Are assessments responding to a dynamic environment? Evidence from four emerging techno-scientific domains

Journal:	*Science and Public Policy*
Manuscript ID:	SPP-2013-132.R2
Manuscript Type:	Article
Keywords:	assessment, trends, emerging techno-scientific domain, policy advice, impact
Abstract:	Assessment of emerging science and technologies can assist actors to anticipate and influence technological development. Although the importance of contextual factors in technological development has been stressed previously, it is unknown to what extent economical, societal and political trends are integrated in assessment practices. Focussing on a number of such trends, this analysis shows that there are distinct differences regarding how trends are being addressed in different techno-scientific domains. The consideration of trends in assessments seems to be influenced by techno-scientific domain specific characteristics, including its maturity, developmental speed, societal awareness and associated impacts. Furthermore, both the extent and quality of trend reflection seem related to applied methodological approaches in assessment conduct, including the use of participatory approaches, temporal orientations and transparency of assessment processes in general.

1 Introduction

Assessments can evaluate the performance and future potential impacts of emerging techno-scientific domains (Petermann, 1999). Through anticipating the direction and rate of techno-scientific development, assessments can support public and private decision-makers (Barker and Smith, 1995; Yoon and Park, 2007) in resource allocation, priority setting and risk reduction (see e.g. No & Park, 2010). Based on the broadened context in which techno-scientific development is taking place (Lee et al., 2009; OECD, 1993), advising on such development thus is influenced by several societal, economic and political trends (Bütschi et al., 2004). However, it is largely unknown as to what extent assessments – being able to facilitate science and technology policy making processes – take such trends into account.

The aim of the presented analysis is two-fold. First, in the context of four techno-scientific domains, we analyse the consideration and reflection on trends in assessment practices. Second, we identify relations between trend inclusion, assessment purpose and methodological approaches applied in assessment conduct.

The outline of this paper is as follows. We begin with a short review of the potential relevance of trends in techno-scientific development and decision making processes. In the subsequent section, a short description of the methodological approach and data collection is given in relation to our investigation of the integration of trends in assessment practices. This description is then followed by a reflection on our empirical findings, both in relation to characteristics of different techno-scientific contexts and intended purposes of reviewed assessments. We close with concluding remarks and suggestions for future research.

2 The application of trend-based knowledge in assessment practices

2.1 Trends, indicators and assessments

A trend can be defined as a description of a continuing directional change in the value of an indicator related to a response over time or other dimensions (Urquhart et al., 1998). The discovery and explanation of trends has historically been a particular focus within the natural sciences. In environmental science, statistical approaches have been developed over time for detecting and estimating trends present in several environmental variables (Esterby, 1993). In health care, trend research is being conducted based on various motivations, including patient monitoring on new drug effects and the detection of life style dependent impacts on specific health indicators (e.g. Conley et al., 2008). In geology, trends being analysed include those related to elementary natural forces (e.g. sediment transport in rivers (Mclaren et al., 2007)) as well as trends associated with anthropogenic geological changes (e.g. landscape change and urbanisation (Weng, 2007)).

Trends have also been discussed in domains of social science and innovation research. Here, trend analysis can enable the projection of future visions (Cornish, 2004) and facilitate proactive responses to future events. For example, media and communication research has contributed to issues related to public issue visibility and the uptake of social media applications (Patchin and Hinduja, 2010). In innovation research, trends have been analysed regarding the impact of R&D and business strategy review on competitive behaviour and market dynamics – including analyses regarding industrial and organisational competition (Wu et al., 2011). Related to trend research, several communities have also directed considerable attention towards social indicators. Social indicators refer to a set of statistics that can serve as a proxy, or metaphor, for social phenomena that cannot be measured directly but may

be used to investigate causes of social change.[1] Researchers have also started to examine relationships between various social indicators (Bramstedt and O'Hare, 2002) to identify underlying scales and discover social patterns (Anselin et al., 2006). Another emerging theme regards so-called 'megatrends' that describe a series of changes shaping or constructing the global system over relatively long periods (Henderson, 1995; Slaughter, 1993).

Another domain of social science trend research relates to the development of technologies. Technology trends are being analysed to obtain information about (1) functional differences between technologies, (2) timing of future technological breakthrough, (3) possible technology-based solutions for future problems, (4) directions and perspectives of future technologies, (5) evolving future market shares of technologies, (6) potential short- and long-term impacts of technologies on market, social and economic environments (Martino, 1993; Bright, 1968; Cetron and Monahan, 1968) and (7) potential future merging and overlapping of emerging technologies (Gorraiz and Schloegl, 2008; Gupta and Bhattacharya, 2004).

Typically, technology trends can be analysed in assessments. Assessments are understood as the assembling, summarizing, organizing, interpreting, and possibly reconciling of existing knowledge (Parson, 1995). Organizing scientific capacities in assessments of technologies attempts to anticipate possible outcomes regarding techno-scientific development, as well as to identify and interpret associated risks and benefits (Petermann, 1999). In addition, assessments frame concepts, values, customs or views on how individuals or populations evaluate data, communicate ideas and regulate behaviour (Szapiro, 2004). Assessments can be conducted by a variety of private and public actors involved in scientific exploration, technological development or product commercialization (Vig and Paschen, 2000). As a result, different assessment forms and communities have emerged over the past decades, including constructive technology assessment (Schot and Rip, 1997), real-time technology assessment (Guston and Sarewitz, 2002), parliamentary technology assessment (Decker and Ladikas, 2004), risk assessment, life-cycle analysis, (social and environmental) impact assessment (Bond & Pope, 2012; Morgan, 2012; Weston, 2010; Vanclay, 2003), ethical assessment, technology foresight (Technology Futures Analysis Methods Working Group, 2004), technology forecasting, and economic assessment.

2.2 The value of trend information for informing decision makers

In addition to the identification, interpretation and anticipation of outcomes, assessments are also conducted to explore opportunities to shape and influence techno-scientific developments (Petermann, 1999). Based on the argued need for transition dynamics in providing intelligence for governance and policy-making (Meadows et al., 1992), trends that can potentially influence scientific and technological development are likely to be crucial in assessment practices. It has been stated that sound appreciation of contextual factors is important to apply appropriate methodological approaches to achieve assessment goals (Bütschi et al., 2004), also with respect to trends that potentially affect technology choices and governance mechanisms (Szapiro, 2004).

Despite the regarded potential significant influence of trends in policy advice and decision making, there is still limited knowledge regarding the relevance of explicit trends for specific policy issues. A similar phenomenon has been observed in ecology, a scientific domain characterised by substantial research on trend detection (Esterby, 1993) but limited discussion on what constitutes a policy-relevant trend (Hess et al., 2001). Many policy questions concern trends that are not context specific,

[1] For example, Ogburn investigated the role of technological change as a precedent for cultural change (in Cobb and Rixford, 1998).

but are being posed across collections or populations of systems. Also, certain trends might become more relevant at later stages of development.

