Report

SUSTAINABLE NANOTECHNOLOGIES

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1 Introduction

Nanotechnologies are ‘enabling technologies’. They support and promote innovations in other technological areas, such as the information and communication technologies, medical engineering or technologies for the generation and storage of energy or approaches for wastewater treatment. The use of nanotechnologies in the various areas is increasing rapidly.

The technological integration and enhanced use of nanotechnologies has been accompanied by a stakeholder dialogue since 2004. This dialogue first took place in the NanoCommission (first and second dialogue phase) and in the third phase and since 2011, has been organised in form of topic related dialogue conferences (FachDialoge). The identification of technology impacts and options to prevent and manage possible risks from the use of nanomaterials played a central role in all discussions.

This report summarises different aspects of the ‘guiding concept sustainability’ and the assessment of the sustainability of nanotechnologies. In the introduction the development of the ‘guiding concept sustainability’ is explained and some general characteristics and functions of guiding concepts are described. Then, the guiding concept ‘sustainable chemistry’ is introduced, which could in principle also address nanotechnologies. In the last part of the report some aspects of ‘sustainable nanotechnologies’ are discussed.

The content and results of the two-day FachDialoge on ‘sustainable nanotechnologies’ organised by the Ministry of Environment, Nature Protection and Nuclear Safety (BMU) in June 2012 have been integrated into this report.

2 Sustainability

At the United Nations Conference on Environment and Development in Rio de Janeiro (1992) the guiding concept of ‘sustainability’ was explicitly agreed on for the first time and documented in the action programme ‘Agenda 21’.

Sustainability is understood as a ‘3 column model’ that aims to balance ecological, economic and social interests. In general, the following specification of the three columns exists:

- natural resources are only used to the extent that they can fully regenerate (ecology),
- no economic burdens are transferred to the next generations (economy) and
- a peaceful co-existance is ensured (social).

Since 1992 the guiding concept 'sustainability' has been further developed and has been concretised in order to be used in sustainability assessments and to provide some orientation for decision making.

It can be observed that sustainability as an overall goal and performance benchmark has not only entered political strategies[1] and research agendas at the national[2], EU und international level[3], but also in policies and management systems of enterprises[4] as well as in assessment concepts[5] and instruments. The guiding concept 'sustainability' can therefore be regarded as generally anchored in the awareness and routines of societal and economic actors[6].

3 Guiding concepts

3.1 Content and function of guiding concepts

In this chapter an interpretation of the role and function of guiding concepts is described at a general level[7].

Guiding concepts formulate an assignment (mission) and related strategic goals (vision) and give orientation on how to implement them (values). The following aspects can be regarded as characteristics of guiding concepts:

- Guiding concepts pictorially describe societal wishes and feasibilities.
- They make societal values explicit.
- They are vague and usually not specified by goals or indicators. Therefore, they can be integrated flexibly into different processes and approaches and it is possible to derive sub-concepts.
- Guiding concepts are not exclusive and allow plurality.
- They are directed to the future and refer to wanted and unwanted change.
- Guiding concepts steer via the context and not directly.

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1 One of the three key areas of the programme Europe 2020 is for example sustainable growth, i.e. the support of an economy that uses resources carefully, is environmentally sound and competitive.

2 The German 'High-Tech Strategy' and 'Nanotechnology Action Plan' are oriented to sustainability: Safety research is an integral part of most projects; however an explicit integration of the topic sustainability in general does not take place.

3 The OECD supports technologies and uses with high benefits for society and the environment while aiming to prevent risks. Nanotechnologies should contribute to problem solving, e.g. the need for renewable energies and clean water.

4 For example the sustainability strategy of BASF (www.basf.com/group/corporate/de/sustainability/index)

5 E.g. the NanoCommission's criteria catalogue (www.bmu.de/chemikalien/nanotechnologie/nanodialog/doc/46552.php)

6 However, this does not mean that the most sustainable options are actually implemented every time, but only that sustainability is (increasingly) considered.

7 Compare e.g. A. Ahrens, A. Braun, A. Effinger, A. von Gleich, K. Heitmann, L. Lißner: „Gestaltungsoptionen für handlungsfähige Innovationssysteme zur erfolgreichen Substitution gefährlicher Stoffe" (SubChem), September 2004.

