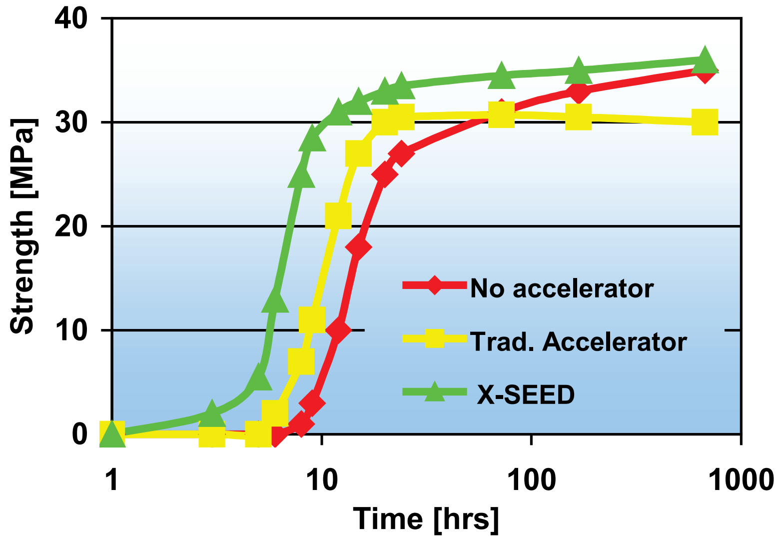

Figure 8: Crystal Speed Hardening (CSH) (Source: Kompatscher, BASF SE 2011)

The utility aspect of X-SEED is therefore to be considered as an important technical functionality of the product relating to the strength of the concrete. In order to correctly model this functionality in the context of the comparative assessment between the nanoproduct and the reference product, the system boundaries of the investigation have to be extended to the finished concrete for both products.

The functional unit of the nanoproduct is therefore defined as a cubic metre of a precast concrete component. The volume of cement contained in this precast concrete product is 400 kilograms, the remaining amount consisting of aggregates and optionally of other concrete admixtures and additives (see above).

X-SEED consists of inorganic nanomaterials (calcium silicate hydrate) with a wide distribution of particle sizes, approximately ten to 30% of the particles being smaller than 100 nm.

Using this wide range of calcium silicate hydrate particles (including the nanoparticulate calcium silicate hydrates), crystallisation seeds which are necessary for the concrete to harden, are added to the concrete. Initially, seed crystals are not existent in the reference product yet; they still need to be formed (see following figures):

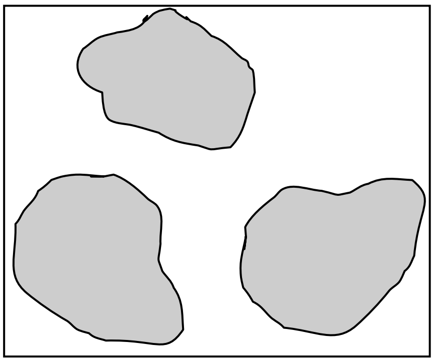

Figure 9: Concrete hardening without addition of X-SEED (Source: Kompatscher, BASF SE 2011)

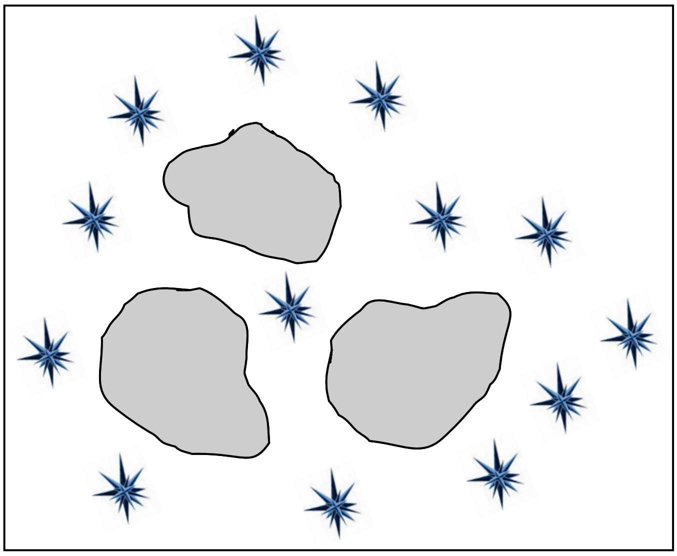

Figure 10: Crystallisation seeds in concrete hardening process with addition of X-SEED (Source: Kompatscher, BASF SE 2011)

X-SEED is manufactured as an aqueous suspension and remains in this form during sale and during the addition in the concrete manufacturing process.

After the curing process of the concrete, X-SEED, in chemical terms, is firmly embedded into the structure of the concrete.[36] Neutralisation, that is to say evaporation or drying of the X-SEED suspension, results in the formation of crystalline silica which comprises all nanoscale particles of calcium silicate hydrate.

In the context of this case study, a material as well as an energy scenario was investigated in order to elucidate two basic uses of X-SEED. In the following paragraphs, these two scenarios are defined with a view to the nanoproduct and the reference product:

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[36] Data received from Mr. Kompatscher, BASF SE 2011.

- In the **material scenario**, it is assumed that a special cement-type with a lower proportion of clinker can be used for the nanoproduct. So far, low-clinker cements containing a higher proportion of fillers such as blastfurnace slag and fly ash had the disadvantage that they used to cure considerably slower than others. Hence, there was only a narrow field of application for them on the market for precast concrete parts up until now. The optimisation of the curing process achieved by the use of X-SEED shall alleviate this drawback. In the material scenario, it is specifically assumed that 400 kg cement of type CEM II with a clinker content of 70% and 10 kg of X-SEED are used in the production of the nanoproduct (one cubic metre of precast concrete). In the manufacture of the reference product, a cubic metre of precast concrete is specified, assuming that 400 kg cement of type CEM I with a clinker content of 95% are being used in order to achieve the same strength of concrete at an early stage of curing.
- The **energy scenario**, however, addresses the accelerated curing of concrete made possible thanks to X-SEED. According to the current state of the art, the concrete in the precast concrete production is heated to 50-60 degrees to speed up the manufacturing process of the precast concrete components. The heat energy required to do so is provided in the form of steam which is usually generated by burning fuel oil. Based on findings from the literature[37], 10.7 litres of fuel oil are needed per ton of precast concrete product, which is equivalent to approximately 22 litres of fuel oil per cubic metre of concrete. As regards the manufacture of the nanoproduct, one cubic metre of precast concrete product again was taken as the basic unit, assuming that 400 kg of CEM I and 10 kg of X-SEED have to be used to produce this volume. The curing time assumed was 5 hours at room temperature. The manufacture of the reference product, too, according to the assumption that one cubic metre of precast concrete is to be produced, requires 400 kg of CEM I. The curing time assumed is also 5 hours, whereas, owing to the absence of X-SEED, heat treatment by the means of steam has to be accomplished.