More fundamentally, there has been scepticism towards the integration of trends in policy making. In system dynamics communities, trend forecasting has been regarded as a dysfunctional basis for decisions due to the self-fulfilling nature of forecasts (Forrester, 1961; Lyneis, 1982). In addition, trends are a source of instability and could amplify changing conditions when used in policy (ibid.). In contrast, trend information has also been generated and used with a high degree of reliability regarding derivative control in engineering (Takahashi et al., 1972). It seems important to what extent variable based information originates from within or outside the system under study. Due to complex interactions between elements within socio-economic systems, trend information is often generated and applied without the intention to control. On the other hand, it has also been claimed in engineering that derivative control and trend information could be applied reliably in policy design when the structure of involved policies is carefully identified (Saeed, 2007).

2.3 Knowledge gap and research aim

Despite the present uncertainty regarding the value and relevance of trend information in policy making, its potential significance in assessments of emerging techno-scientific domains – which require a high appreciation of contextual factors – seems evident. Emerging techno-scientific domains, which are typically characterized by multiple interdependent components, widespread application potential (Fleischer et al., 2005) and a high degree of uncertainty and complexity, imply that information regarding the presence and direction of trends might be valuable in assessment practices. Trends might have an impact on technology advice in at least three ways: a) by representing specific issues in assessments; b) by forcing advisors to methodologically adapt to the trends; and c) by forming explicit or implicit assumptions about the present and the future in the made appraisals. Building on Decker & Ladikas (2004), we hypothesise in this study that techno-scientific focus, assessment purpose and applied methodological approaches might influence the appropriateness and value of trend consideration in assessment practices. However, it is unclear to what extent trend research is being integrated in assessment practices of emerging techno-scientific domains. Additionally, there is limited knowledge regarding the relation between trend integration and the nature of assessment practices and purposes.

In order to improve our understanding regarding the nature and value of trend integration in emerging techno-scientific assessments, our research aim is two-fold. First, we aim to shed light on how, and to what extent, trends are being addressed in assessments of emerging science and technologies. Second, we try to identify potential relations between trend reflection, applied methodological approaches and the purposes of assessments.

3 Trends in science and technology assessments – An empirical study

3.1 Methodological approach & data collection

Our methodological approach and data collection can be divided into three parts: (1) selection of techno-scientific domains and assessments, (2) selection and measurement of trends, and (3) analysis of assessment context and practice.

3.1.1 Selection of techno-scientific domains and assessments

In order to shed light on trend integration in assessment practices, four emerging techno-scientific domains were selected: biofuels, cloud computing, nano-food and synthetic biology. These domains were studied in, respectively, the United Kingdom, Denmark, the Netherlands and Germany. In

addition, a number of European and international assessments were included as being potentially influential on the national situations. We believe that this selection limits potential bias regarding techno-scientific associated impacts, challenges and phase of development. The inclusion of multiple techno-scientific domains can therefore improve understanding of how context specific trend integration is. The data with respect to the techno-scientific domains were collected during four independent case studies, comprising in total 65 assessments.

3.1.2 Selection and measurement of trends

Although there are multiple trends that can influence technological development, we selected six trends as being potentially significant in techno-scientific domain development:

- *Liberalisation:* Liberalisation refers here to the tendency to move away from state control involving government steering, regulation or control of social and economic systems, towards increased relaxation of global economic and trade policies. With regard to such relaxation efforts, liberalisation is often strongly related to internationalisation or globalisation based processes.
- *Internationalisation:* Internationalisation refers here to the cross-national development of education, science, innovation, technologies and markets (Held et al., 1999). It is a process that initiates increased economic integration between countries which could lead to the emergence of a global marketplace or a single world market (O'Sullivan and Sheffrin, 2001; Ritzer, 2011).
- *Public-private partnerships:* Public-private partnerships refer here to long-term cooperation structures between public bodies and private companies with the purpose of establishing and maintaining infrastructure, run public services and support trans-national cooperation (e.g. see Buse & Walt, 2000; Knapp et al., 2013). A public-private partnerships is a type of cooperation that is receiving increased global interest (Hodge and Greve, 2007), arguably as a partly result of macroeconomic dislocation in the late 20th century.
- *Policy integration:* Policy integration refers here to the attempt of addressing cross-cutting issues in situations where policy seeks to reach beyond a single domain. In such situations both goals (priority setting) and instruments applied (implementation) seek to avoid contradictions and achieve coherence. The need for policy integration, coordination, coherence and consistency goes hand in hand with the processes of increased specialisation and organisational differentiation within the public sector (Mintzberg, 1979; Thompson, 1967).
- *Consumer acceptance*: Consumer acceptance refers to the potential presence of critical reflection among consumers on products associated with emerging techno-scientific domains (e.g. see Bagozzi & Lee, 1999). Consumer acceptance seems relevant with regard to the potential increased influence of consumer preference in the development of specific products, as well as the potentially rising safety and security impacts associated with technological development. In addition, governance based on deliberative democracy might have increased the relevance of – and attention towards – consumer acceptance over the past few decades.
- *Focus on sustainability*: Focus on sustainability should here be interpreted as representing the emergence of values oriented towards sustainable development. Sustainable development is defined as meeting "the needs of the present without compromising the ability of future generations to meet their own needs" (UN, 1987) and is argued to include interdependent and reinforcing components related to economic development, societal development and environmental protection (UN, 1997). Arguably, sustainable development has become a guiding principle in European public policy and has stimulated increased public awareness regarding its meaning and potential implications.

By means of assessment review, the extent of trend consideration in assessments was qualitatively determined in two ways. First, it was determined whether or not trends – as selected and described

above – were *reflected* upon in assessments. Second, it was determined whether or not trends were *assumed relevant* – with regard to trend presence and trend direction – in assessments.

3.1.3 Selection and measurement of assessment characteristics

It was argued that the consideration of certain trends might be dependent on the context in which assessments are being conducted. In addition to potential techno-scientific domain dependence, we focus on three additional assessment characteristics that we assume to be able to influence the context of assessments: assessment purpose, considered impacts and the nature of assessment practice.

Purpose

Depending on the 'knowledge need' in a specific techno-scientific context, different assessment purposes could be aimed for. For instance, required knowledge might differ with respect to the temporal orientation of assessments – an orientation that could be anticipatory or retrospective. In addition, knowledge need is also likely to be closely linked to the maturity of a techno-scientific domain.

