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Sustainability and product risks: identifying and preventing risk migration

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Contents

1. Introduction

1.1. Meeting the challenge of risk transformation

In the process of technological development and product innovation aimed at sustainable development the attention is primarily focused on the proclaimed benefits (Geels and Smit, 2000; Harremoës et al. 2001). The intention is to meet societal demands or assumed demands such as renewable energy products, products designed to save energy, products designed to save material use, products made from less harmful materials or biomaterials, products produced with lower emissions throughout their life cycle, products with lower health risks or lower environmental risks, etc. Unavoidably, new technologies also have disadvantages which often manifest themselves as risks of a very different nature than the risks these innovations claim to reduce. These new risks are often unforeseen and apparent only after a new technology or consumer product has become widespread. This is referred to as 'risk migration' (Alcock and Busby, 2006) or 'risk transformation' (Busby et al, 2012). Classic examples include: Flame retardants (risk of fire has been reduced, but flame retardants turned out to be endocrine disruptors causing long term health risks); Halocarbon refrigerants (CFCs turned out to destroy the ozone layer, they were banned under the Montreal Protocol and replaced by PFKs and HFKs which turned out to be strong greenhouse gasses that in turn had to be phased out under the Kyoto Protocol); Asbestos (a building material that reduced the risk of fire but turned out to cause mesothelioma, a special type of lung cancer). Such new risks can become failure factors for innovations aiming at more sustainable technologies.

In a recent paper, Busby et al. (2012) review this phenomenon of risk transformation. They propose a categorisation of risk transformations according to: (1) whether they were interpreted as involving physical change or interpretational change and (2) whether they were translational, replacing one risk with another, or diffusional, merely adding to a stock of risk. Where public understanding of this phenomenon often frames these risk issues as being accidental or emergent, Busby et al identified other framings where these risk issues are framed as deliberate and functional instead. Note that some of these framings involve a strong risk of public opinion turning against the invention, and of losing trust.
A second finding is that risk transformations could be seen relative to the commitments we are prepared to relinquish: "replacing risk associated with one flame retardant chemical by risk associated with another involves trade-offs that only arise because we retain a commitment to chemicals as flame retardants."

1.2. Research questions

Here, we explore the question to what extent the introduction of new, sustainable consumer products and technologies has led to unexpected, new or increased environmental and health risks and if so, under what circumstances this occurs. The aim is to identify ways to enable and promote detection and prevention of risks in the entire product life cycle as early in the innovation process as possible.

To this end we address the following research questions

1. What lessons on risk migration are known from the literature?
2. Are these lessons well known amongst key players in the field of sustainable innovation and what bottlenecks occur when attempting to apply these lessons in the daily practice of innovation and regulation?
3. What new examples of risk migration in sustainable product innovation are known form the literature and from practice?

4. What (new) lessons can be learned from these cases to help avoid future cases of risk migration?
5. Is it possible to link particular aspects of sustainability of technologies to particular types of new and emerging risks of these technologies?
6. How can the various lessons be better utilized in the daily practice of sustainable innovation in order to detect and avoid risk migration?
7. How can risk governance be improved with a practice of risk exploration aimed at early detection and avoidance of possible risk migration, well before the market introduction?

1.3. Structure of the report

To answer these questions we used literature review, document analysis, expert interviews, and an electronic survey. Our findings are presented in the following chapters. Chapter 2 analyses historic cases and summarizes the main lessons known from the literature. In intermezzo's we explore and illustrate the challenges of risk migration of two sustainable energy innovations: LED lighting and the smart electricity grid. Chapter 3 presents the results from in-depth interviews with eight Dutch experts in the field of sustainable product innovation. To validate and supplement these findings we held an electronic survey amongst a broad international group of experts from two relevant research communities: experts involved in the European Environment Agency Late Lessons from early Warning studies from 2000 and 2013 (Harremoës, 2000; EEA, 2013) and all partners form the EU FP7 EPINET (Integrated Assessment of Societal Impacts of Emerging Science and Technology from within Epistemic Networks) research consortium. The results from the survey are presented in chapter 4. Chapter 5 synthesises the results and presents the main conclusions.

2. Historical examples

This chapter discusses historical examples of risk migration in the development of sustainable products. Historical, in this case, implies that analyses have already been performed and lessons have been drawn from these cases. Four of the six cases, however, are 'innovations in progress'. The chapter draws upon the earlier analyses to discuss the cases and their implications, and closes with an overall discussion in the context of the present report.

2.1. Case descriptions

This section describes six cases of risk migration in sustainable products: hydrogen vehicles, asbestos for use in isolation, nanotech products, halocarbons (CFCs) for refrigeration, compact fluorescent lamps, and neonicotinoid insecticides.

2.1.1. Hydrogen-powered road traffic vehicles

In the search for sustainable fuels, hydrogen has often been suggested as a 'green energy' carrier for cars, busses and other road traffic vehicles – as alternative to fossil fuels. Hydrogen vehicles can store the hydrogen in a tank and power the vehicle via a combustion engine or fuel cell. The hydrogen itself can be produced using e.g. electrolysis of water, steam-reforming of methane, or gasification of other fossil fuels. Depending on the way the hydrogen is produced, greenhouse gas emissions related to hydrogen-powered vehicles may be considerably lower than those of traditional fossil-fuel cars. Other benefits include reduced air pollution, particularly in traffic-intensive areas such as cities, and less noise pollution and associated sleep-disturbance and associated health impacts for vehicles with fuel cell plus electric motor (see e.g. Health Council of the Netherlands, 2007). There are potential risks as well: fire and explosion risks, potential environmental contamination and health risks due to harmful substances (including nanomaterials) used in the hydrogen tanks and fuel cells (in production and use, as well as the waste phase), atmospheric changes due to leaked hydrogen (which react with OH-radicals that are important for the atmosphere's self-cleaning capacity, with potential implications for climate change and ozone depletion; the overall effects are highly uncertain and heavily debated), potential for 'dirty' production of cheap hydrogen on a global market, and reduced traffic safety due to silent vehicles (Health Council of the Netherlands, 2007). The Health Council report also suggests that, although some known risks (fire, explosion, harmful substances) are manageable to some extent due to prior experience, other risks will likely only become apparent after large scale introduction of hydrogen vehicles. It suggests stepwise and reflexive introduction of the technology. In terms of risk migration, this technology involves shifting environmental and health risks to environmental and safety risks (short term health risks).