[37] Cf. Ganzheitliche Bilanzierung von Grundstoffen und Halbzeugen, *Teil II Baustoffe* München, im Report 065.1/ KEA Forschungsstelle für Energiewirtschaft [Comprehensive Assessment of Primary Products and Semi-Finished Goods, *Part II Building Materials* Munich, see Report 065.1/CER Research Center for Energy Economics (FfE) (1999)].

8.2 SWOT Matrix

The study comes to the conclusion that, in either scenario, most of the key indicators are to be counted as strengths or as opportunities in favour of X-SEED. The only weakness identified with regard to X-SEED related to the life-cycle costs that have been disclosed in the material scenario, these costs, however, being classified as a further strength in the context of the energy scenario.

In both scenarios, “Workplace exposure”, “Legal framework and research funding”, “Recyclability” as well as “Resource availability” have been classified as indifferent key indicators.

The results of the individual key indicators for X-SEED (material scenario) are summarised in the following SWOT matrix.

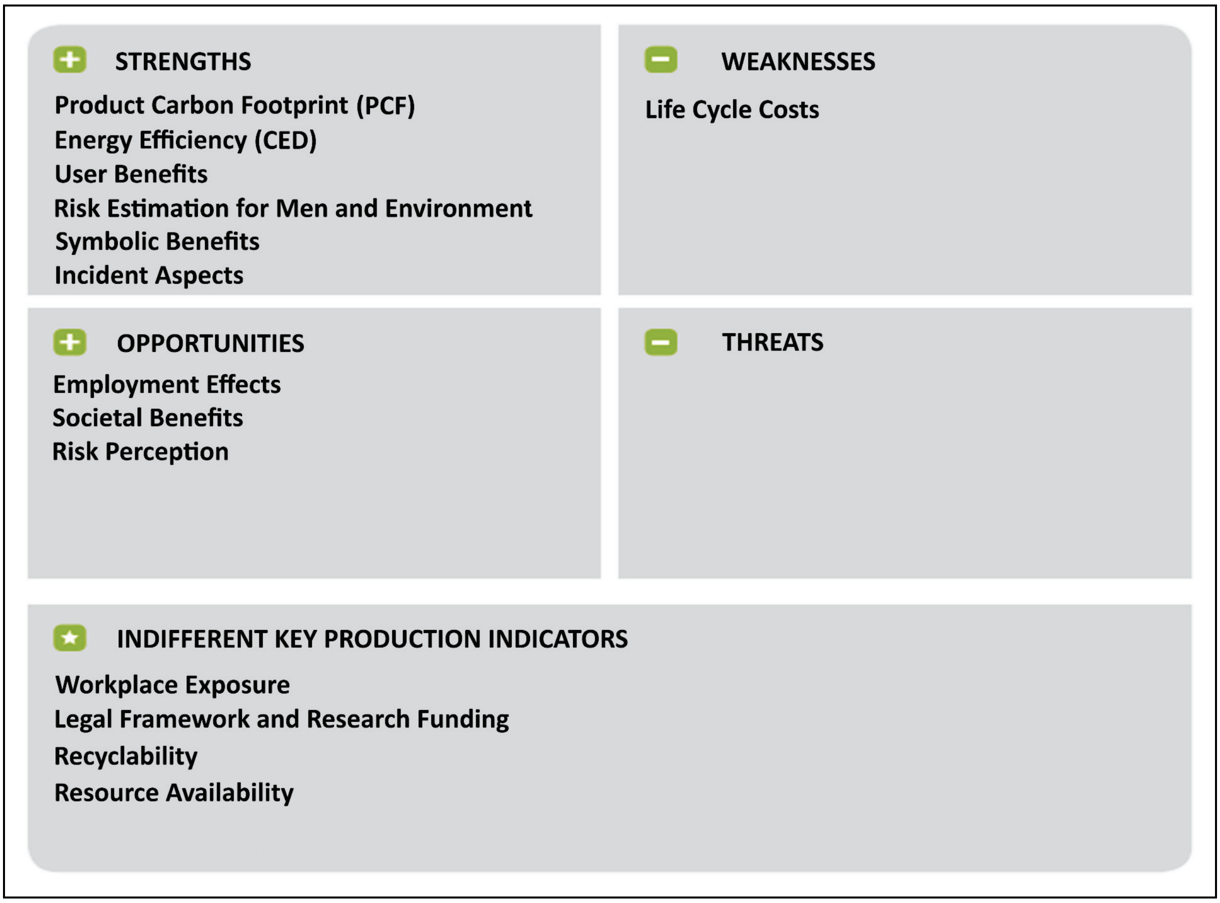

Figure 11: SWOT matrix summarising the results of the key indicators for the case example of “X-SEED” (material scenario) – (Source: Öko-Institut 2011)

The outcome of the SWOT analysis for the energy scenario of X-SEED can be seen from the following figure:

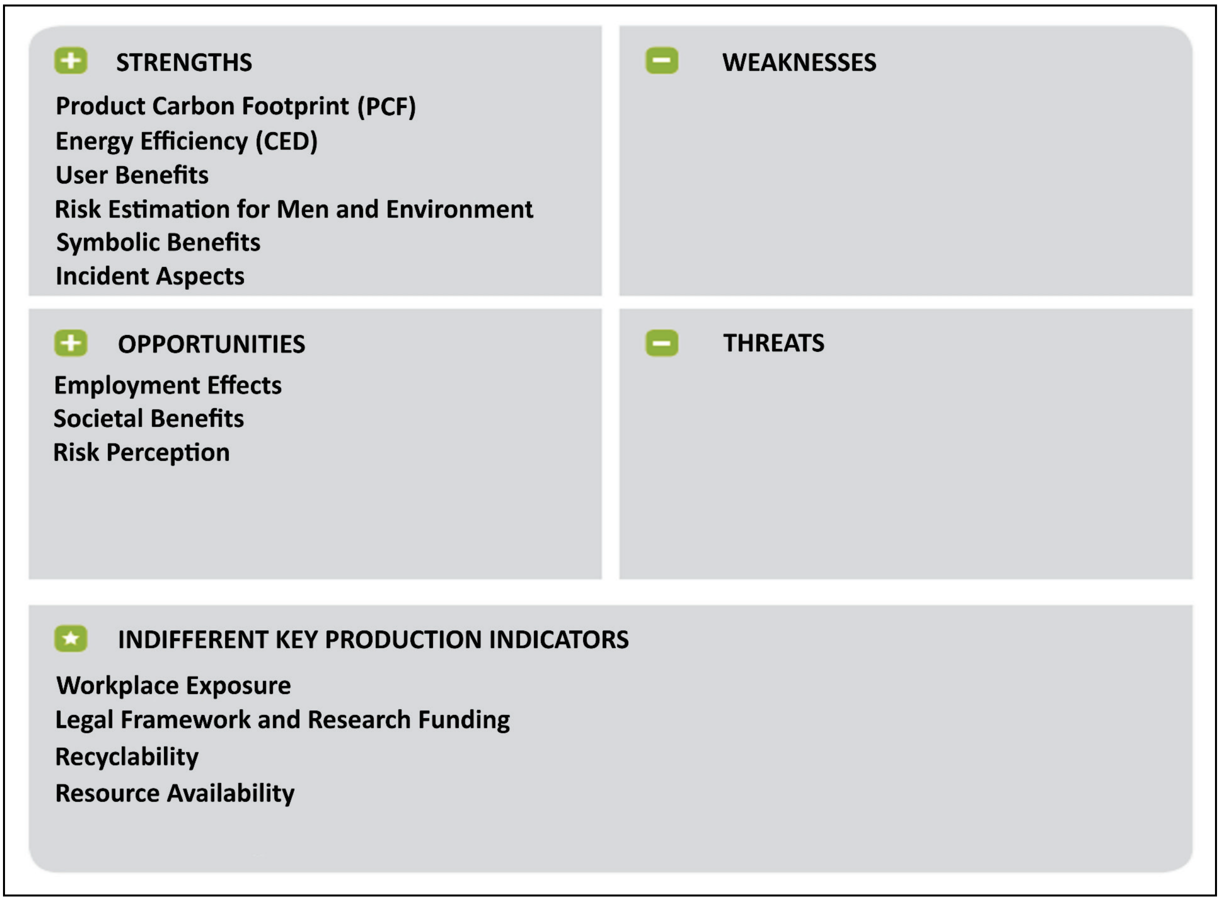

Figure 12: SWOT matrix summarising the results of the key indicators for the case example of “X-SEED” (energy scenario) – (Source: Öko-Institut 2011)

8.3 Individual Results of the Key Indicators

The following section will present the results of the self-evaluation of X-SEED carried out by BASF SE for the individual key indicators of the Swot analysis. First, the strengths / weaknesses level will be depicted. We then proceed to the level of opportunities / threats.

8.3.1 Strengths / Weaknesses Analysis

The outcomes of the analysis of strengths and weaknesses are presented in the following section.

Product Carbon Footprint

In the material scenario as well as in the energy scenario, a considerable extent of greenhouse gases could be saved thanks to the use of X-SEED as compared to the reference product.

In the material scenario, the reason for this lies in the fact that, when manufacturing the precast concrete part, X-SEED enables the use of cement type CEM II which has a lower proportion of clinker than cement type CEM I, and thus produces less CO_2 emissions in the upstream chain. Only relatively small amounts of greenhouse gas emissions are caused by the production of X-SEED, which, in total, permits a reduction of the overall environmental burden in comparison to the reference product. The better performance of the nanoproduct in the energy scenario results from the fact that heating and thus the combustion of fuel oil in the production of precast concrete parts may be omitted. In the case study, the use of X-SEED, in terms of the net result, leads to specific savings of 53 kg of CO_2 (in the energy scenario) and 74 kg of CO_2 (in the material scenario) per cubic metre of concrete. This corresponds to a saving of 14% (in the energy scenario) and 22% (in the material scenario). In both scenarios, the product carbon footprint of X-SEED is therefore rated as strength when comparing it to the reference product.

Extrapolating the specific CO_2 savings per cubic metre of concrete to the European market for precast concrete products in the material scenario, up to approximately 2.7 million tons of CO_2 can be annually saved in the future when X-SEED is used.

This is based on the conservative assumption that, with a volume of precast concrete formulations equalling roughly 90 million cubic metres, about one half of this amount can be converted to cement with reduced clinker components when X-SEED is used. Under the energy scenario, the CO_2 savings potential per year amounts to approximately 1.2 million tonnes. This is assuming that about 25% of the precast concrete products in Europe undergo an additional heat treatment to achieve an accelerated hardening. In order to effectively exploit this savings potential, however, there actually is a need to do without the heat input. If heating is nevertheless carried out for the sake of an even faster production process, the greenhouse gas saving effects will be cancelled out again.