Based on an approach suggested by Decker & Ladikas (2004), assessment purposes can be categorised according to two dimensions. One dimension depends on whether the assessments focus on technological/scientific, societal or policy aspects. The other dimension depends on whether the assessments are cognitive (raising knowledge), normative (forming attitudes/opinions) or pragmatic (initialising actions) of nature. This approach was applied to (1) systematically map the purposes of the reviewed assessments in a specific techno-scientific domain, and (2) to compare findings between the different techno-scientific domains under analysis. The purposes of assessments were qualitatively determined and categorised according to the applied typology. The distribution of aggregated scores was compared over the four different techno-scientific domains.

Considered impacts

Technologies associated with various techno-scientific domains are known for their potential to create impacts. Closely related to assessment purpose, the focus on specific impacts can influence the knowledge required for conducting an assessment. In order to highlight the contextual nature of impacts, we analyse the presence of five different impact types: *economic*, *environmental*, *social*, *security* and *safety/health* impacts. Impacts may be specific to a techno-scientific domain or phase of development. The presence of considered impacts in assessments was qualitatively determined by means of assessment review.

Nature of assessment practice

For both assessment purpose and considered impacts, we review to what extent they have influenced the nature of assessment practice with respect to issues related to the *applied evidence base* and the integration of possible *normative considerations*. By means of assessment review, the following variables in assessments were scored: *impartiality*, *transparency*, *expert participation*, *lay people participation*, *stakeholder participation*, *scientific evidence basis*, *focus on uncertainties*, and *explicit values/ethics*. Variable scoring was based on their consideration, presence and importance in the individually selected assessments, ranging from 1 (very low) to 5 (very high).

3.2 Data collection & results

Trends in assessments

Insert Figure 1 around here

In general, we see that none of the analysed trends are reflected upon in a large majority of the assessments (Figure 1). *Focus on sustainability*, *internationalisation*, *consumer acceptance* and *liberalisation* are reflected upon in about half of the assessments. Of these, *focus on sustainability*, *internationalisation* and *liberalisation* are assumed to be relevant in the majority of assessments; regarding *consumer acceptance*, assumed relevance is not evident. Assessments address *policy integration* and *public-private partnerships* considerably less; assessments in general are also unspecific to what extent these two trends are assumed relevant or present.

Insert Figure 2 around here

There are, however, notable differences between the different techno-scientific domains. Biofuel assessments mainly reflect upon the *focus on sustainability,* a trend that most of these assessments also assumed to be relevant (Figure 2). Such reflection on – and assumed relevance of – sustainability is much more pronounced in biofuel assessments than in the other domains. Other trends are much less addressed in biofuel assessments. *Liberalisation, internationalisation* and *consumer acceptance,* trends that receive quite some consideration in other domains, are scarcely reflected upon in biofuel assessments. Of these trends, only *internationalisation* and *liberalisation* seem to be assumed relevant to a certain extent. Like for other socio-technological domains, *public-private partnerships* are not intensely addressed or assumed relevant in biofuel assessments.

In the cloud computing domain, *liberalisation* and *internationalisation* – in comparison to other trends – are relatively intensely reflected upon (Figure 2). Reflection, and assumed relevance of, *public-private partnerships* – compared to the other techno-scientific domains – is relatively high. Also *liberalisation, internationalisation* and *consumer acceptance* are assumed to be highly relevant in cloud computing assessments, whereas the assumed relevance of the trends *focus on sustainability* and *policy integration* is less apparent.

Trend patterns of nano-food assessments (Figure 2) are comparable to those observed across our techno-scientific domains (Figure 1). The trends *liberalisation*, *internationalisation, consumer acceptance* and *focus on sustainability* are relatively strongly reflected upon in comparison to *policy integration* and *public-private partnerships*. There is, in comparison to the other techno-scientific domains, a strong reflection (although not a generally assumed relevance) upon *consumer acceptance*. Of all trends, only *internationalisation* seems to be assumed relevant – to a certain extent – in nano-food assessments.

In the synthetic biology domain, there is a particular reflection on *liberalisation*, *internationalisation* and *consumer acceptance* (Figure 2). Compared to the other techno-scientific domains, synthetic biology assessments have limited reflection on the trend *focus on sustainability.* In addition, there is limited reflection on *policy integration* and *public-private partnerships*. Only *liberalisation* and *internationalisation* are assumed relevant by the majority of analysed synthetic biology assessments. Regarding the other trends, the observed assumed relevance was limited.

Purpose, considered impacts and the nature of assessment practices

With respect to assessment purpose, there are a number of observed differences across our four techno-scientific domains (Figure 3).

Insert Figure 3 around here

Biofuel assessments are mainly directed towards raising knowledge. With regard to raising knowledge, there is strong focus on the *identification and assessment of technical options*, the *assessment of existing policies* and the *exploration of policy objectives*. Although the impact dimensions forming attitudes/opinions and initialising actions receive relatively less attention, there is considerable focus on *increasing comprehensiveness in policies* and on *proposing new initiatives to scrutinise the problem at stake*.

In cloud computing assessments, most focus seems to rest on raising knowledge and forming attitudes. Similar to biofuel assessments, the strongest focus is on *identifying and assessing technical options*. Two other relatively important purposes of cloud computing assessments concern *setting the agenda in the political debate* and *proposing new initiatives to scrutinise the problem at stake*.

Nano-food assessments show a certain similarity compared with assessments of cloud computing, with a general focus on raising knowledge and forming attitudes. However, in contrast to biofuels and cloud computing assessments, there is limited attention on *identifying and assessing technical options*. Instead, assessments focus more on *providing comprehensive overviews* and *stimulating public debate*.

Unlike the other techno-scientific domains, *synthetic biology assessment* purpose seems relatively balanced with regard to raising knowledge, forming attitudes and initialising action. A similar balance is observed with respect to a focus on technical/scientific, as well as on societal and policy aspects. Relatively important purposes for assessing synthetic biology include the *exploration of policy objectives*, *setting the agenda in political debates* and *introducing new ways of governance*.

Insert Figure 4 around here

Regarding the nature of assessment practices, *scientific objectivity* and *impartiality* is scored as sufficiently dealt with across all techno-scientific domains (Figure 4). *Scientific evidence* is in particular considered in nano-food and synthetic biology assessment. In addition, we observe that the nano-food domain is relatively *transparent* concerning the conduct of assessments. With regard to *addressing uncertainty,* biofuel assessments seem to score relatively poorly compared to the other techno-scientific domains. Across the different techno-scientific domains, we observe that *participation of experts* is relatively high compared to *participation of lay people and stakeholders.* The use of participatory approaches seems related to techno-scientific maturity; in this respect, biofuel assessment practices show less pronounced differences between the inclusion of experts, stakeholders and lay people in comparison with the other, less mature, domains. Finally, we observe a relatively high presence of *explicit values and ethics* in synthetic biology assessments. This finding seems reflected by the observed strong focus of synthetic biology assessments on attitude formation.