2.1.2. Asbestos for isolation

Asbestos, a type of natural fibrous minerals, has been mined commercially since the late nineteenth century, with European imports peaking in the 1970s (Gee and Greenberg, 2001). The material had various useful properties, such as resistance to heat, fire, electricity, and chemicals. In the context of (what we nowadays would name) sustainability, it has been used extensively for decreasing fire risks and isolating for instance buildings, pipes, and machinery. As such, it increased fire safety, reduced heating costs and increased energy efficiency. Inhalation of asbestos dust, however, could lead to various diseases such as mesothelioma, asbestosis, and lung cancer. Such diseases were particularly prevalent among those with high exposure over a longer period of time, such as people who worked with the material or have had long-term environmental exposure to damaged asbestos isolation. The health effects seem related to physical properties such as the fibre size (easier to inhale and transport deep into the lungs) and the persistence of the fibres in the body (e.g. difficult to break down). Gee and Greenberg (2001) also warn that proposed alternatives for asbestos should not be of similar physical form (long, thin, persistent fibres), because such fibres might lead to similar effects. Regulatory action took place very long after the first signs of potential risk were available at the end of nineteenth century. These early warnings were indicated by factory inspectors (non-expert, but 'competent observers') and concerned the lung disease asbestosis. However, they were not followed up by extensive medical and exposure studies. Evidence for the cancers emerged much later; from the 1930s onward, but it took until 1998 before asbestos was banned in Europe and it still is allowed and used on large scale in India, China and Russia. Notable aspect of this risk migration, is the long time lag between exposure and some of the most serious effects, mesothelioma and lung cancer: for the UK, the mesothelioma peak is expected in the 2020s, some 60-70 years after the peak in imports (Peto et al., 1999).

2.1.3. Nanotech products

The development and use of nanomaterials in consumer products has increased strongly over the past years. At present, an estimated 1300 consumer products worldwide contain nanomaterials, although knowledge on which products contain nanomaterials is limited (Health Council of the Netherlands, 2011). Because of their small size and large surface area per unit of mass, nanomaterials have interesting new properties that can be used for a wide range of applications. In the context of sustainability, for instance, they can be used to create strong, lightweight plastics for use in vehicles or planes, reducing material use and potentially increasing energy efficiency. Other examples include the use of nanomaterials to create durable and/or self-repairing paints and wear-proof car tyres, which would reduce material use. Concerns have however emerged regarding the potential effects of nanoparticles on health and the environment, based on earlier experiences with ultrafine particulate air pollution (see e.g. Knol et al., 2010) and fibres such as asbestos, as well as on emerging toxicological evidence on engineered nanoparticles (see e.g. Borm et al., 2006). In addition, anti-bacterial particles such as nanosilver in cosmetics, clothing and laundry applications may pose a problem for systems that depend on bacteria to function, such as waste water treatment. Potential problems can be expected to become more prominent as use and application of these particles become more widespread. Important difficulties in assessing these novel risk are that the development of new particles outpaces risk assessment, and that the waste stage of nanomaterials-containing products and environmental fate of these particles is somewhat neglected (partially due to the absence of suitable measurement techniques and equipment) (e.g. Health Council of the Netherlands, 2011). Some nanoparticles are persistent and there are indications that current waste management techniques, such as recycling, incineration and waste water treatment, may not remove all nanoparticles. The latter consequently end up in the environment. This risk migration shifts an environmental issue (material and energy consumption) to a health and environmental issue.

2.1.4. Halocarbons for refrigeration

Halocarbons, such as CFCs and halons, were introduced as refrigeration agents from the 1930s onward. They replaced earlier agents, such as sulphur dioxide, (anhydrous) ammonia, and chloromethane, which were toxic and sometimes flammable (e.g. chloromethane). Halocarbons on the other hand had low toxicity, flammability and reactivity, and could therefore reduce the health and safety risks associated with refrigeration. They are currently known to deplete stratospheric ozone, leading to increased ultraviolet (UV-B) radiation reaching the planet surface, resulting in health impacts such as skin cancer, cataract and effects on the immune system, as well as environmental impacts. In addition, many halocarbons are greenhouse gases. In 1974, the first papers appeared indicating that the inertness of the CFCs would result in these compounds ending up in the stratosphere, where they might lead to ozone depletion (Molina and Rowland, 1974). It was also acknowledged that this would have health consequences. Following regional efforts in the late 1970s and early 1980s, such as a US ban on CFC use as spray can aerosols, more extensive international action (Montreal Protocol) was set in motion only after the discovery of the 'ozone hole' in 1985 (Farman et al., 1985; Farman, 2001). As a consequence of the Montreal Protocol CFCs were replaced by alternative substances such as HCFCs (also ozone depleting, but less than CFCs) and HFCs such as PFCs (not ozone depleting, but a strong greenhouse gas). Ironically, in 1997 the Kyoto Protocol, an international agreement linked to the United Nations Framework Convention on Climate Change, subsequently required the emission reduction of PFCs because of their substantial contribution to the greenhouse effect. This risk migration shifts small scale, near-term risk to a large scale one with long-term implications: CFCs are persistent in the environment and emissions from existing refrigeration equipment continue long after the ban on CFC use and the greenhouse effect of PFCs persists long because of its long atmospheric lifetime.