Guiding concepts can fulfil different functions, e.g.:

- provide orientation to companies for decision making based on incomplete knowledge,
- motivate to innovate, give security regarding the direction of innovations and advertise an overall vision,
- coordinate and synchronise research activities,
- structure and support internal and external communication in institutions and organisations,
- reduce complexity and
- indicate how to overcome ignorance.

Guiding concepts are related to specific (groups of) actors and are developed and determined by them. If and how impacts of guiding concepts actually realize (or not) depends on different factors, such as whether or not they contribute to relevant societal problems and stimulate a respective resonance in public opinion. Furthermore, their impact is influenced by the questions of whether they agree with the action capacities of the actors, if they emerge at the 'right' time and if they have 'potent' promoters.

The concretisation of guiding concepts is frequently the first step in operationalizing them so they can provide orientation on the sustainability of (decision) processes or products. Concretisations can have different forms, such as:

- principles that are included in management systems or policies,
- goals specifying the direction of developments and making them measurable,
- catalogues of criteria and assessment instruments which define sustainability demands to products or processes,
- indicators to compare the sustainability of products, processes or approaches.

3.2 Impacts of guiding concepts

It can retrospectively be determined that at least some guiding concepts, such as the circular flow economy, have had a steering impact and could motivate different actors. There are various angles at which guiding concepts could impact, such as the type of societal challenge to be solved, the curiosity of researchers and developers, the feasibility of processes and products, the people and their ambitions, the awareness of responsibility of organisations and people etc.

The steering impact of guiding concepts cannot be determined in detail because there are no simple relations and many influencing factors. Since guiding concepts impact via their context, it is also not possible to 'apply' them in a targeted and controlled manner to influence processes[8].

[8] In contrast, if guiding concepts are concretized as assessment instruments or management principles it is possible to directly and measurably steer processes and decisions.

Guiding concepts could be particularly helpful in research and development because regardless of the change of knowledge resulting from new findings and researchers' perspectives, their original function to provide orientation remains valid. This is due to their vague and pictorial description of the desired or undesired change. Nevertheless, it is challenging to actually integrate guiding concepts into research processes and the scientists' approaches.

Currently, the integration of the guiding concept 'sustainability' is only indirectly visible in research funding. This is mainly due to institutional and structural reasons within the funding institutions (e.g. a general difficulty to integrate horizontal issues) and the wish to not restrict basic research.

Company guiding concepts (mission statements) initiate internal and external discussions in their practical implementation and thereby create awareness. Issues are brought up, which are not normally on the management agenda. In order for a guiding concept to have a targeted and specific impact it is necessary to operationalize it in form of principles, criteria or instruments which can be integrated and used in the established development and management processes (e.g. phase gates). The principles on the responsible use of nanomaterials and the criteria and assessment instruments of the NanoCommission can be regarded as operationalization of the guiding concept 'sustainable nanotechnologies'.

4 The guiding concept 'sustainable chemistry'

The guiding concept 'sustainable chemistry' evolved from the discussion on 'green chemistry'. The guiding concept 'green chemistry' describes a use of chemistry that reduces environmental burdens and (eco)toxic effects of the production and use of chemical substances as much as possible. The guiding concept 'green chemistry' was concretised by Anastas and Warner by twelve principles, such as:

- emission minimisation, e.g. by design of chemical syntheses, processes and reactors,
- design of safer chemicals; i.e. production of the products with the highest benefits, the lowest toxicity and which are (easily) degradable,
- use of renewable resources,
- increased efficiency, e.g. by use of catalysts instead of stoichiometric reagents or avoidance of unnecessary intermediate steps in chemical processing,
- maximisation of atomic efficiency by design of syntheses and reactions that completely use up the reactants and prevent the development of unwanted substances,
- minimisation of accident risks.

The guiding concept ‘green chemistry’ aims at the minimisation of risks and negative (environmental) impacts and includes only indirect references to the social and economic dimensions of sustainability[9].

At the global summit on sustainable development in Johannesburg (2002), the goal to minimise adverse impacts of chemicals on human health and the environment until the year 2020 (safe use along the entire lifecycle) evolved. This integrates the principles of ‘green chemistry’. The goal should be achieved in particular via the Strategic Approach to International Chemicals Management (SAICM[10]). SAICM considers the social and economic sustainability dimensions, e.g. by enhancing efforts to raise overall living standards and to implement the precautionary principle to balance the dimensions of sustainability. In addition, global cooperation should be established (financing and transfer of knowledge).