Energy Efficiency

The boundary conditions assumed for determining energy efficiency were the same as those on the basis of which the determination of the CO_2 footprint was carried out. Also in terms of energy efficiency, the manufacture of X-SEED only plays a minor role, contributing to energy input only with 62 megajoules per cubic metre of concrete. According to the material scenario, the manufacturing of X-SEED altogether produces approximately 1630 MJ, thus only representing a share of 3.8%. The enhanced energy efficiency of the nanoproduct compared to the reference product, as revealed by both the material and the energy scenario, is mainly attributable to the manufacturing phase, while there are no significant differences between the two alternatives in terms of the life-cycle stages of transport, use and disposal. In the material scenario, approximately 340 megajoules per functional unit, as compared to the reference product, can be saved when manufacturing the nanoproduct. Analogous to the key indicator “Product Carbon Footprint”, this is largely attributable to the fact that the nanoproduct enables use of cement type CEM II, the production of which requires less energy than the production of cement type CEM I which is used in the reference product. In the energy scenario, the energy savings realised are even higher: while roughly 2040 megajoules per functional unit are required for the nanoproduct, approximately 2970 megajoules are needed for the reference product. This is primarily due to the savings made by doing without the additional heat treatment to which precast concrete parts otherwise have to be subjected.

An extrapolation of the energy efficiency in the material scenario results in a savings potential of 11 gigajoules for Europe per year. The underlying assumption is that about 80% of the precast concrete products are manufactured with CEM I and that half of this share could be converted to CEM II with the use of X-SEED. On the basis of a market volume of 90 million cubic metres of precast concrete parts, this would correspond to 36 million cubic metres (or functional units).

An extrapolation of the energy efficiency in the energy scenario leads to a savings potential of 20 gigajoules for Europe per year. This is based on the fact that about 25% of the precast concrete products, especially in the cold winter months, must be subjected to an additional heat treatment. On the basis of an estimated market volume of 90 million cubic metres of precast concrete parts, the potential relates to 22.5 million cubic metres (or functional units).

Based on these results, the key indicator “Energy efficiency” is classified into the category of strengths.

Workplace Exposure

On the basis of the self-evaluation carried out by BASF, the key indicator “Workplace exposure” can be classified as an indifferent indicator; that is to say, there is no essential difference between nanoproduct and reference product. This is particularly due to the fact that nanoparticles, in the production of X-SEED, are only generated in the reactor (in the liquid phase) and X-SEED is processed exclusively in the form of an aqueous suspension.

A slight advantage in the production of precast concrete products with X-SEED compared to the reference product, that has to be taken into account in the energy scenario, is the avoidance of a steam generation involving the use of fuel oil. As a heating of concrete is not required with the nanoproduct, the storage of heating oil may be dispensed with, thus eliminating the risk of fire. Depending on whether heating oil is also needed for other processes or not, the fuel oil tank becomes entirely obsolete. In terms of the other criteria or key questions relating to the key indicator, no differences could be observed between the nanoproduct and the reference product.

User Benefits

With regard to “User benefits”, concrete supplemented with X-SEED offers slight advantages compared to the reference product. Worth noting are, besides the high level of reliability to fulfil its function, the excellent robustness of the precast concrete components along with a constant or enhanced final strength, as well as the durability properties that are considered superior to those of the reference product. Moreover, the addition of X-SEED has a positive impact on the microstructure formation taking place within the cement. In terms of comfort, the application of X-SEED is easy and ensures a rapid processing of precast concrete products, the increased rate of early strength development helping the rework to quickly proceed, allowing that forms may be removed soon and that the precast concrete parts can be lifted at a relatively early stage, as compared to the reference product.

Life-Cycle Costs

As revealed by the analysis of the life-cycle costs, the additional costs for X-SEED in the energy scenario are more than compensated by the energy cost savings made by the manufacturers of precast concrete products. Assuming that heating oil costs EUR 0.70 euro per litre, the saving per cubic metre of concrete approximately amounts to EUR 6. In this case, the indicator must therefore be regarded as strength. The material scenario, however, came to the conclusion that the additional costs for X-SEED cannot be compensated by the savings on cement (resulting from the substitution of cement type CEM I by the cheaper type of CEM II). The price for one cubic metre of concrete with X-SEED addition in this case is around three euros higher than that for one cubic metre of the reference product. The indicator therefore has to be classified as a weakness in the material scenario.

Risk Estimation for Men and Environment

The key indicator of “Risk estimation for men and environment” is to be regarded as a strength, the reason being that the nano-specific risks of X-SEED identified on the basis of the Swiss precautionary matrix are deemed to be low even without further clarifications (classification into class A). The result of the precautionary need depending on the hazard potential on the one hand, and on the potential human exposure and the emission into the environment on the other hand, shows that the precautionary need

- for workers reaches 8.1 scores,
- for consumers reaches 0.5 scores and
- for the environment reaches 9.0 scores.

The levels are thus well below the threshold value of 20 scores, above which a nano-specific need for action arises in accordance with the precautionary matrix.

Incident Aspects

When looking at the incident aspects, framework conditions that are basically comparable to that underlying the risk estimation for men and environment (minor potential impact along with rapid incorporation of nanoparticles into the product matrix) have to be taken into account. For the investigation of the incident aspects, it is essential that manufacture as well as sale and addition of X-SEED during the manufacture of concrete are exclusively done in the form of an aqueous suspension. Neutralisation, that is to say evaporation or drying of the X-SEED suspension, results in the formation of crystalline silica which comprises all nano-scale particles of calcium silicate hydrate. After the curing process of the concrete, X-SEED, in chemical terms, is firmly embedded into the structure of the concrete. Altogether, the indicator "Incident aspects" has to be assigned to the category of strengths. Concerning the parameter "Precautionary need for workers", the result of 4.5 remains well below the defined threshold of 20, above which a need for action has to be assumed. With a value of 0.23, the same applies to the precautionary need for the population.

Symbolic Benefits

As regards the symbolic benefits, concrete with X-SEED addition offers slight advantages compared to the reference product. In terms of design it is noteworthy that X-SEED provides the possibility to produce concrete surfaces of more attractive appearance. The more homogeneous acceleration of the hardening process furthermore results in a finer, more homogeneous, crevice-free and non-porous concrete surface. As a consequence, the final product does not so much resemble concrete, thus providing more design freedom. Moreover, BASF has indicated that the use of X-SEED reflects the application of an advanced state-of-the-art technology, accordingly bestowing a prestigious image to the manufacturer.