2.1.5. Compact fluorescent lamps

Fluorescent lamps were invented at the end of the nineteenth century. Compact fluorescent lamps (CFLs) gained popularity in the late twentieth century. CFLs have a longer lifespan and higher energy efficiency, and a generally lower environmental impact over its life-cycle (e.g. Weltz et al., 2011), compared to traditional incandescent light bulbs. Consequently, they have been promoted in order to reduce energy consumption and material use. In recent years, many developed countries have started phasing out incandescent bulbs, in favour of CFLs and other energy efficient lights, such as LEDs. Some health and environmental concerns have arisen in connection to CFLs. One important concern relates to the fact that CFLs contain mercury, which can be released into the environment during production and upon disposal (environmental risk), or into the indoor air when broken before disposal (health risk). The overall environmental emissions are not necessarily higher than those of incandescent bulbs: some forms of energy generation, particularly coal-based, also emit mercury. Therefore, the effect of replacing incandescent lamps with CFLs depends on a country's energy mix: e.g. for Norway emissions increase, while for the Netherlands they decrease (Eckelman et al., 2008). In lamp production (and mercury mining), some regional inequalities could emerge if lamps are produced primarily in for instance low-wage countries (e.g. see Streets et al., 2005 for an emissions inventory for China, where mercury emissions are a considerable problem), although Eckelman et al. (2008) assume production-related increases in emissions to be insignificant compared with other life-cycle stages. Other suggested risks associated with CFLs include health effects due to UV and blue light emitted (skin and retinal damage), flicker (exacerbation of e.g. epilepsy and migraine symptoms) in CFLs with magnetic ballasts, and electromagnetic fields (e.g. electromagnetic hypersensitivity). A recent assessment by the European Commission's scientific committee on emerging health risks (SCENIHR, 2008) concluded that no evidence was found indicating flicker and electromagnetic fields as significant health risk, although noting some studies that did (and others that did not) indicate flicker-related effects for old, defective lights (which can have lower flicker frequencies, that are more likely to trigger e.g. epileptic events). The assessment did identify blue light and UV emission as a risk factor for light-sensitive groups, as well as potentially for office workers (for some CFL types in "extreme conditions").

2.1.6. Neonicotinoid insecticides

Neonicotinoids are a new generation of insecticides introduced in the early 1990s (Maxim and Van der Sluijs, 2013). In contrast to the older insecticides which they replaced, these chemicals are much less toxic to humans, birds and mammals. However, evidence is mounting that these chemicals play a key role in bee disorders and pollinator decline observed globally over the past decades (Van der Sluijs *et al.*, 2013).

These neurotoxic agrochemicals act systemic. They are widely applied as a coating to seeds of crops or treatment of soil and during growth the active substance is taken up by the roots and make the whole plant toxic to insects for a long period. Unintendedly, neonicotinoids also end up in nectar and pollen, which are the food sources for bees. (Maxim and Van der Sluijs, 2013)
After their introduction to the market in the early 1990s, neonicotinoids use grew rapidly to occupy more than a quarter of the world market of insecticides within less than 15 years (Jeschke and Nauen, 2008; Jeschke et al., 2011, Van der Sluijs et al., 2013). Neonicotinoids are now the most commonly used and fastest growing type of insecticide in the world. In Europe neonicotinoids are authorized for hundreds of crops.

Neonicotinoids are persistent in soil and water, remain in the environment for a long time and spread quickly through surface water. Through systemic uptake it also contaminates wild flowers. In the Netherlands imidacloprid levels far in excess of what is considered safe for aquatic ecosystems have been measured continually in the surface water since 2004 (Van Dijk et al., 2013), 1000 to 25000 times the Maximum Permissible Concentration. Van Dijk et al. (2013) found that high levels of imidacloprid in surface water consistently correlate to low aquatic insect abundance. Tennekes (2010) links the insect decline through large scale imidacloprid pollution to the observed strong declines in insectivorous birds.

For honeybees, imidacloprid is more than 7,000 times more toxic than DDT (acute toxicity. Furthermore, it gradually becomes lethal to insects as a result of prolonged exposure to extremely low levels (chronic toxicity) and has behaviour-disturbing effects on almost all non-target insect species. In low dose it disturbs flight behaviour, navigation, brood development and impairs individual and social grooming. Synergistic effects with other agrochemicals have been found. (Van der Sluijs et al., 2013)

Over the past ten years, Increases in honeybee disorders have been reported in many European countries. In the same period, many American and Canadian and Asian apiaries have suffered similar honeybee disorders and sudden colony losses (Van der Sluijs et al., 2013). Following a new evaluation by the EFSA, In May 2013 the European Commission has decided to partially ban the use of three neonicotinoids in crops attractive to bees for a period of two years starting 1 December 2013.

In this case the risk migration shifts a human health risk and risks for birds of prey (due to earlier, generations of insecticides such as DDT and organophosphates) to an ecological and food security risk (pollinator loss) and risks for insectivorous birds.

2.2. Lessons learnt

Six historical cases have been discussed above. This section will discuss (a) the lessons that have been learnt regarding these cases (in the context of sustainable innovation) and discussed in existing analyses in the literature, and (b) which overall conclusions can be drawn based on the set of historical cases, particularly considering sub-question 5:whether there are any links between the aspects of the sustainability improvements intended and the types of new risks that are introduced.

2.2.1. Lessons in past analyses

Regarding the use of hydrogen for road traffic vehicles, the Health Council report (Health Council of the Netherlands, 2008) concluded that this new technology has both potential advantages and potential drawbacks. Some of these depend on the exact societal implementation of the technology, for example, the potential reduction of greenhouse gas emissions strongly depends on how the hydrogen is produced in the first place (e.g. coal-based production is associated with considerable emissions). The report also noted that new technologies often involve unexpected risks that may emerge only after a technology has become established. It advised that the government should carefully monitor the situation, and argues for careful transition management by the government and stepwise introduction of the technology in a democratic setting. Furthermore, issues such as trust and public perception and support are critical for the technology's success (particularly when applied at larger scale); due attention should be paid to public concerns.

A Health Council report regarding nanomaterials in waste (Health Council of the Netherlands, 2011) noted that it is unclear what happens with nanomaterials once the products that contain these are discarded, to what extent such materials are present in waste, and to what extent they can be released into the environment. It advised to pay more attention to the waste stage of a product in the process of product development. This includes trying to limit the amount of waste and to take progressing insights into nanomaterials into account in the innovation process. Monitoring of the developments in nanomaterials, waste management, and the presence of materials in air and water is important. The latter is complicated by a lack of suitable methodologies; suitable methods should be developed. The report also suggests that scenario analyses can be used to explore which nanomaterials end up in which waste flows.