The further development of ‘green chemistry’ to the guiding concept ‘sustainable chemistry’ is evident in particular by the extension of the principles by the following aspects:

- A chemical’s function has an increased importance and is used as a reference unit for comparisons with alternatives.
- The purpose and use context as well as the economic, ecological and social benefits and opportunities of ‘chemistry’ are considered.
- The entire lifecycle is important.
- The spatial and temporal range of chemistry and its products are integrated into the concept.
- The societal demand for products / processes / procedures and possible rebound effects[11] are important orienting parameters for the assessment of sustainability.

Some actors, such as the Umweltbundesamt (German Federal Environmental Agency - UBA), evaluate the ecological dimension of sustainability as more important than the economic and the social dimension. They argue that the natural environment is the basis of any economy and of a functioning society. Therefore, the ecological dimension should be the fundamental framework within which societal and economic development can take place. Not all stakeholders share this view and regard a shift of importance of the original equivalent dimensions as contradicting the idea of sustainability.

Different concretisations and implementations of the guiding concept ‘sustainable chemistry’ exist in form of assessment instruments, guidelines, principles etc. In the following, one concretisation is introduced, which was developed by the UBA and the OECD. The goal was to combine precautionary

[9] For example, a reduced human toxicity of a chemical has an economic dimension, because enterprises have lower costs for risk prevention at workplaces and a social dimension because of an improvement of the workplace conditions.

[10] http://www.saicm.org/

[11] Higher resource efficiencies may also lead to conflicts, because the reduced production costs (and an increased market demand) may cause an (undue) increase in the production (sufficiency) and an unexpectedly high materials flow with non-sustainable consequences.

oriented protection of the environment and human health with an innovative economic strategy, which also leads to more employment[12].

In these criteria which concretise the guiding concept of 'sustainable chemistry, qualitative demands are differentiated from quantitative demands. Examples of qualitative demands are that non-hazardous substances are developed (or at least substances with reduced hazards for man and the environment), that chemical production conserves resources and that products have a long service-life. Qunatitative demands are e.g. that the use of resources is reduced or that substance and pollutant emissions to the environment are prevented or reduced. Furthermore, the entire lifecycle shall be considered and analyses be carried out on how raw materials are obtained as well as on the effects of production, processing, use and disposal of chemicals and products.

Using the criteria should motivate companies to take decisions and implement actions that prevent environmental and human health hazards as well as economic risks and remediation costs. In addition, excessively using the environment as a source of resources and sink of pollutants should be prevented. The application of the criteria is expected to increase trust in chemical production and products and to contribute to the economic success of enterprises.

To support economic actors in the implementation of these criteria[13], the Umweltbundesamt has published a practical guide[14] and tested it in practice.

5 Demarcation of nanotechnologies

The term 'nanotechnologies' is often used in a vague manner. The EU Commission defines nanotechnologies as "[…] the study of phenomena and fine-tuning of materials at atomic, molecular and macromolecular scales, where properties differ significantly from those at a larger scale"[15].

According to the participants' understanding at the BMU's FachDialoge, the term includes the different intermediate and final products which are produced using nanotechnologies as well as the respective manufacturing processes. In addition, not only the manufacturing of nanoparticles, their functionalization and their use in basic materials, mixtures and products are addressed, but also those technologies which enable their manufacture. The methods and devices used to analyse nanomaterials are also included[16].

Figure 1 shows this broad understanding of nanotechnologies graphically.

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[12] http://www.umweltbundesamt.de/chemikalien/nachhaltige_chemie/index.htm

[13] E.g. in the context of an assessment of alternatives / substitution

[14] Guide 'Sustainable Chemistry', Öko-Institut & Ökopol 2010, available at http://www.umweltbundesamt.de/uba-info-medien/dateien/4168.html

[15] http://ec.europa.eu/nanotechnology/index_en.html

[16] Devices and methods to determine exposures of nanomaterial, e.g. at the workplace are normally not meant.