Insert Table 1 around here

Regarding cross-domain impacts, there is particular consideration of *environmental*, *economic*, *security* and *societal* impacts (Table 1). However, the balance concerning considered impacts differs between domains. In biofuel assessments, consideration of *environmental impact* is dominant, whereas in the cloud computing domain a dominant attention is given to *economic* and *security* impacts. In the domains of nano-food and synthetic biology, the focus regarding considered impacts seem to be more balanced.

3.3 Discussion of results

The results indicate a number of relations regarding the nature and intensity of trend reflection in assessments of emerging techno-scientific domains. These relations can be roughly categorised into three themes: (1) *trend emergence*, (2) *participation* and (3) *knowledge availability.*

3.3.1 Theme 1 – Increased importance of sustainability and internationalisation

The supporting role of information and communication technologies in globalisation

Focus on sustainability and internationalisation are the only trends that are reflected upon in the majority of assessments. Both trends have gained considerable significance in the past few decades. The information and communication technology (ICT) revolution that started in the second half of the 20th century increased the global accessibility of many industries and their related R&D efforts (Arnold and Smith, 2003). This might explain the prominent presence of the internationalisation topic in the cloud computing assessments, a domain in which internationalisation could almost be seen as a pre-requisite for the technology's success. In this respect, quite a few assessments advocate further integration of European national economies and harmonization of market rules in order to reap the economic benefits of cloud computing. In addition to internationalisation, the considerable attention directed towards policy integration in cloud computing assessments – in comparison to the other techno-scientific domains – could be interpreted as an acknowledgement of the importance of a high degree of institutional alignment and policy coherence.

The importance of sustainable biofuels

In the context of emerging science and technology, focus on sustainability is another relatively young concept. With respect to the discussion around climate change and potential sources thereof, the energy market was one of the first to react to this as an institutional orientation (e.g. see Dincer, 2000), in which (increased) production of biofuels might even be seen as one of the first market expressions of sustainable products (e.g. see Bailis & Baka, 2011). The large reflection on, and assumed presence of, sustainability as an important focus in biofuel assessments is therefore not surprising. Environmental impacts of biofuels refer to claimed relations between biofuel production and land use change, natural ecosystem degradation, localised biodiversity decrease and greenhouse gas emissions (e.g. see Havlík et al., 2010). There is also some inclusion of social and economic impacts. Biofuel markets are associated with changing economic and social conditions in developing countries; in particular, internationally oriented biofuel assessments seem to address such issues. The food-fuel debate with respect to food availability and prices seems to be exemplary of the integration of various related impacts in biofuel assessments.

Still, the strong focus on sustainability seems to come at the expense of reflection on, and assumption of, internationalisation in biofuel assessments. Considering the international nature of the biofuel

sustainable development theme, the limited inclusion of internationalisation seems an awkward gap in assessment methodology and focus. In addition, the general negligence of values and ethics in biofuel assessments could be judged as unexpected, as it seems to conflict with some of the underlying normative principles of sustainable development including global economic prosperity, social justice, human equality and equity, the inherent values of nature and environmental protection (e.g. see Binder, Feola, & Steinberger, 2010; Hahn, 2011; Renn, Jager, Deuschle, & Jehle, 2009). Regarding crop optimisation, the substantial use of biotechnology by means of plant growth and production related genetic optimisation has likely driven increased reflection regarding the normative and ethical limits of human interference.

Limited inclusion of sustainability in other techno-scientific domains

In the other reviewed techno-scientific domains, increased focus on sustainability based values is not evident. In cloud computing assessments, sustainable development is most likely not regarded as directly related to ICT advance. Although little reflection on sustainability in synthetic biology assessments seems surprising due to the many and diverse impacts being envisioned for its future applications, this low reflection could simply be the result of synthetic biology's early-phase character and its initial short-term envisioned 'contained' use. On the other hand, in contrast to biofuel assessments, values and ethics receive considerable attention in synthetic biology assessments. In the face of synthetic biology's potential to shift or trespass existing ethical boundaries (Dabrock, 2009), the presence of these debates in assessments is not unexpected, seizing an opportunity to influence the institutionalisation of normative limits with regard to advancements in both biotechnology and synthetic biology approaches.

In general, although focus on sustainability figures as an overarching value in many policy documents, it appears hard to implement in the assessment of emerging science and technology. The integration and measurement of sustainable development as an overarching concept seems limited in the reviewed assessments. Although more specific topics related to the sustainability concept – such as climate change and biodiversity – are being considered to some extent, a holistic approach is lacking.

3.3.2 Theme 2 – Participation, public awareness and consumer acceptance

Cloud computing and biofuels – young versus old

With regard to ascertaining and integrating normative orientations and values in assessment processes, the issue of participation seems particularly relevant. Although the necessity of participation is often mentioned in assessments across techno-scientific domains, practical inclusion of stakeholders and lay people seems to be relatively underrepresented in assessment practices.

This observation may not be surprising for cloud computing. The limited inclusion of lay people, in combination with a strong focus on technological aspects, could be partially explained by its arguably limited associated societal conflicts at the time assessments were conducted. Although issues related to privacy and data protection are important and relevant, such issues are unlikely to have emerged as a result of cloud computing (e.g. see Bennett, 1991). The relevance of ICT issues in general for cloud computing, like those associated with privacy and data protection, might be explained by cloud computing's incremental innovative nature – being mainly based on the recombination of existing technologies.

However, the limited inclusion of lay people in the more mature biofuel domain is surprising. Especially in light of diverse controversies with respect to land use change, food availability, greenhouse gas emission reduction and operational performance (e.g. see Havlík et al., 2010; Basha, Gopal, & Jebaraj, 2009), one would expect biofuel assessment practices to consider stakeholders and

lay people more extensively. In addition, reflection on consumer acceptance seems limited in biofuel assessments. This is another unanticipated observation given the stated necessity of public support for biofuel-market development (Bureau et al., 2010). Considering the competitive disadvantage of biofuels compared to the dominant conventional fossil-based fuels, biofuel market development and expansion might be problematic without public support, even if most of the associated negative impacts of biofuel production remain undetected in industrialised countries (e.g. see Van der Horst & Vermeylen, 2011).