The European Environment Agency (EEA) (Harremoës et al., 2001) distilled twelve lessons from a large number of historical cases, of which asbestos and halocarbons were included in this chapter. The cases and lessons were placed in the context of 'early warnings' and the Precautionary Principle (cf. UNESCO, 2005). The lessons can be found in Box 1 below.

The study indicated that the fact that there would always be factors remaining outside the scope of a risk analysis – resulting in ignorance and surprise – was often neglected. Particularly, complex, cumulative, synergistic and indirect effects are often inadequately addressed. Compounds or products may be quite safe under normal conditions, but turn out to behave differently under conditions not considered in the risk analysis. Factors such as novelty, persistence, and bioaccumulation should be warning signs; they relate to potential surprises and irreversibility of actions. Past cases also suffered from a lack of systematic monitoring and investigation of causes for concern, and research suffered from 'blind spots' due to assumptions of what could or should happen with compounds or products, or too strong a focus on the fact that the new technology solves an existing problem (neglecting potential drawbacks). For lesson 5, Harremoës et al.(2001) mention that it was often assumed that "technologies perform to the specified standards", and that compounds "could be constrained within 'closed' operating systems". Problems emerged due incorrect installation of systems, poor maintenance, illegal disposal, et cetera., and overly optimistic assumptions were made regarding the standard performance of systems. The application of a technology might also change from what had been originally intended (and assessed in the risk assessment). Similarly, the environmental fate of chemicals can be different than expected, as can their consequences: e.g. unexpected chemical reactions, or (unforeseen) strong differences in sensitivity within an affected population (i.e. vulnerable groups). This underlines the key importance of post-marketing surveillance of new technologies.

In general, many cases suffered from an incomplete (overly narrow and partial) assessment of pros and cons of innovations and solutions to problems that emerge or were expected. Therefore, it is important to include a broader spectrum of knowledge, such as more scientific disciplines (prevent domination by a single discipline, and use knowledge from similar/related disciplines), and more types of information and knowledge (involve relevant stakeholders; practical, 'lay', and local knowledge). Institutional and societal factors can also present obstacles; e.g. short time horizons, tensions between different departments or levels of government (including between different countries), uneven distributions of costs and benefits, information overload, and lack of political will. These should be identified and reduced.

Relating to innovation, Harremoës et al. (2001) indicate that technological systems can have a tendency to 'lock-in', and that technologies may become widespread due to "arbitrary reasons" such as "chance and first-leader advantage" rather than due to their qualities. As such, it is important to carefully assess the alternatives (with deliberate choices and commitments) in an early stage of the innovation process. In addition, robust, diverse and adaptable technologies, and a mix of multiple technologies, would likely entail smaller surprises than when a single, inflexible technology has a monopoly. Careful (pre-emptive) consideration of public perceptions and values, as well as better coping with and communication of ignorance and complexities, are also described as important.

Box 1. Twelve 'Late Lessons from Early Warnings' (Harremoës et al., 2001):

1. Acknowledge and respond to ignorance as well as uncertainty and risk, in technology appraisal and public policymaking.
2. Provide adequate long-term environmental and health monitoring and research into early warnings.
3. Identify and work to reduce 'blind spots' and gaps in scientific knowledge.
4. Identify and reduce interdisciplinary obstacles to learning.
5. Ensure that real world conditions are adequately accounted for in regulatory appraisal.
6. Systematically scrutinize the claimed justifications and benefits alongside the potential risks.
7. Evaluate a range of alternative options for meeting needs alongside the option under appraisal, and promote more robust, diverse and adaptable technologies so as to minimize the costs of surprises and maximize the benefits of innovation.
8. Ensure the use of 'lay' and local knowledge, as well as relevant specialist expertise in the appraisal.
9. Take full account of the assumptions and values of different social groups.
10. Maintain the regulatory independence of interested parties while retaining an inclusive approach to information and opinion gathering.
11. Identify and reduce institutional obstacles to learning and action.
12. Avoid 'paralysis by analysis' by acting to reduce potential harm when there are reasonable grounds for concern.

The Maxim and Van der Sluijs (2007) study on neonicotinoid insecticides concluded that to remedy these major flaws in discourse that hamper effective and timely precautionary risk governance and timely recognition of and response to early warnings, they proposed six knowledge quality criteria that can assist in the assessment of the information communicated in an argumentative public process. They are as follows: reliability of the information – it must be based on all available scientific knowledge; robustness of the information – it must take into account criticism; use of the information produced by other stakeholders; relevancy of the arguments for issue under debate; logical coherence of the discourse; and legitimacy of the information source. Compared to the twelve lessons of the EEA's "Late lessons from early warnings" (Harremoës, 2001), the study concluded that many of these 'late' EEA lessons can also be drawn from the insecticides case. Furthermore, the Maxim and Van der Sluijs (2007) study drafts two additional lessons:

- Update risk assessment methods to fit new risks
- Assure adequate institutional capacity for efficient administrative procedures of risk governance

All of these lessons should be applied to future policies in order to minimize the repetition of past mistakes.

In 2013 the European Environment Agency issued a second volume of Late Lessons with many new cases studies (EEA 2013). The analysis of these new case studies led to various new lessons which are summarized in box 2.

Box 2. More 'Late Lessons from Early Warnings' (EEA, 2013)

Diagnosis of problems

- Key decisions on innovation pathways are made by few on behalf of many
- Lack of (institutional) mechanisms to respond to early warning signals
- Misleading market prices fail to reflect all costs and risks to society and nature

Recommendations for innovation governance

- Broaden application of the principles of precaution, prevention and polluter-pays
- Make government and business accountable
- Broaden evidence considered (lay/local knowledge) and public engagement
- Build resilience in governance systems and institutions
- Reduce delays between early warnings & actions
- Acknowledge complexity: multiple effects and thresholds
- Rethink & enrich environment & health research
- Improve quality & value of risk assessments
- Foster cooperation between business, government & citizens
- Correct market failures: polluter pays & prevention principles

2.2.2. Comparison in the context of sustainability innovation &risk migration

This section aims to assess which patterns emerge within the historical cases, in the context of this report. Particularly, the question was posed whether any connections can be elucidated between the aspects of sustainability that the innovations aim to improve, and the types of new risks that are introduced.