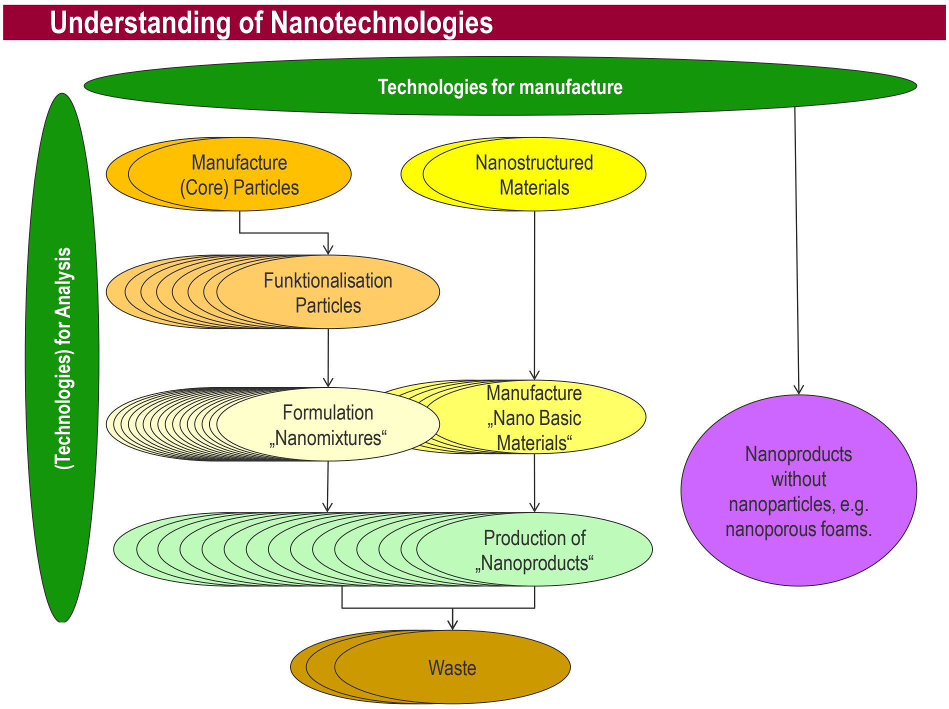

Figure 1: Understanding of the term ‘nanotechnologies’

In this report the term ‘nanotechnologies’ is used according to the above shown broad understanding. If the term nanomaterial is used, the manufacture and use of nanomaterials in a narrow sense is addressed and other technologies, such as for analysis and the manufacturing processes are not included.

6 Sustainability of nanotechnologies

An explicit guiding concept ‘sustainable nanotechnologies’ is not formulated or documented as of yet. In the discourses on sustainable chemistry, nanomaterials and nanotechnologies are implicitly and partly explicitly included, for example in the OECD and SAICM. In discussions on research funding in the area of nanotechnologies and in technology development in general the concept is frequently mentioned. This raises the question of whether a self-standing guiding concept ‘sustainable nanotechnologies’ is necessary and which functions it could have. This was a key discussion point at the FachDialog.

Figure 2 shows a possible place of such a guiding concept ‘sustainable nanotechnologies’ in relation to guiding concepts and concretising criteria and principles. Concepts, principles and criteria are arranged in the figure according to a range (Y-axis) and according to their abstractness (X-axis).