8.3.2 Opportunities / Threats Analysis

The following section outlines the results of the opportunities / threats analysis:

Employment Effects

The employment effect of the nanoproduct is rated as an opportunity. This rating is primarily due to a rise in the total employment in the processes carried out by the company BASF SE. BASF, as the manufacturer of X-SEED, estimates an accumulated volume of at least 50,000 tons of X-SEED on a ten-year-basis, provided that the potential offered by technology is fully exploited and that marketing will be successful. If so, about 50 full-time jobs are to be created. If linearly distributed, an annual production of 5,000 tonnes would entail the creation of 5 new jobs on average per year.

Other manufacturers in the upstream process chain (source materials for X-SEED or concrete constituents), however, should not count on positive employment effects, nor will they have reason to fear negative effects, since neither more nor less concrete constituents will be used in the future.

Also with regard to the users of X-SEED (enterprises of the precast concrete manufacturers), no significant changes in the employment effect are anticipated because of the use of X-SEED. In the material scenario, it is therefore not expected that any employment effects will materialise externally, i.e. outside the BASF group. According to the energy scenario, the heating of the concrete elements is no longer necessary, thus permitting workflows to become more flexible. It can therefore be assumed that the vacant manufacturing capacity will either be attended to by the same number of workers or that more workers will be employed to exhaustively operate the newly created capacities.

For those companies, which use the precast concrete components for building purposes, the employment effect of the nanoproduct is considered to be unchanged as compared to the reference product. The nanoproduct used on the building site thus replaces the corresponding reference product in the identical application.

Societal Benefits

Similar to the two other aspects of utility (see above), the nanoproduct in comparison to the reference product provides a small advantage in terms of societal benefits. As regards the aspect “Sustainable use of scarce resources”, the self-evaluation revealed that the use of X-SEED in a prefabricated concrete part helps to conserve abiotic resources such as limestone and clay, the reason therefore being that, in the case of the material scenario, the nanoproduct allows the use of CEM II as a cement type with a lower proportion of clinker (70% instead of 95% for the reference product). Consequently, the consumption of the resources of limestone and clay that are required for the production of clinker can be reduced to the same extent. In the energy scenario, too, the use of X-SEED positively affects the conservation of resources, as 22 litres of heating oil can be saved per cubic metre of concrete by doing without the heat application in the manufacture of precast concrete products. In addition, the enhanced functional characteristics relating to continued use of concrete (weathering resistance) that are provided by X-SEED, result in a virtual immobilisation of the chemicals in the concrete.

The contribution to the promotion of economic stability provides another slight advantage. The reason for this contribution can be considered to be the possibility for small and medium enterprises using X-SEED to flexibly adapt their production volume without the need to seek loans in order to provide the capital required to finance additional investments (for production facilities, for example).

Legal Framework and Research Funding

The key indicator “Legal framework and research funding" is to be considered as indifferent, the analysis of the three individual areas of investigation relating to this indicator exhibiting both problematic and favourable assessments. As regards the area of “Research promotion within the company”, the assessment is likely to be favourable, as sustainability and technological progress are key elements of BASF’s company policy, and BASF is making targeted investments in nanotechnology – one of BASF’s five growth clusters. “Research funding by state governments” is another field which, overall, may be categorised as favourable. Although BASF has not taken advantage of public funds to promote X-SEED, the nanoproduct that is considered here, it benefits from the methods and the results on security assessment that, in cooperation with other companies and scientific institutions, have often been developed within publicly funded research networks. The legal framework conditions, however, has been found somewhat problematic. This is mainly due to the uncertainties prevailing with regard to the existing and anticipated future regulation of nanomaterials at the EU level and concerning the manufacturers' and the environmental liability.

Recyclability

The key indicator of "Recyclability" is classified as indifferent. A significant reason for this is that, when it comes to the disposal, the precast concrete products containing X-SEED, in physical and chemical terms, do not differ from components produced without X-SEED. As suggested in section 8.1, the nanoparticles within X-SEED, after the curing process of the concrete, in chemical terms, are tightly embedded in the concrete. After the hardening, X-SEED particles and concrete particles can no longer be distinguished from one another regarding their chemical and physical properties. Hence, it is not possible that nanoscaled substances are present in a concrete manufactured using X-SEED, the separation of which would be required in the course of recycling, since these components should not be incorporated in the new product, inter alia for reasons of health protection or environmental conservation or because they might adversely affect the quality of the new product.

Moreover, the use phase of the nanoproduct does not produce any extra waste as compared to the reference product.

Resource Availability

On the basis of the self-evaluation, the key indicator "Resource availability" can neither be assigned to the category of opportunities nor to that of threats. The resources which were examined with respect to the manufacture of both the nanoproduct and the reference product, include: cement, fillers, water and recycled aggregate. The availability of those resources is classified as not very critical and is deemed to be similar for both products. As regards the nanoproduct, sodium metasilicate and calcium nitrate are additionally needed for the production of X-SEED. The availability of those resources, too, is to be rated as rather non-critical. If, accordingly, the same overall classification, i.e. "rather non-critical", applies to both the nanoproduct and the reference product, the key indicator must be regarded as indifferent. It can therefore be assumed that a secure physical, temporal (timely), financial and technological access to the resources will be ensured with a view to manufacturing a precast concrete product with X-SEED addition.

Risk Perception

All in all, X-SEED can be classified as an opportunity as regards the aspects of risk perception. This assessment results from the examination of the following four areas: "Company-internal assessment of the nanoproduct's potential risks", "Analysis of the product environment", "Risk management" and "Risk communication". According to BASF, there are no or only very low nano-specific risks for human beings and the environment due to the use of the nanoproduct. This is due to the fact that X-SEED is produced, used and sold in the form of a solution. After the hardening process, the added nanomaterials, in chemical terms, are tightly embedded in the concrete. Based on this company-internal assessment, BASF, thanks to its position in the product environment and due to the risk management and risk communication measures that have already been taken, is able to adequately respond to the perception of risks by society. With respect to the subject of nanotechnologies, BASF SE, as a matter of principle, pursues a proactive communication policy vis-à-vis stakeholders, workers, customers and downstream stages in the value chain. The specific communication with customers in the value chain, relating to X-SEED itself, is mainly effected via the technical information sheet and the safety data sheet. The general debate about nanoproducts as well as the uncertainty about the consequences this will have for legislation and markets, at least in the medium term, is seen as a problem by BASF.