Table 1 below summarizes the types of innovations, aims and introduced risks in the historical cases.

Table 1. Properties of historical cases.

Case	Type of product or innovation	Aimed sustainability improvements	Potential risks introduced	Other relevant aspects
1. Hydrogen vehicles	New energy carrier (gaseous) plus related energy conversion systems.	Environmental (greenhouse gas emissions; long term). Human health (air quality, noise; short and long term).	Environmental (atmospheric impacts of leaked hydrogen, waste, greenhouse gas emissions). Safety (fire, explosion, traffic accidents due to silent vehicles; short term).	Prior experience with small scale use, but not with large scale. Emission reduction depends on assumed way of production.
2. Nanotech	Novel material (small solid particles) with special properties (due to small size and structure).	Environmental (material saving, energy saving).	Human health (medium and long term). Environmental (ecosystem health; long term). Functioning of societal systems (e.g. waste water treatment).	Special material properties (small size, persistence) a problem. Rapid spread to large scale application. Existing risk assessment frameworks & tools insufficient.
3. Asbestos insulation	Novel material (small solid particles) with special properties (due to small size and structure).	Environmental (energy saving). Safety (fire-resistant).	Human health (long term).	Special material properties (small size, persistence in body) a problem. Rapid spread to large scale application.
4. Halocarbons for refrigeration	Novel material (gaseous) with special properties (low reactivity).	Safety (replaces aggressive alternative).	Environmental (ozone layer, climate change; long term).	Special material properties (low reactivity, i.e. environmental persistence) a problem. Rapid spread to large scale application.
5. Compact fluorescent lamps	New lighting product.	Environmental (energy saving, material saving).	Ecological (mercury; short term) Human health (mercury, light frequency; short term).	Risks due to both components (mercury) and product itself (light frequency).
6. Neonicotinoid insecticides	Novel material (water soluble) with special properties (systemic, specific).	Human health (replaces acutely toxic alternative). Ecological(replaces non-specific alternative).	Ecological (pollinator loss, risk for insectivorous birds). Food security (via pollinator loss).	Unforeseen non-acute, sub-lethal low-dose effects. Persistent in both plant and environment.

Table 2 cross-tabulates the aims and risks. The cross-tabulation (Table 2) suggests a small clustering of cases, in which innovations aimed at improving energy and material efficiency result in risks regarding human and ecological health. However, the number of cases involved seems too small (2-3) to conclude a clear relation, based on the historical cases only. The analysis in Table 1 shows several other similarities between cases. Four of six cases involve a novel material, with special properties. These special properties result both in the initial sustainability improvement and the risk migration. Particularly, persistence in the body and/or the environment seems to be a common issue. Furthermore, several cases involve rapid shifts from small to large scale application. In such cases, potential earlier experiences on small scales may not apply anymore, and the shift may be too quick to allow for proper analysis of the potential consequences.

Table 2. Cross-tabulation of aims & risks in the historical cases (numbers refer to the case numbers).

Risk: Aim:	Atmospheric	Energy saving	Material saving	Safety	Human health	Ecological health
Atmospheric	1			1		1
Energy saving					2, 3, 5	2, 5
Material saving					2, 5	2, 5
Safety	4				3	
Human health	1			1		1, 6
Ecological health						6

Comparing the historical cases in the light of the twelve lessons of Harremoës et al. (2001), one notable problem that seems to emerge often is that of incomplete assessment of the life-cycle of the products involved (including waste stage and environmental fate of compounds). This includes inclusion of non-standard/unexpected use and misuse of the product. Such incomplete assessments can be caused by simply forgetting to take other stages/aspects into account in the analysis. However, analysts may also lack suitable measurement techniques and other analytical tools & methods, or required basic knowledge to perform such analyses. Furthermore (and in the light of the former point), innovators and regulators often seem to neglect to deal explicitly with ignorance and surprises, or to lack ways to do so.

Intermezzo I: LED lamps and risk migration

As part of their policies to promote sustainable development, the EU started in 2009 to phase-out incandescent light bulbs for lighting because of their low energy efficiency. The > = 100 Watt incandescent light bulbs have been banned in 2009 and as of 1 September 2011 production and import of the 60 Watt incandescent light bulbs is no longer allowed in the EU. The aim is to reduce energy use and encourage the use and technological development of more energy-efficient lighting alternatives, such as compact fluorescent lamps (CFLs) and Light-Emitting Diode (LED) lamps.

From a risk migration perspective, white LED lamps bring together a surprisingly large number of characteristics that need careful attention by innovators, regulators and consumers:

- Unprecedented brightness of the (point)light source
- Unidirectional nature of LED light, analogy with risks of laser light
- Blue light hazard
- Blue light as endocrine disruptor: melatonin and the biological clock
- Indoor emissions of toxic substances from plastics used in LED lamps
- Electro-safety issues
- Impact of light quality on labour productivity

We will briefly explore these risk migration challenges.