Awareness of synthetic biology impacts – lessons from the past

Based on the review of the synthetic biology domain, limited public awareness seems to have been a major driver for initialising assessments. Due to uncertainty associated with synthetic biology and the lack of empirical evidence of its potential impacts, there has been considerable focus in assessments on the shaping of attitudes. Consequently, consumer acceptance is frequently discussed. However, there is no consensus among assessments with regard to framework conditions or specific determinants that could influence consumer acceptance of synthetic biology based products. In this respect, the relatively low inclusion of lay people and the relative lack of stakeholder participation in synthetic biology assessments seems striking. This is particularly so in light of the argued lack of information based transparency between consumers, producers and governments about potential but unknown impacts during commercial introduction of genetically modified organisms, driving scepticism and precaution in Europe (e.g. see Von Schomberg, 2013). This historic case is an important reference in many synthetic biology assessments for indicating the relevance of upstream engagement in biotechnology – as well as in biotechnology related – development, especially with regard to products that are likely to have potential impacts on personal safety and security. However, although many of the reviewed synthetic biology assessments consider consumer acceptance, the integration of consumers in synthetic biology assessment practices seems limited.

The diversified purposes of synthetic biology assessments could also be explained through the current association with past and on-going biotechnology practices. Although an important purpose of assessments is to raise synthetic biology specific knowledge, another strong focus is directed toward the evaluation of existing policies and new policy options. It has been observed that a majority of synthetic biology assessments assume importance in assessing the appropriateness of existing political frameworks for regulating current and future synthetic biology practices. These purposes of synthetic biology assessments – also taking into consideration the various potential global impacts on safety and security associated with synthetic biology practices (e.g. see Garfinkel, Endy, Epstein, & Friedman, 2007) – seem related to the high weight put on consumer acceptance, internationalisation and liberalisation. The relatively strong focus on safety and security impacts includes themes such as bioterrorism, ‘garage’ and ‘do-it-yourself’ bio-communities, and the unintended release of engineered organisms. In this respect, this focus correlates with the strong reflection on liberalisation, which in turn addresses issues related to the regulation of biotechnology’s use in public and private spheres.

Nano-foods – a personal issue

Like synthetic biology, a main purpose of nano-food assessments is the provision of comprehensive overviews of consequences and the stimulation of public debates. These resonate with strong reflection on sustainability and consumer acceptance, both being trends that are highly entrenched in personal behaviour and societal norm setting (e.g. see Barr, 2003; Schepers & Wetzels, 2007). As in the case of synthetic biology, the introduction of nano-foods could become controversial and unacceptable if consumers’ opinions are not sufficiently represented in assessments that could facilitate policy making and influence regulation. This resonates with the finding that nano-food assessments in general do not assume consumer acceptance. This observation might be related to a

general consumer conservatism on the introduction of novel food based on technologies characterised by uncertainty regarding potential safety and health concerns (e.g. see Chen, Anders, & An, 2013). Compared to prominent impacts considered in assessments of other techno-scientific domains, the inherently strong connection between nano-food and personal consumption might explain the great consideration of consumer perspectives.

The strong consideration of consumers is also illustrated by large transparency. This may be required to optimise assessment legitimacy through both the involvement of potential consumers and the integration of their deliberations. Considering the strong reflection on consumer acceptance, nano-food assessments seem to be most active in lay people involvement among the reviewed techno-scientific domains. However, the question remains to what extent such inclusion promotes citizen empowerment and democratisation (see e.g. Krabbenborg, 2012) or could influence departmental and interdepartmental policy making.

3.3.3 Theme 3 – Towards commercialisation: transforming knowledge into innovations

The influence of techno-scientific domain maturity

A final identified theme in the analysed assessments concerns to what extent assessment practices and trend inclusion is influenced by techno-scientific domain maturity.

First of all, there seems to be a relation between the age of techno-scientific domain and the temporal orientation taken in assessments. Whereas generally half of the biofuel assessments focus on reviewing past performance of biofuels, the other three techno-scientific domains focus in particular on potential future developments. Therefore, it is not surprising that certain trends that might influence future trajectories – like liberalisation, internationalisation and consumer acceptance – receive relatively little attention in biofuel assessments; these are all trends that rank considerably higher in the other reviewed techno-scientific domains. The existence of a global biofuel market and growing commercialisation might make the integration of such economic trends, relatively, less relevant.

Second, the high degree of scientific objectivity in emerging domains might be explained by a need for legitimate information sources. The relatively strong focus on uncertainty in assessments of more 'emerging' techno-scientific domains might be the result of limited knowledge availability, compared to the more 'established' biofuel domain in which uncertainty is considered less intensely. Nevertheless, it should be noted that, in general, biofuel assessments are still uncertain with respect to the relevance of analysed trends. Such observation indicates that, despite extensive knowledge availability, potential impacts and trend driving dynamics are still far from certain. In addition, the limited knowledge availability of early-phase techno-scientific domains seems to create a need for more inclusive assessment practices that integrate every potential impact.

Commercialising emerging technologies

The commercialisation of emerging technologies is particularly highlighted by assessments performed in the cloud computing domain. The early commercial phase of this technology explains the great focus on economic effects in these assessments. Since the general value and function of this technology seems well understood, indicated by the growing share of related ICT-infrastructures, the assessment of future economic trajectories does seem to be – at least from a rational perspective – interesting. In addition, assessing potential economic impacts might prove insightful regarding the facilitating nature of mature ICT infrastructures and technologies. Moreover, the relatively young history of cloud computing, in combination with its comparatively rapid commercialisation, might explain that the purposes of these assessments are wide ranging – from raising knowledge to initialising action. These emerging commercialisation activities are confirmed by the strong focus in

cloud computing assessments on short-term anticipation, whereas the generally unknown extent of anticipation in nano-food and synthetic biology assessments is in concordance with their rather conceptual phase of development.

Commercialisation of emerging technologies relates also to a potential trend towards more public-private partnerships. Public-private partnerships became part of European research policy, being represented in the Joint Technology Initiatives (JTI) instrument within the 7th Framework Programme. However, despite the increased focus on public-private partnerships in several policy measures, they are rarely addressed in assessments. Although public-private partnerships could contribute to shaping techno-scientific trajectories, they are only noticeably addressed in cloud computing assessments; although to a limited extent, this attention in assessments might be due to cloud computing's perceived institutional importance with regard to the significance and prevalence of issues related to privacy and data-protection.

Nevertheless, it could be argued that the manifestation of collaboration structures to drive emerging techno-scientific based markets, such as public-private partnerships, require increased focus to strengthen economic concerns in science and technology policy making. In addition, the potential effects of market liberalisation boundaries on responsible governance is not intensely discussed across the reviewed techno-scientific domains. With regard to the more emerging domains of synthetic biology and nano-food, the focus on commercialisation potential is quite limited and mainly conceptual. Despite the argued importance of co-development in the early phases of technological development (e.g. see Heiskanen et al., 2007), there seems to be limited involvement of stakeholders and potential users of products related to such technologies.