8.4 Discussion of Results

Concerning the question of whether the nanoproduct, as compared to the reference product, may substantially contribute to protecting the climate and the environmental in the construction industry, X-SEED, on the side of strengths, especially convinces with the two key indicators "Product Carbon Footprint" and "Energy efficiency". The positive outcome is primarily based on the fact that, in comparison to the reference product, the same functionalities (increased rate of early strength development and constant or enhanced final strength) can be achieved by the use of X-SEED, also providing simpler, that is to say less polluting cement qualities (material scenario).

The relative CO_2 and energy saving potentials in the energy scenario can be attributed to the acceleration of the curing process thanks to X-SEED and to the waiving of heating during the manufacturing process of the precast elements that is consequently enabled. These potentials can only be realised, however, if the manufacturers really renounce from heating the precast elements and do not strive for an even more rapid curing by applying, for scheduling and workload reasons, a heat treatment although X-SEED is used as well. Analogue, when looking at the material scenario, it has to be noted that the manufacturers of precast components may continue to use cement of type CEM I, whilst at the same time using X-SEED, even if this would imply higher production costs on the one hand and wasting the savings potentials associated with X-SEED on the other hand. Hence, in both scenarios, the actual implementation of the CO_2 and energy saving potentials does not primarily lie in the hands of

BASF SE, i.e. the manufacturer of X-SEED, but is rather the responsibility of the customers of BASF. Therefore, BASF, in the context of its communication with customers, should highlight not only the benefits of X-SEED, but also the mentioned rebound effects.

The fact that X-SEED is exclusively produced, distributed and processed in the liquid phase and the fact that, after the curing process of the concrete, the nanoparticles contained in X-SEED are tightly embedded in chemical terms and virtually dissolve into the product matrix, have a considerable influence on the key indicators “Risk estimation for men and environment”, “Incident aspects”, “Workplace exposure” and “Recyclability”. In the case of the indicators of “Risk estimation for men and environment” and “Incident aspects”, the above mentioned properties of X-SEED allow their classification to the category of strengths, as regards the nanoproduct. Despite the use of a nanomaterial, no significant precautionary need has been identified in relation to the reference product.

When comparing the indicators “Workplace exposure” and “Recyclability” to the reference product, an indifferent result is arrived at. For the indicator “Workplace exposure” this is due to the fact that the processes related to the nanoproduct do not differ significantly from those processes associated to the reference product. As regards the indicator of “Recyclability”, the indifferent result may be attributed to the fact that no differences in disposal exist between the prefabricated components, irrespective of whether or not they have been manufactured with the addition of X-SEED – the reason being that the nanoparticles of X-SEED, after the curing of the concrete, are firmly embedded in the product matrix.

The indicator “Legal framework and research funding” is also to be classified as indifferent. Notwithstanding the positive assessment of government incentives and company-internal research funding, it is not reasonable to assume that this is an opportunity, since there is still uncertainty as to whether a future adaptation of legislation at EU level, in particular in accordance with REACH, might entail disadvantages regarding the marketing of X-SEED. After all, the indicator of “Resource availability”, too, has to be classified as indifferent. This is primarily due to the fact that nanoproduct and reference product only differ in the addition of X-SEED. When considering the two source materials for X-SEED, i.e. sodium metasilicate and calcium nitrate, the analysis shows that the global reserve considerably exceeds the global demand.

8.5 Strategic Optimisation

The overall result of the Nano-Sustainability Check, based on the data gained from BASF, confirmed that X-SEED, in comparison to the reference product, performed well regarding all investigated key indicators. At the moment, only the material scenario reveals a certain weakness with respect to the life-cycle costs of precast concrete products manufactured using X-SEED.

This is due to the fact that, in terms of the costs of source material, the additional costs for X-SEED overcompensate the savings associated with the substitution of the higher priced type of cement CEM I. In this scenario, the nanoproduct is thus somewhat more expensive than the reference product.

Although the indicated, overall positive effects in terms of sustainability along with the technical advantages of concrete manufactured using X-SEED, as described above, might justify this cost, the cost differential may prove to be disadvantageous in exploiting the potential of both CO_2 and energy savings in the mass market. In this respect, it is important to take into consideration, in particular, that according to the material scenario, which is more unfavourable from the point of view of cost, the leverage effect of the existing CO_2 and energy savings potential is a significant one. In this scenario, the specific amount of CO_2 emissions saved is 74 kg of CO_2, for example, while the equivalent value in the energy scenario is lower, equalling 53 kg. These disparaties become all the more apparent in the extrapolations of saving potentials concerning the European market for precast concrete products, which, amounting to up to about 2.7 million tonnes of CO_2 per year in the material scenario, are more than twice as much as the amount stated in the energy scenario, which is roughly 1.2 million tonnes of CO_2 per year.

This means that the current cost structure of the nanoproduct could hinder or even prevent the realisation of the maximum possible savings potentials identified in the material scenario. A significant optimisation potential, to which priority is given by BASF, is therefore the continuous optimisation of the product costs associated with X-SEED in order to influence the current high level of overall costs in favour of the nanoproduct. With this aim in view, the price trends for the cement types CEM I and CEM II must also be taken into account as their costs, according to the material scenario, have a significant influence on the total costs, too. Yet another starting point is to further improve awareness of the markets concerning the value of positive sustainability effects through the application of nanoproducts. In this context, more targeted promotional activities presenting X-SEED as an inherently safe nanoproduct could prove to be instrumental, whereas it is recommended to mainly focus on the aspects relating to the benefits in the areas of climate protection and resource conservation. In order to actually realise these benefits aspects, it is in the interest of the construction industry, and of particular interest to BASF, to draw the attention of concrete producers as the users of X-SEED and of building owners as users of concrete alike to the contribution they can make to exploiting the savings potentials.