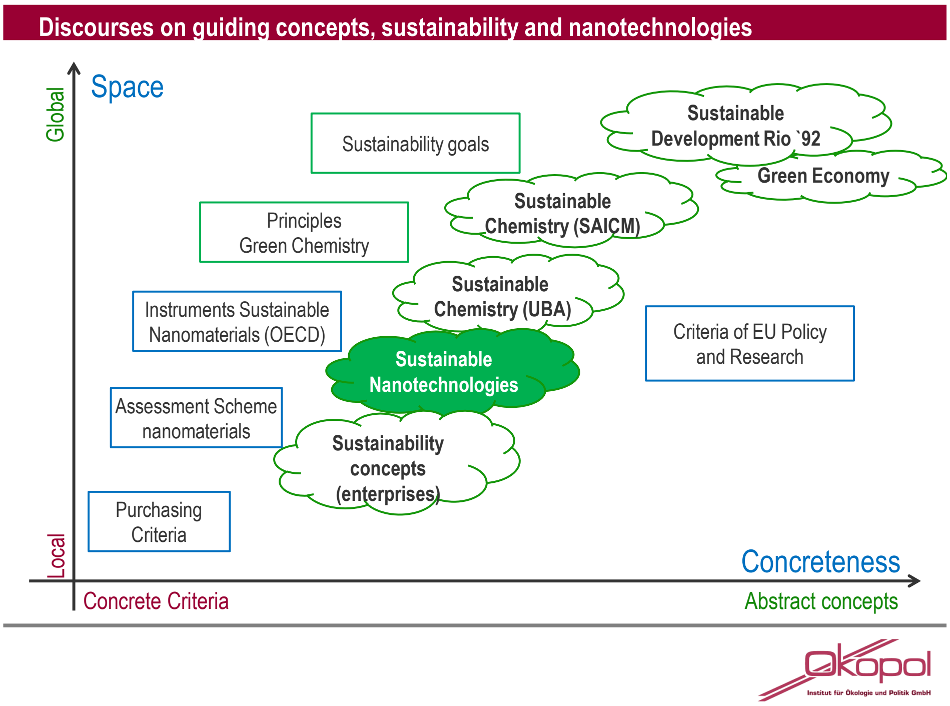

Figure 2: Guiding concepts and their concretisation in the context of nanotechnologies

6.1 Design principles 'green nano'

A working group of the NanoCommission (second dialogue phase) developed design principles[17] for sustainable nanomaterials. These can be regarded as specification of the ecological dimension of a sustainability guiding concept ('green nano') for nanomaterials, which not only aims to prevent or minimise adverse effects, but also to realise positive impacts on man and nature.

The design principles are arranged in four main areas (Figure 3) and the extent of the innovativeness normally increases from the lower left to the upper right. The design principles are not 'commands' but visions and orientations which may compete with each other or which may even be contradicting.

[17] www.bmu.de/chemikalien/nanotechnologie/nanodialog/doc/46552.php

Sustainable Nanotechnologies – 13 design principles

Resource efficiency
- Atomic efficiency and molecular specificty
- Energy efficiency over the lifecycle
- Possibility for circular flow

Biomimetic
- Use of local substance and energy sources
- Self-organisation as production paradigm
- Physiological manufacturing conditions

Energy & environmental technology
- Emission minimisation
- Environmental monitoring
- Environmental remediation
- Change to renewable substance and energy sources

Low risk
Prevention / Minimisation of:
- Nanostructures, morphologies and toxic substance dangerous to safety, health and environment
- Nanofunctionalities dangerous to safety, health and environmental
  Energy efficiency over the lifecycle
- Possibilities of exposure

Figure 3: Structure of the design principles

The concept 'benign by design' also promotes that substances should not only be inherently safe but should also contribute to the prevention of problems. Nanomaterials should therefore not be persistent[18], not transform to problematic metabolites from degradation, reactions or aging and should not have critical morphologies. In addition they should be 'natural', i.e. the core particles should not be rare elements but rather occurring frequently in nature, such as iron.

The opportunities and risks of any innovation are not only determined by the technology itself, but also by the conditions under which an innovative product or technology is used, the purpose of its application and the use context. The more the impacts of (new) materials, processes and products are determined by their uses, the more important the use context in an assessment should be, thus ensuring that a comprehensive overall picture can be drawn. Taking into account the use of an innovation is a particular challenge for the assessment of nanomaterials and nanotechnologies, because they are an 'enabling technology' that is applied in various contexts which could then lead to different related opportunities and risks.

The NanoCommission's design principles as such do not provide a comprehensive orientation regarding the sustainability of nanomaterials, because they only refer to the safety, the resource – poor and the resource protective design. On the one hand the social and the economic dimension are not covered and on the other hand the possible use contexts are only integrated indirectly via the type and functionality of the material.

[18] This is not generally applicable to inorganic nanomaterials. Persistence can be interpreted as 'persistence of a compound' and 'persistence of nano properties'. The latter can also be applied to inorganic nanomaterials.

6.2 Sustainable nanotechnologies to solve societally relevant problems

Guiding concepts can contribute to the solution of societally relevant problems, for example by providing orientation on the type or quality of possible solutions (e.g. sustainability) preventing unwanted change (e.g. exclusion of certain risks or technologies) or by supporting the setting of specific goals and milestones.

There are different views between and within stakeholder groups on whether the definition of societally relevant problems and the search for solutions drive the development of technologies or whether the possibilities of a technology drive the search for use areas and problems to solve.

In the first case, guiding concepts would support and steer both, the weighting and evaluation of the urgency of a defined problem (allocation of the demand within a system of values) and the selection of (technological) solutions (which technologies could provide solutions inside the boundaries of the desired change). In the second case, guiding concepts would only be applied to select an appropriate technology; hence here they impact at a later stage of the process.