3.4 Limitations of this study

Our selection of assessments and techno-scientific domains may have influenced our observations. Although this selection was discussed with practitioners in the field through interviews and workshops - and therefore seems justified input for deriving domain specific conclusions – the generalizability of made conclusions might be inappropriate for countries outside the scope of the executed case studies. Moreover, subtle differences between techno-scientific interpretations of trends and impacts might have influenced our comparative approach.

The chosen methodological approach of this research might have excluded certain highly relevant trends in a specific techno-scientific context. A more systematic approach of both trend identification and trend selection could make the analysis of trend integration in assessments more robust. In parallel with our analysis, we developed an approach for the systematic identification of important trends in science and technology studies (see text box). We believe that such systematic approach could form a solid basis for conducting future trend research in emerging techno-scientific domains.

A systematic approach to identify important trends in emerging techno-scientific domains

Seven reports (Ernst & Young, 2011; European Commission Joint Research Centre and Institute for Prospective Technological Studies, 2010; European Environment Agency, 2011; European Strategy and Policy Analysis System and Institute for Security Studies, 2012; ICSU, 2011; OECD, 2001; EC DG Research and Innovation, 2012) were used to obtain an overview of perceived important and technology policy relevant socio-economic trends. Collecting the main trends from these reports yielded a total of 25 trends. In a second step, trends were excluded that (a) were only mentioned once in reports, (b) were not deemed to be inherently relevant for technology appraisal and governance or (c) had arguably lower importance. In addition, certain trends were added based on common agreement in consultation with experts. In the end, this systematic approach resulted in the following trends: (1) new governance networks, (2) liberalisation and globalisation, (3) public-private partnerships, (4) citizen empowerment and public deliberation, (5) rapid technological change, (6) increased focus on sustainability and climate change, (7) economic change, (8) quantification, and (9) policy integration. Despite certain differences, this set shows certain alignment with the trends analysed in this study.

Finally, it should be questioned as to how knowledge in assessment conduct, both used and produced, could be judged as being sufficient and appropriate. In this study, the observed relations and related conclusions were made at the level of techno-scientific domains. However, the relevance of such observations depends on the considered role of individual assessment communities. This issue highlights a fundamental challenge in reviewing individual assessments, since an underrepresentation of trends at the level of individual assessments might not necessarily indicate an overly limited consideration of such trends in the techno-scientific domain as a whole. Although difficult to identify, assessment practices within techno-scientific domains might be complementary. Our analysis, scoping a broad range of assessments in a techno-scientific domain would to a certain extent be able to pick up such complementarity. Despite no indications were found for the potential presence of complementary assessment approaches, such possible dynamic – also due to the unknown importance of specific assessments in a techno-scientific domain – could have remain hidden in our analysis.

4 Conclusion

Emerging techno-scientific domains are generally characterised by uncertainty regarding their future evolution. Without firm establishment in existing institutional arrangements, market infrastructures and societal awareness, the direction of techno-scientific development might be strongly influenced by contextual changes. In this respect, trend information can provide valuable information for sound assessment practices. Assessments have a rich history in facilitating governance by means of providing the knowledge required for robust and legitimate decision making and are gaining attention as important sources for influencing short-, medium- and long-term techno-scientific trajectories.

In this study, we analysed how trends are addressed and integrated in emerging techno-scientific domain assessments. We observed that both trend reflection and perceived trend relevance is context dependent. Technology age, availability of knowledge and the presence of commercialisation potential influence how, and to what extent, specific trends are integrated into assessment practices. In addition, we found several relations between trend consideration, techno-scientific impacts, intended purposes and the nature of assessment practices. Such relations might prove valuable in the identification of emerging techno-scientific domain specific knowledge gaps, as well as how the conduct of assessments could address such gaps effectively.

It seems, therefore, that trend information is already being applied considerably in assessments of emerging techno-scientific domains. However, it remains unclear how grounded such consideration is with regard to the selection of integrated trends, the analysis of trends and the weight of trend data in

evaluations. With respect to the critical role of trend knowledge in policy making, assessors should be aware of the power of trends. Therefore, we might need to strive for more systematic trend integration in assessment practices of emerging techno-scientific domains. Only then could assessments become better suited to manage uncertainty, to apply available information sources comprehensively and optimise strategic development of emerging science and technologies.

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5 Tables and figures

5.1 Tables

Table 1 Assessment characteristics regarding considered impacts. The presence of considered impacts was qualitatively determined in the individual selected and reviewed assessments. Based on aggregated scorings, average percentages within and across techno-scientific domains were calculated accordingly.

Impacts considered	Biofuel	Cloud computing	Nano-food	Synthetic biology	Total average
Environment	41%	18%	26%	20%	26%
Society	21%	16%	23%	16%	19%
Security	7%	30%	13%	25%	19%
Economy	26%	36%	9%	16%	22%
Health / Safety	5%	0%	30%	23%	14%

5.2 Figures

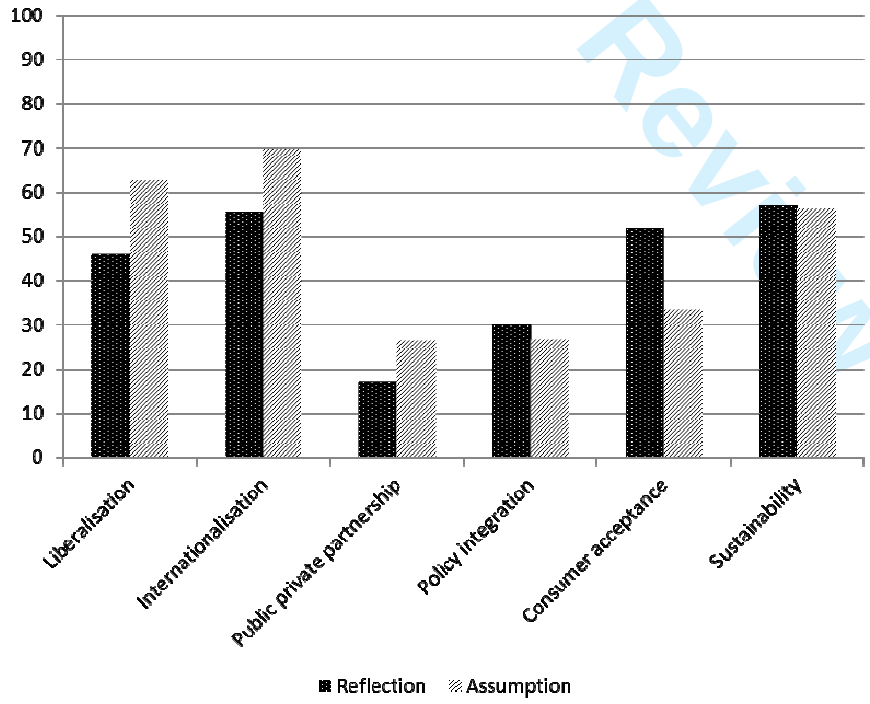

Figure 1 Trend consideration across the reviewed techno-scientific domains. The relative share of trend consideration in a techno-scientific domain was calculated based on the aggregated scorings of individual assessments. The extent of trend consideration within assessments was reviewed in two ways: (1) whether or not a trend was explicitly reflected upon in assessments, and (2) whether or not trend presence and trend direction was assumed relevant.