9 Proposed Areas of Application, Strengths and Limitations of the Tool

The testing of the analysis grid in both case studies has shown that the Nano-Sustainably Check allows for a differentiated consideration of sustainability aspects when comparing a nanoproduct to a reference product. Although in both cases the products under consideration were still in the phase of market introduction, the data required for the key indicators could be determined. Thus, a **self-evaluation tool** is made available to both large companies such as

BASF and small and medium businesses like Nanogate alike, enabling them to quantify and systematically harness the existing potentials of nanotechnological applications in the course of the various development stages. The most important results of the case studies were summarised in a brochure, which also contains a description of the cornerstones characterising the methodological approach. This brochure is available online at www.oeko.de/nano_-nachhaltigkeitscheck.

Based on the “preliminary step” in which the list of criteria drawn up by issue group 2 (IG 2) of Germany’s NanoCommission is applied, the Nano-Sustainability Check, in a “second step”, allows the potential benefit and risk aspects of nanoproducts to be analysed in greater detail, and to be quantified to the greatest possible extent. From a methodical point of view, it is advantageous, in this context, that both the list of criteria of IG 2 and the Nano-Sustainability Check are based upon the life-cycle perspective, while targeting a case-by-case as well as an integrated consideration of risk and benefit aspects, and furthermore undertaking a comparative analysis relating to a reference product. As a means to further increase harmonisation between both tools, the “product profile" elaborated by IG 2 (cf. section 4.2) is also recommended for the Nano-Sustainability Check, serving as a basic document for the characterisation of nano- and reference product as well as of the nanomaterials used.

Starting from a first screening by means of the list of criteria formulated by IG 2, the Nano-Sustainability Check enables a more detailed consideration, quantifying sustainability aspects by means of the suggested key indicators, or at least collecting semi-quantitative statements on the basis of a query on defined criteria and key questions. Potentials within nanoproducts, where they exist, may furthermore be extrapolated for selected quantitative key indicators such as the product carbon footprint or energy efficiency. This reflects the objective-oriented formulation of the instrument and makes it possible to estimate the extent of the leverage effect produced by the investigated nanotechnological development against the background of the guiding vision of a sustainable development.

Beside this prospective benefit analysis using comparative ecological profiles and a prospective exposition and hazard analysis, the Nano-Sustainability Check broadens the observation horizon by incorporating, in addition to the sober / rational level of judgment, also aspects relating to the public **perception of risks** as an integral part of the investigation. From a practical viewpoint, information on this is considered to be very important in the market entry phase of a new nanotechnological development, and therefore must not be missing in an integrated approach. Another consideration going beyond the traditional life-cycle approach is the **analysis of hazardous incidents**.

Apart from a clear presentation of results, the chosen **SWOT approach** offers the additional advantage to early identify optimisation potentials as a result of comparing strengths, weaknesses, opportunities and threats. Results, however, are deliberately not further aggregated in terms of a one-point assessment, for example, since the sole communication of this result would entail the loss of too much information. Instead, the transparent presentation of the findings associated to each key indicator should promote a differentiated picture and, on the basis of this overview of results, stimulate a closer examination of the results on the key indicators.

Limitations of the instrument can primarily arise through **data gaps** or deficiencies regarding the representativity of the available data. In this context, it must be noted that currently there are far too few LCA data sets on the specific production procedures of nanomaterials. This could significantly affect the resilience of the key indicators which are reliant on these data sets (as product carbon footprint, energy efficiency). Hence, a critical questioning of the results obtained and, moreover, a documentation of the quality of the data used is particularly important.

In addition, the **operationalisation of some key indicators** (such as “Symbolic benefits” or “Aspects of risk perception“) is not a trivial task either. Since the analysis for these key indicators is not carried out primarily on the basis of objectively verifiable facts, but is done by means of subjective judgments, an extensive experience, but also much veracity is essential to make sure that controlling errors are avoided within the scope of the self-evaluation. Moreover, other methodical limitations arise from the difficulties in assessing whether an indicator is indifferent (cf. section 6.6). A company might thereby be tempted rather not to convey a negative evaluation of their own enterprise, if the result is to be discussed “publicly”. From a methodological point of view, appropriate precautions were taken, defining the “indifference band” fairly broadly, especially as regards the semi-quantitative key indicators. This ensures that the key indicator will only "deflect" in the direction of strength or weakness when there is sufficient information on which to base the decision.

A **final** sustainability assessment of nanoproducts, however, is something the Nano-Sustainability Check basically cannot provide. To this purpose, the instrument particularly lacks the comprehensive **assessment** of human and ecotoxicological risks in view of exposition and hazard potential, for which there are traditional scientific methods. These, however, usually require a comprehensive testing programme which cannot be carried out within the scope of a screening instrument like the Nano-Sustainability Check. If, however, a comprehensive risk assessment is already available for the nanoproduct in question, reference should be made to the findings of this assessment rather than to the analysis of the key indicator “Risk estimation for men and environment” (cf. BMU 2010).

Apart from the toxicological aspects, a final sustainability evaluation requires data- and evidence-based statements on further risk aspects, for example in the area of waste disposal. While this area is basically covered by the Nano-Sustainability Check – the most important aspects being addressed in the form of guiding questions (see key indicator “Recyclability”, section 6.5.4) – the main intention of the Nano-Sustainability Check, however, is rather to take a look at the relevant questions at an early stage. In many cases it will not be possible to fully clarify and quantify such aspects. This is particularly the case when the instrument is used at a very early stage in the innovation process. In comparison to the criterion paper elaborated by IG 2, the relevant sustainability aspects will nevertheless be addressed at a more specific level, thereby preparing and structuring the “third step” of a final sustainability assessment (cf. figure below):

Step 1: **List of criteria formulated by issue group 2** of the NanoCommission (tool for the organisation of multi-stakeholder dialogues)

⇩

Step 2: **Nano-Sustainability Check**
(self-evaluation tool for the innovation process)

⇩

Step 3: **Final sustainability consideration** including the assessment of human and eco-toxicological risks using traditional scientific methods

Figure 13: Embedding the Nano-Sustainability Check into existing instruments of the sustainability analysis (own flow chart)

In the end this means that the emphasis in the application of the Nano-Sustainability Check for some key indicators is less on the quantified results themselves than on the investigation of the relevant sustainability aspects and the **process of defining them more specifically** – and thus also quantifying them.