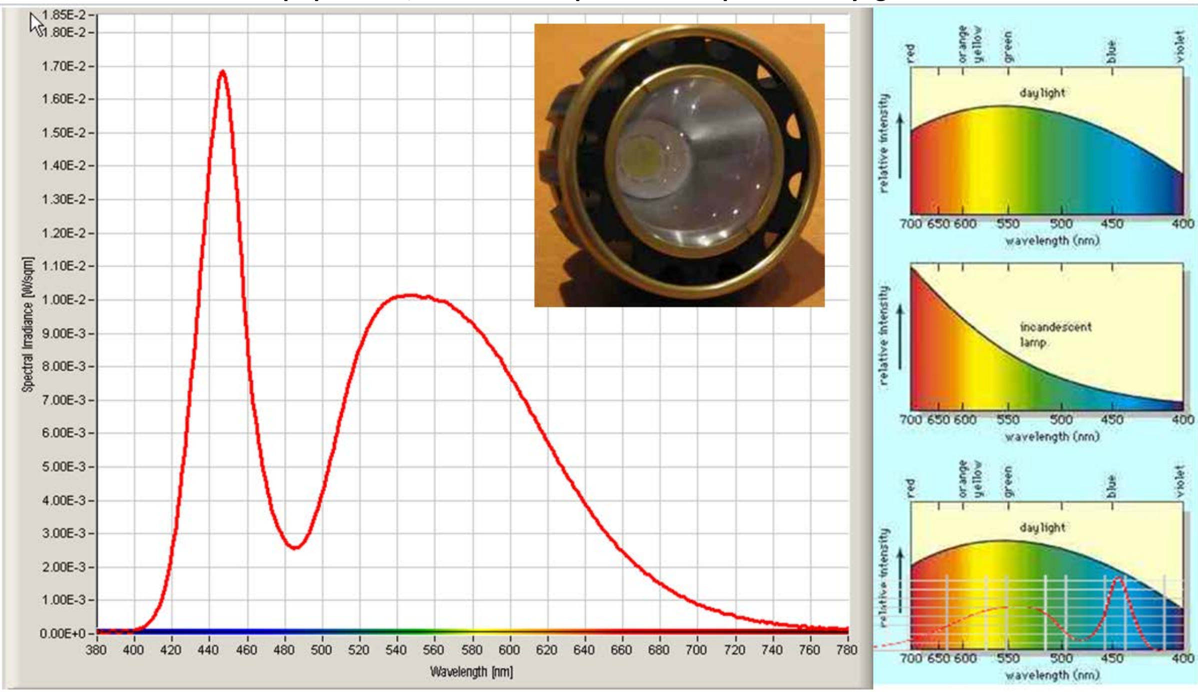
Brightness of the (point)light source
"*Looking directly at any of the high powered LEDs in production today, they are so uncomfortably bright that even a momentary glimpse of the source can leave a strong afterimage on the retina persisting for several minutes in many cases*" (Archenhold, 2007). Indeed, the light output of high power LEDs can be so bright that the intensity of the light can cause retinal hazard to the human eye when looking straight into the light source through dangerous photo-thermal (the heating power of the light beam) or photochemical (the chemical energy of the light beam) exposure. Discussion has been going on about the question whether the IEC Laser Classification scheme should be applied to LED lighting technology. For instance, in some countries (e.g. Germany), LED torches are labelled Laser class 1. It could be harmful if for instance children shine directly in one an others eyes with powerful LED torches.

Unidirectional nature of LED light
Where incandescent light bulbs tend to radiate light in all directions, LEDs tend have a narrower beam, leading to a lower decrease of intensity of the light as a function of distance to the source. This property amplifies the problems of the exceptionally high brightness. It places LED light sources somewhere between laser light and traditional light sources.

Blue light hazard
The light-spectrum of a white LED lamp is very different from incandescent light and tends to have a high peak in the blue part of the spectrum (figure I.1). The human eye is extremely vulnerable to 420 nm light, extended exposure can cause irreversible damage to the macula through the so called blue light hazard. Long term exposure to blue light is hazardous and a possible cause for Macular Degeneration in the human eye. Blue-light Hazard is the potential for a photochemical induced retinal injury resulting from radiation exposure at wavelengths in the blue and ultra violet parts of the spectrum of light primarily between 400 nm and 500 nm. Photochemical induced retinal injury can occur following the absorption of light by photoreceptors in the eye. Under normal conditions when light hits a photoreceptor, the cell bleaches and becomes useless until it has recovered through a metabolic process called the visual cycle. Absorption of blue light, however, has been

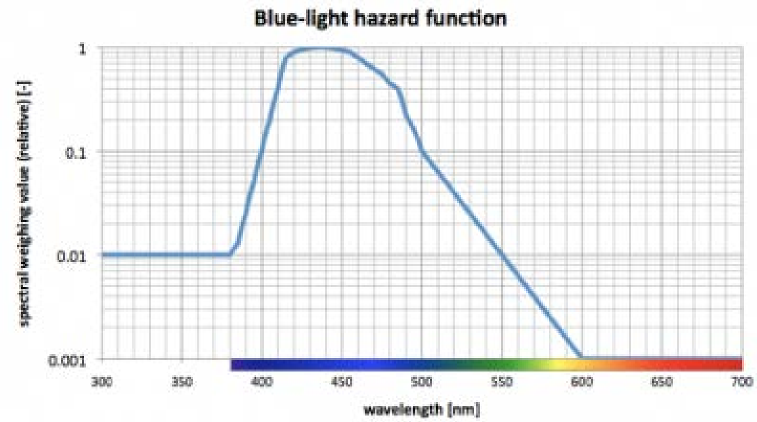
shown to cause a reversal of the process where cells become unbleached and responsive again to light before it is ready. This greatly increases the potential for oxidative damage. By this mechanism, some biological tissues such as the retina may show irreversible changes induced by prolonged exposure to moderate levels of short-wavelength light.

Figure I.1: Example of the power spectrum of a white LED lamp. Right hand panel: top: Daylight spectrum; middle: Incandescent lamp spectrum; bottom: LED spectrum compared to daylight.



The figure I.2 below shows how strong each part of the spectrum contributes to the blue light hazard, the peak is at a wavelength of 420 nm.

Figure I.2. The blue-light hazard function (source: olino.nl)



In experiments with adult rhesus monkeys Koide (2001) reported serious damage from a blue (460 nm) light emitting diode. A 3 mm beam of 0.85 mW was imaged onto the retina through a lens positioned before the cornea and exposure damage was determined at time intervals for 12 to 90 min. A threshold level was found around 40 minutes for causing irreversible impairment of vision.

The Dutch Health Council (2003) proposed an exposure limit for the blue light hazard. Later documents (IEC 62471:2006 and update in 2008) improved this exposure limit. See for details Olino (2010 and 2011).