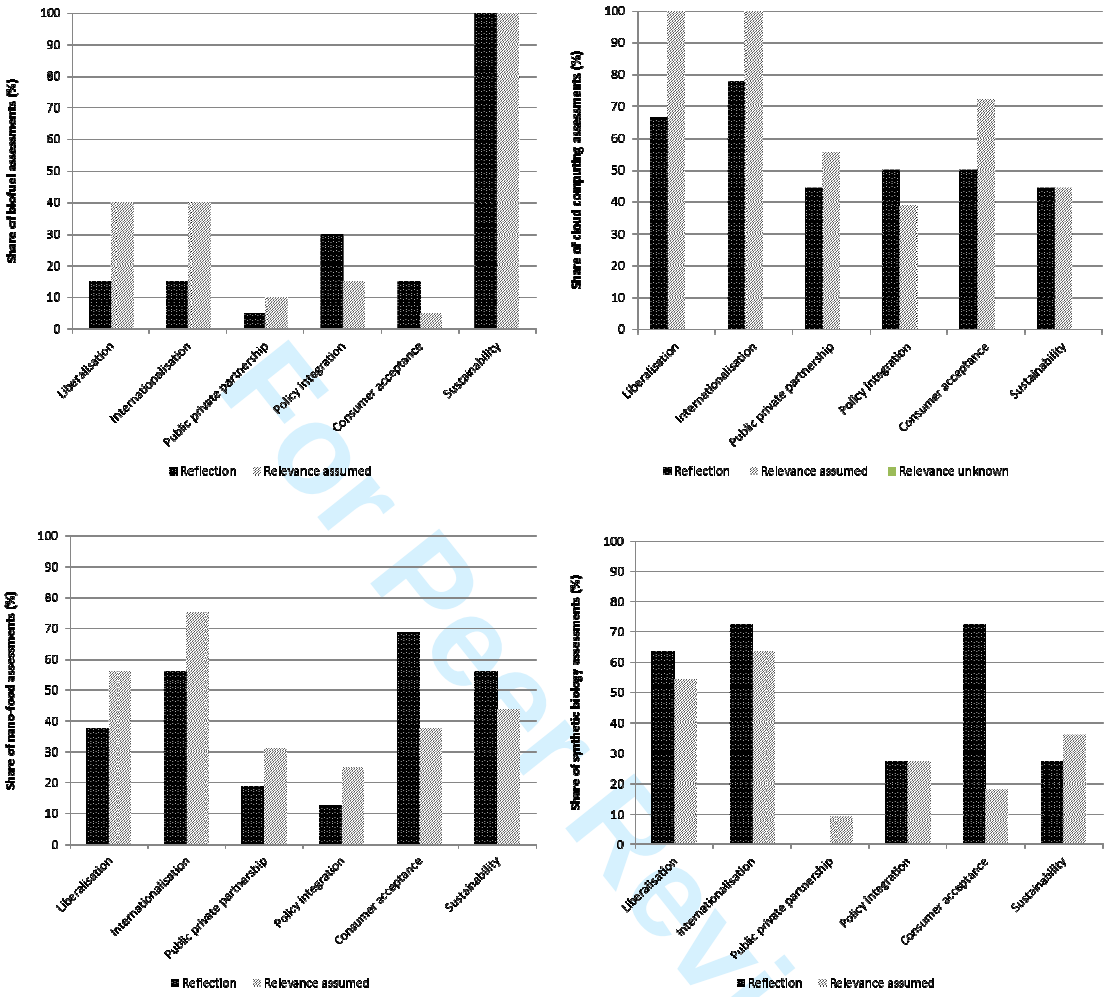

Figure 2 Trend consideration in the reviewed techno-scientific domains. Top left = biofuel; top right = cloud computing; bottom left = nano-food; bottom right = synthetic biology. The relative share of trend consideration in a techno-scientific domain was calculated based on the aggregated scorings of individual assessments. The extent of trend consideration in assessments was reviewed in two ways: (1) whether or not a trend was explicitly reflected upon in assessments, and (2) whether or not trend presence and trend direction was assumed relevant.