In conclusion, the Nano-Sustainability Check provides a good basis for manufacturers and developers to systematically consider sustainability aspects relating to their products or new developments. Although it is not to be used as a substitute for a comprehensive risk assessment, the Nano-Sustainability Check – within the scope of a **prospective innovation and technology analysis** – helps to identify knowledge gaps and risks, where they exist, at an early stage, and to develop appropriate problem solving strategies. The Nano-Sustainability Check offers users the facility of an **early warning system** and thus provides an important **indication as to what direction should be taken in the innovation process** of nano-products.

10 Strategic Development Options and Outlook

The original German final report has been translated into English (i.e. the present version) in order to make the results of the report accessible to countries beyond the German-speaking area. This English version, inter alia, shall be used to supply the relevant committees also internationally with the proposed approach of the Nano-Sustainability Check. In this context, especially the OECD's "Working Party on manufactured nanomaterials" (WPMN) is to be mentioned, whose Steering Group 9 (SG 9) specifically deals with sustainability aspects of nanotechnology products. The principal aim of SG is to support the assessment of the use of nanomaterialials throughout the various stages of the innovation cycle by developing an appropriate methodological framework. This assessment framework should be applied using practical examples, providing for an increased focus on environmental aspects and thereby taking into account the entire life cycle of the examined products. SG 9 first and foremost sees its mission as furthering and supporting the collaboration between existing or planned initiatives from various Member State delegations. In particular, nano-sustainability initiatives from Australia, Germany, the United Kingdom, Italy, Canada, Korea, Austria, Thailand, the United States and the European Commission, UN / SETAC[38] and BIAC[39] should be involved. Moreover, nano-specific aspects of the evaluation methodology, if such aspects exist, should be identified in the scope of these case studies. On 14th September 2011, the primary author of the present final report, who also belongs to the expert team of the SG 9, presented the results of this project in the frame of an international "Workshop on Environmentally Sustainable Use of Manufactured Nanomaterials". On the basis of concrete case examples, the aim of this workshop was to further develop the methodological conditions for a life-cycle-based evaluation of nanoproducts.

For the purpose of enabling a wide use of the Nano-Sustainability Check as a self-evaluation tool for companies in practice, it is suggested to establish a central **point of contact** for potential users. This contact point's role could be to make the tool, with all its elements, (introduction, guidelines on the indicators and Excel Tools) available for download free of charge to all interested users. Apart from the provision of working materials, the point of contact should also, to a certain extent, be available to answer questions of users, and be able to develop and update working materials. By means of the two case studies, the Sustainability Check has already been tested in practice for the first time. It is, however, expected that there will be further adjustments and developments of the instrument, for example, in terms of certain product groups, earlier development stages of a nanoproduct or other user types. Institutions that might take the role of a contact point are, apart from the Federal Environment Agency, the Öko-Institut e.V. or some other independent body.

Regardless of this role, the Öko-Institut, with a view to developing further case studies, offers the possibility of cooperation in data collection, the interpretation of results and the external

[38] SETAC is the accronym for "Society of Environmental Toxicology and Chemistry". This organisation is an international partnership of experts in the sphere of analysis and resolution of environmental problems.

[39] BIAC stands for "Business and Industry Advisory Committee" and represents the interests of industry at OECD level.

communication of the outcomes, in the form of a joint brochure, for example (as it has already been the case in the scope of the project) (cf. section 9).

A further development of the Nano-Sustainability Check as a potentially suitable labelling instrument or as an instrument for the award of a quality label is neither intended nor possible in its current format, as the methodological approach as a self-evaluation tool has been chosen to determine the product status quo of a nanoproduct relative to a reference product, with the aim of identifying the optimisation potential of the product. The latter is not the goal of a quality label. A quality label would also require absolute criteria and limit values, which are not delivered by the Nano-Sustainability Check.

In terms of perspective, the Nano-Sustainability Check could also offer orientation on the extent to which nanotechnology products or processes can make a significant contribution to achieving the (national) climate protection goals. If Germany is to reach its current climate protection targets – to reduce up to 95 percent of greenhouse gas emissions until the year 2050 – 60 percent of these savings have to be achieved through technological innovations (cf. section 2). Innovations in the field of nanotechnologies that can help to meet this target primarily need to come from the areas of supply of renewable energy, thermal insulation, energy storage, new manufacturing and building materials as well as industrial production processes. In the light of these prospects for the future, a better matching and coherence between technological requirements for the protection of the environment on the one hand and the supply of nanotechnology products and processes on the other hand is required. We therefore recommend to systematically analyse the sustainability potential of promising nanotechnology products and/or research and development efforts in the foregoing technology fields. Besides the requirement to contain an economic utilisation plan, research and development programmes should also provide information and scenarios relating to the expected climate protection potentials of individual R&D projects in the scope of an "**ecological utilisation plan**".

Just like a conventional map, a **road map of "Climate Protection through Nanotechnology"** developed on the basis of this information could structure the process, identify options for action and specify priorities. Eventually, the confidence in the development of nanotechnological solutions might thus be strengthened. In addition, the goal-oriented exploitation of the savings potentials existing in the mentioned fields of technology will presumably gain considerable momentum.

Within the framework of a **monitoring**, the individual R&D projects, in terms of the actual CO_2 savings achieved, must be measured according to the pre-determined reduction targets. Life-cycle analyses conducted on the basis of a systemic approach fit particularly well to fulfil this objective. With its quantitative key indicator "Product Carbon Footprint", the Nano-Sustainability Check constitutes an appropriate instrument for the identification of existing potentials as well as for monitoring.

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