The participants at the FachDialog 'sustainable nanotechnologies' agreed that nanotechnologies are not a purpose in themselves, but should serve overcoming societal challenges. There was no agreement; however, to the question of whether nanotechnological innovations are more driven by their possibilities (technology – push) in practice or rather by the societally and technically formulated demand for solutions (demand-pull). This depends on the underlying views on whether the early innovation process is only targeted at achieving specific material characteristics or whether it follows more or less concrete visions on possible uses.

The stakeholders stated that in an ideal case nanotechnologies should be applied after a problem had been defined, society's demand had been identified and prioritised and a sustainability assessment of technological options (or alternative behaviours) had taken place[19]. But in the real world, according to many stakeholders, technologies – including nanotechnologies –develop in parallel to the identification of problems and to the assessment of the sustainability of their use in the respective contexts.

6.3 Assessment of the use of nanomaterials

In the assessment of 'the nanotechnologies', the evaluation of nanomaterials is the most critical and difficult area, because the potential use spectrum of a single particle is very broad and because the highest risk potentials for humans and the environment are connected to the release of nanomaterials 'as such'. In the following some discussions of the sustainability assessment of nanomaterials are summarised.

[19] In basic research this does not apply; however, also here the exploration of new possibilities could be guided by design principles or guiding concepts into the direction of sustainability.

Instruments for the assessment of the use of nanomaterials are one form of concretising the implicit guiding concept ‘sustainable nanotechnologies’. Various instruments exist, which may have different assessment perspectives. The NanoCommission, for example, developed one set of criteria for the assessment of nanomaterials (only regarding potential risks) and one set of criteria for the assessment of nanoproducts (including social and economic dimension).

A comprehensive sustainability assessment of nanomaterials requires not only defining what exactly should be assessed, but also considering the respective purpose and use context. This is necessary in order to take all benefits and risks into account as well as the social, ecological and economic consequences of the use of nanomaterials and to make a complete comparison with possible alternative solutions (c.f. Chapter 4).

One must ask the fundamental question; is it at all possible to evaluate the ‘use of nanomaterials’ at early research and development phases. There are three main arguments, why such comprehensive sustainability assessment is not possible for a nanomaterial at an early stage (without a specific use context):

- Possible risks are determined by the release potential of a nanomaterial along its lifecycle, including the waste stage. Nanomaterials which are firmly bound to the material matrices will be released at a lower extent (lower exposure) than those, which are not chemically bound. Knowledge of the use is needed to anticipate this lifecycle.
- The type of product, its purpose and the context of its application are important determinants on the further sustainability dimensions:
    - The product type determines the release potential (e.g. the disposal pathway depends on the type of final product) and who will be exposed (consumer products, toys or products which are only used by professionals) and at which exposure levels.
    - The product benefits may be so high that certain risks are accepted or outweighed. For example could the societal / health benefit of nanoproducts which are used to avoid disease justify the possible risks.
- The sustainability assessment is relative. Without the use context an absolute evaluation of sustainability would have to be performed, because no comparison with alternative solutions is possible.

Nanomaterials which don’t pose risks for the environment or human health, e.g. because based on testing they have no hazardous properties, may nevertheless be not sustainable. This could e.g. be the case when they are used in products, which are not wanted by the society.

A different view on the issue, which considers that the sustainability assessment of nanomaterials at an early development stage (without specific use context) is possible, at least to a certain extent, is based on the argumentation that the type and functionalisation of nanomaterials does determine the future applications to a certain degree. According to this view, the design of nanomaterials and the search for possibilities to generate specific properties are driven by desired functionalities and are therefore already inspired and guided by potential uses. Furthermore, the nanomaterials' potential uses could be indicators or scenarios for the sustainability assessment. According to this view researchers and developers of new nanomaterials already aim at a specific functionality (design of technical properties) and frequently also at a specific use.

In the specific case of the substance design via 'computational 'chemistry', firstly all possible molecules are selected which could in principle have the desired functionality. In the second step, those molecules which have properties indicating inacceptable hazardous properties (and potential risks) are excluded. In addition at this stage a selection based on criteria, which is derived from potential future uses, may be performed.

According to the statements of the FachDialog participants, for basic materials normally the quality demands for the material are defined but no specific uses are known in the development phase. The quality demands may exclude certain uses but usually don't enable identifying the most likely future use areas. This is also because the future uses also depend on the aims and considerations of the market actors, the (funding) policy settings and the demands of societal actors.