Biological effects of blue light, Melatonin and the biological clock
The human biological clock is modulated by the light-sensitive sleep-hormone melatonin. Light suppresses melatonin in humans, with the strongest response occurring in the short-wavelength portion of the spectrum between 446 and 477 nm that appears blue (West e.a. 2011; Holzman, 2010). Normally melatonin levels are low during the day time and in the evening melatonin levels rise and induce sleepiness. Evening exposure to blue light can suppress this rise in melatonin. Incandescent light has very low levels of blue light whereas white LED lamps emit a substantial part of their light energy in the blue part of the spectrum.

Blue monochromatic light has also been shown to be more effective than longer-wavelength light for enhancing alertness. Disturbed circadian rhythms and sleep loss have been described as risk factors for astronauts and NASA ground control workers, as well as civilians. Such disturbances can result in impaired alertness and diminished performance. (West e.a. 2011)

In fact, light exposure can cascade numerous effects on the human circadian process via the non-imaging forming system, whose spectral relevance is highest in the short-wavelength range (the blue end of the visible light spectrum). Chellappa et al. (2011) investigated if commercially available compact fluorescent lamps with different colour temperatures can impact on alertness and cognitive performance. Healthy young men were studied in a balanced cross-over design with light exposure of 3 different light settings (compact fluorescent lamps with light of 40 lux at 6500K and at 2500K and incandescent lamps of 40 lux at 3000K) during 2 h in the evening. Their findings show that exposure to light at 6500K (high levels of blue light) induced greater melatonin suppression, together with enhanced subjective alertness, well-being and visual comfort. With respect to cognitive performance, light at 6500K led to significantly faster reaction times in tasks associated with sustained attention, but not in tasks associated with executive function. This cognitive improvement was strongly related with attenuated salivary melatonin levels, particularly for the light condition at 6500K.

The findings by Chellappa et al. suggest that the sensitivity of the human alerting and cognitive response to polychromatic light at levels as low as 40 lux, is blue-shifted relative to the three-cone visual photopic system. Thus, the selection of commercially available compact fluorescent lights with high colour temperatures significantly impacts on circadian physiology and cognitive performance at home and in the workplace.

Pross et al. (2011) found similar effects for evening exposure to LED-backlit computer screen, which resulted in attenuated salivary melatonin and sleepiness levels with a concomitant increase in cognitive performance associated with sustained attention and with working and declarative memory. Given that the measured illuminance levels and the subjective ratings of visual comfort of both LED and non-LED screens in the experiment were very similar, Pross et al. argue that the fact that the LED-backlit screen emitted 3.32 times more light in the blue range between 440 and 470 nm than the non-LED-backlit screen is the major factor contributing to the observed effects.

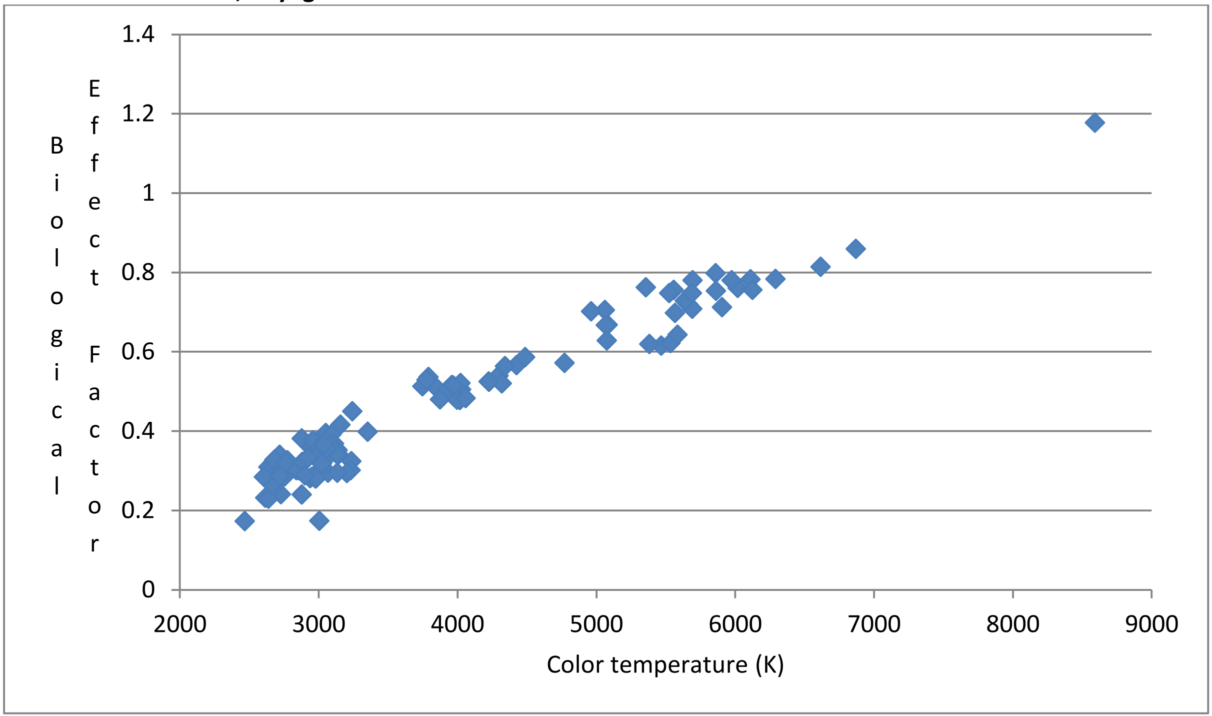
Wood et al. (2013) report a similar experiment with a shorter time of exposure (1 hour and 2 hours respectively) and found that two hours of exposure to tablets produces a significant suppression of melatonin, while suppression after one hour of exposure is not significant.