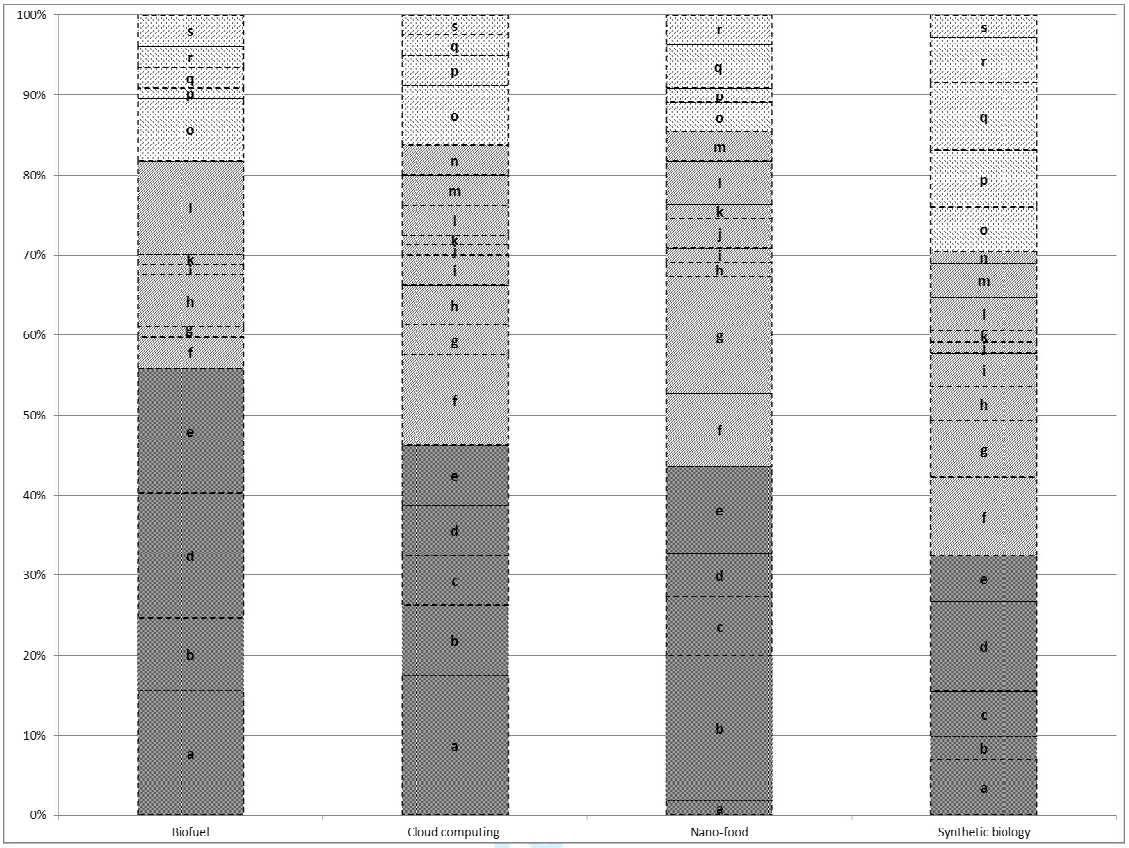

Figure 3 Assessment purpose analysis. The data was qualitatively derived from the reviewed assessments. Lower black fills indicate a 'raising knowledge' (cognitive) purpose, middle grey fills indicate a 'forming attitudes/opinions' (normative) purpose, whereas upper light grey fills indicate a 'initialising action' (pragmatic) purpose. Legend: a = technical options assessed & made visible; b = comprehensive overview on consequences given; c = structure of conflicts made transparent; d = policy objectives explored; e = existing policies assessed; f = setting the agenda in the political debate; g = stimulating public debate; h = introducing visions or scenarios; i = self-reflection among actors; j = blockade-running; k = bridge building; l = comprehensiveness in policies increased; m = policies evaluated through debate; n = democratic legitimisation perceived; o = new action plan or initiative to further scrutinise the problem; p = new orientation in policies established; q = new ways of governance introduced; r = initiative to intensify public debate taken; s = policy alternatives filtered; t = innovations implemented (no scorings); u = new legislation passed (no scorings).

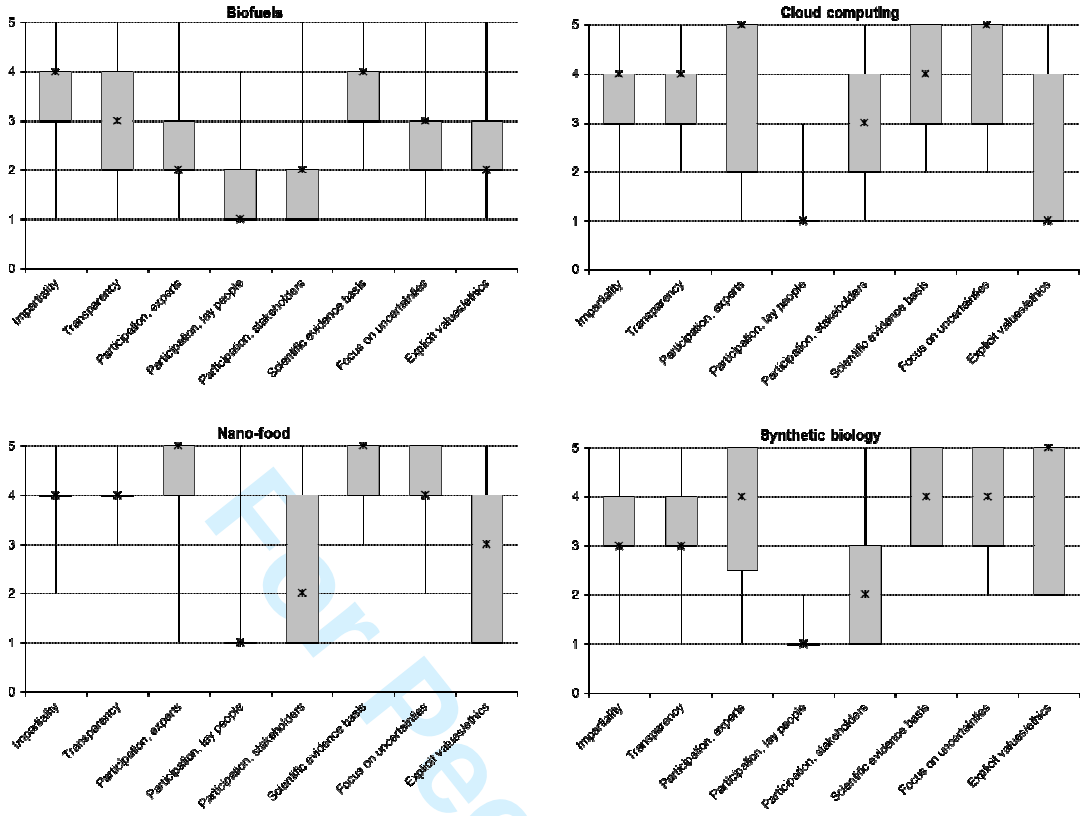

Figure 4 The nature of assessment practices. Individual assessments in a specific techno-scientific domain were scored based on the consideration, presence or selected variables. Scoring ranges from 1 (very low) to 5 (very high). Scorings of individual assessments were aggregated at the level of techno-scientific domains and used to calculate minimum (lowest point lower line), 1st quartile (lowest point box), median (cross in box), 3rd quartile (highest point box) and maximum (highest point upper line) scores. Quartiles are three ranked data values that separate a data-set in 4 equal groups. The second quartile is the median; the minimum and maximum are the lowest respectively highest values within the data set.

Impartiality = balanced inclusion of present perspectives & explicit discussion on the issue of impartiality; *Transparency* = degree to which the applied assessment approach is characterized; *Participation* = inclusion and integration of actors within the assessment process; *Experts* = actors that developed specialized knowledge in the area that they are reporting on; *Lay people* = publics, non-academics and individuals who are not representing a formally organised group; *Stakeholder* = actors representing a specific interest; *Scientific evidence basis* = the prominence of scientifically grounded evidence; *Focus on uncertainties* = the regarding and integration of uncertainty within assessments; *Explicit values/ethics* = the explicit consideration and integration of values/ethics within assessments.