In the discussion on the sustainability assessment of products and processes all participants of the FachDialog stressed that too many demands on the sustainability of products and processes would (too) strongly restrict innovation, research and the willingness of enterprises to take risks.

6.4 Ethical aspects of the sustainability of nanotechnologies

The ethical debate on the sustainability of nanotechnologies has not raised any technology-specific issues. All aspects are also discussed for other technologies (e.g. gene technology or synthetic biology); however the relevance of the issues varies to a certain extent. Besides the management of not knowing the consequences of the use of nanotechnologies, critical issues are the global distributive justice, the 'technical design' of biological system and the related change in the relationship and 'dealing with' life as well as the (societal influence on) the design of the technology.

The possibility of influencing the design of technology is very complex for nanomaterials because of their various use areas. Therefore, the topic 'nano' is rather integrated into a number of discourses (each having different frames and conditions) and hardly exists as self-standing technology discourse. Depending on the type of application, different ethical aspects are in the forefront[20].

Ethical principles can have an orienting impact and function as guidelines for technologies just as the debate on risks. However, ethical arguments frequently

[20] In discussions on 'human enhancement' – the improvement of the human body's functions – the changing understanding of life and how to deal with it are most important. Regarding the use of nanomaterials in consumer products, discussions on risk and how to deal with knowledge gaps are more important. In other technology areas, the discussion on distributive justice is most highlighted.

have a lower importance in technological debates than scientific arguments. In contrast, in the societal debates ethical arguments may be more important than the scientific ones.

In the discussions on societal and ecological sustainability (of nanotechnologies) the limits to growth are important. The limits to growth are relevant in the context of distributive justice and of the responsibility for the next generations and therefore are not only ecological and economic but also ethical questions. Several institutions[21] have attempted to define these limits to growth but so far struggled with their quantification. Also here, there are two views regarding the relationship between the 'limits to growth' and the technology development:

- Technologies can and should push the limits to growth, e.g. by increasing resource efficiency or minimisation of energy use.
- Technologies should only use the possibilities within the defined limits to growth. Therefore, societal needs have to be prioritised and a decision has to be taken if and with which (new) technologies they can be satisfied.

6.5 Handling ignorance

The development of nanotechnologies is accompanied by diverse knowledge generating activities in order to identify and prevent risks and to identify and realize opportunities. However, relevant knowledge and data are missing for a comprehensive sustainability assessment.

The assessment of potential risks for human health and the environment is difficult because of information gaps on hazards and exposures. Strategies to reduce the need for hazard and exposure information are important, among others to take account of the many possible materials and applications. The 'benign by design' concept could be one option to make the generation of exposure data superfluous. The research actives at the EU level (Horizon 2020) which aim to develop models to predict hazards of and exposures to nanomaterials could be an option to satisfy the related information needs.

Economic data allowing statements on the overall economic benefits of the nanotechnology applications are practically absent. This is due to the fact that nanotechnologies are 'enabling technologies' and the related diversity of (possible) uses in very many different products. Therefore, the respective contributions to value creation, innovation and competitiveness can hardly be demarked and quantified.

The possibilities of evaluating the social dimension of nanotechnologies were evaluated as even more unlikely by the FachDialog participants, although the importance of the assessment of the social aspects of technologies was evaluated as high.

[21] C.f. for example one of the first prognoses in the 'Meadows Report' by the Club of Rome or the very recent 'Environmental Outlook 2050' by the OECD.

It is important to note that the above listed types of information are not only necessary for the sustainability assessment of nanoproducts and technologies but also for regulatory impact assessments[22] by the EU.

6.6 Interactions between guiding concepts and technology development

In the discussions at the FachDialog 'sustainable nanotechnologies' the picture shown in **Figure 4** was developed and shows possible interactions of guiding concepts and technologies at different levels.

'Sustainability' or 'sustainable development' has factually evolved to being the fundamental societal concept and goal. The guiding concept of 'sustainable development' remains vague and is directed to all societal actors and processes. It may form a reference point for more specific guiding concepts. The guiding concept 'sustainability' is derived from an underlying world view that is based on the core values of global justice and the conservation of the natural environment as basis for life.

Guiding concepts like 'green economy' or 'green chemistry' are more specific and concretise how sustainability should be understood and implemented in basic areas of the society.

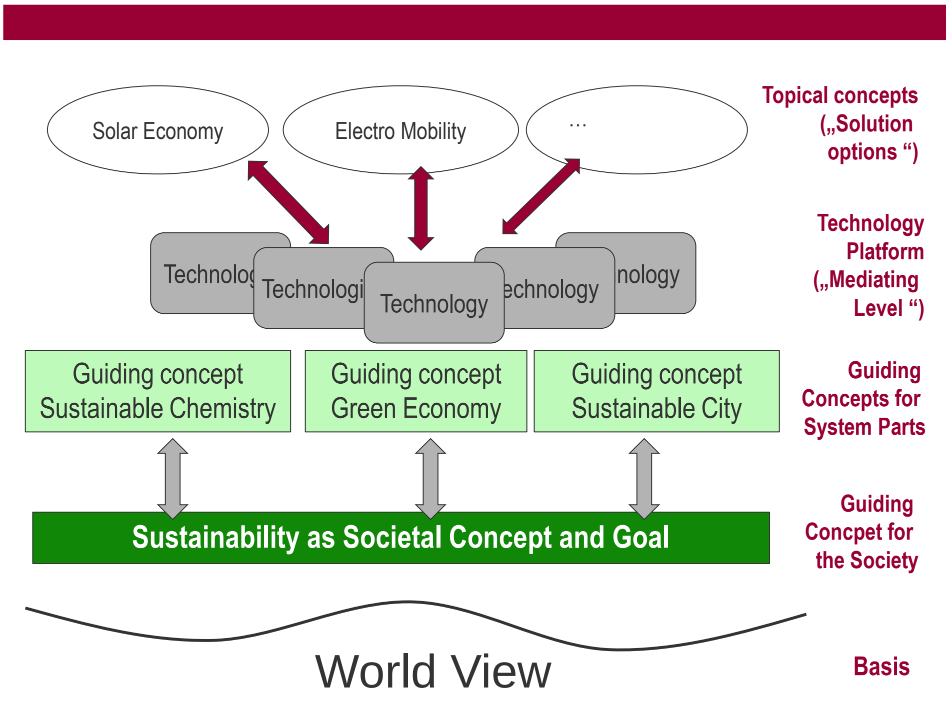

Figure 4: Possible interactions of guiding concepts and technologies

Besides these sub-concepts on sustainability – at the other end – there are topical concepts, like the 'solar economy' or the 'circular flow economy' which relate and describe how the societal needs and the existing framework

[22] http://ec.europa.eu/dgs/secretariat_general/index_de.htm (there click on ‚impact assessment').

conditions could be merged (e.g. the carrying capacities of ecological systems and the aim of sustainable development). They mainly address actors which are directly involved in the implementation of these 'topical concepts.

In this view nanotechnologies are regarded as part of 'technology platforms', which fulfil a mediating role between the different levels of guiding concepts. The technology platforms provide technological solutions from which the actors can choose, taking their specific needs into account and considering their overall aims.

Technology platforms don't have a self-standing (explicit) sustainability guiding concept. Nevertheless, they could be optimized based on adequate criteria with regard to their 'safety' and 'efficiency', so that solutions, which range within a 'safe corridor' and are not contradicting the sustainability of the overall solution or application are primarily offered.

The structure of the different levels of topical concepts and of guiding concepts outlined above replaces the need for a self-standing sustainability assessment of nanotechnologies. It also could make a respective self-standing guiding concept 'sustainable nanotechnologies' superfluous. However, it would be necessary to develop principles and criteria, similar to the NanoCommission's design principles 'green nano', which could support an early and orienting quantification of non-sustainable products, processes and procedures.

7 Summary

Sustainability as societal concept and goal is factually integrated into societal and economic decision and development processes. The assessment of the sustainability of products and processes or the development of technologies among others requires comprehensively taking into account the purpose and the context of the application. This is particularly relevant for nanomaterials because they can be used in very many different applications.

An explicit guiding concept 'sustainable nanotechnologies' does not exist. However, several instruments and concretisations implicitly contain such a guiding concept, among others that of the 'sustainable chemistry'. To further support and strengthen the anchoring of sustainability in technology development guiding concepts and their specification should be integrated more into the daily routines of all actors, e.g. in scholar or non-scholar education or as a demand in the context of research funding.