Olino Sustainable Energy has carried out measurements of a large number of lighting parameters on a large number of lamps, including LED lamps. The results are published on their website (http://www.olino.org/ov/lampen). At the time we did this research, measurement reports of more than 100 different LED lamps could be found on their website. This enabled us to analyse whether

there is a simple relationship between colour temperature of the LED lamp and its biological effect. For an explanation of the Biological Effect Factor we refer to:
http://www.olino.org/us/articles/2011/08/07/non-visual-effects-of-ocular-light-on-human-beings-the-biological-factors

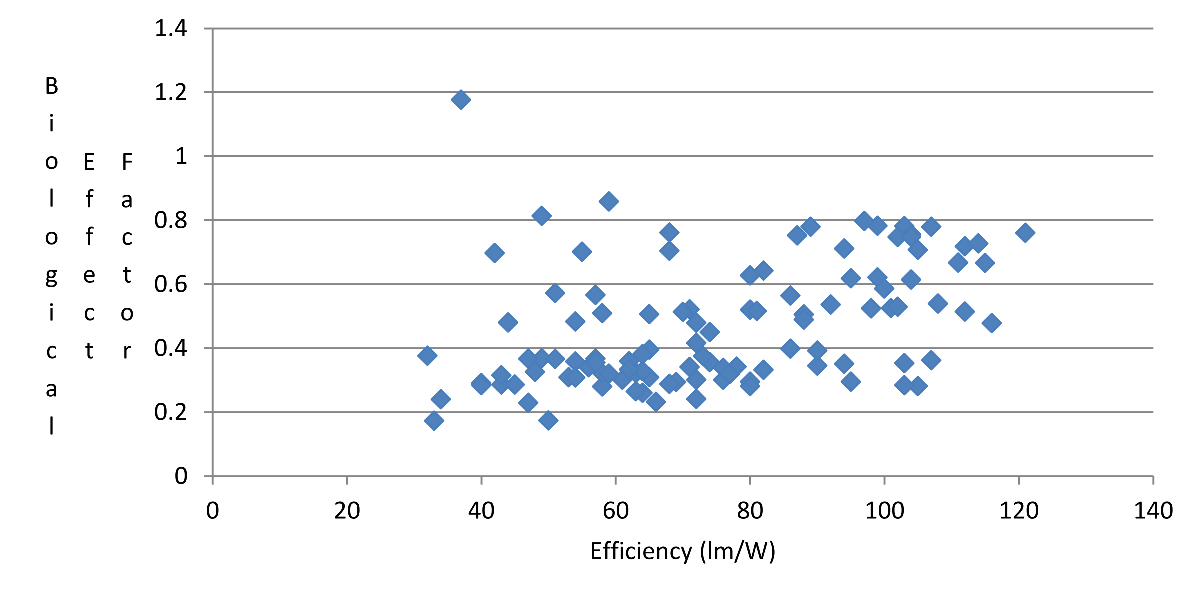
Figure I.3 shows that the colour temperature is a good predictor for the biological effect. Given that the colour temperature is usually printed on the package of a LED lamp, the consumer can use this information to select lamps with a low biological effect. For lighting used in spaces where prolonged evening exposure can occur, colour temperatures well below 3400K should be selected.

Figure I.3 Relationship between LED Colour Temperature and Biological Effect Factor based on data from 111 different LED lamps collected from Olino.nl. For comparison: an incandescent light bulb has a biological effect factor of 0.376; daylight has one of 1.040.



We were also able to test whether or not there is a trade-off between lighting efficiency and biological effect. To our surprise this somewhat invalidates the anecdotal claim that the high blue light output is the result of the maximization of efficiency in lumen of light output per watt of electrical input.

Figure I.4 Relationship between lighting efficiency and Biological Effect Factor based on data from 111 different LED lamps collected from Olino.nl



Indoor emissions of harmful chemicals from plastics used in energy saving lamps
Tests commissioned by the Norddeutsche Rundfunk (NDR) have shown that energy saving lamps for lighting (in their case CFL lamps) emit gases of concern. Among them was phenol, naphthalene and styrene, substances which are suspected to be carcinogenic. The lamp warms during use and plastic components used in the lamp start emitting these substances.

Electro-safety issues
Existing electro safety standards for lamps may not be fit for LED lamps. The electric contacts in LED lamps are much closer to each other than in incandescent lamps. This may lead to risks of short cut.

Impact of light quality on labour productivity
Aries (2005) investigated the lighting conditions in current office types with regard to current standards and non-visual variables and to develop (conditions for) lighting concepts and system solutions that meet both visual and non-visual demands of humans. As discussed above, non-visual photoreception affects the circadian rhythm and directly stimulates parts of the brain that influence e.g. the cognitive functions and operating capacity. The biological clock or the suprachiasmatic nucleus (SCN) is located within the hypothalamus at the base of the brain. Supported by light perception, this biological clock system tells the human body when to regulate multiple body functions such as body temperature, sleep patterns and the release and production of hormones, like e.g. melatonin and cortisol. Particularly melatonin ('the sleep hormone') and, to a lesser extent, cortisol ('the stress hormone') are important for human health, mood, well-being and performance. A transition to LED light at the work place is expected to have some combined impact on labour productivity, wellbeing, and health but the net direction and magnitude of the impact is yet poorly known. The effects can be both positive, negative or mixed.

Intermezzo II: Smart Electricity Grids

This intermezzo briefly explores the challenge of risk migration in smart electricity grids. It is based on a working paper for the EPINET (Integrated Assessment of Societal Impacts of Emerging Science and Technology from within Epistemic Networks) FP7 project (Van der Sluijs et al, 2012).

Smart grids is a rapidly emerging research field, in which a lot of incomplete definitions and ambiguous uses of terms can be found. A smart grid constitutes a vision of an electricity grid that is improved by two-way communication between consumers and suppliers to increase the efficiency of the existing grid. Many authors supplement this definition with Demand Response (DR) and Smart Metering.

In the case of smart grids we see that the technology is often framed as a very positive development that contributes to many aspects of sustainability by for instance increasing energy efficiency of the electricity system and by enabling large scale inclusion of renewable energy in the grid. Attention for risk transformation in the smart grid innovation is limited. Amongst more than 6000 published journal articles found in the Scopus database (www.scopus.com, search date 10 June 2012) containing the word “smart grid” only four papers explicitly addressed the potential new risks of this new technology. Beyea (2010) mainly discusses the privacy issues associated to smart meters. Two papers (Pearson 2012; Pallotti and Mangiatordi 2011) deal with cyber security of the ICT part of smart grid technologies. The fourth paper (Zio and Aven, 2011) reviews the uncertainties, risks and vulnerabilities and proposes some approaches to analyse them. We will briefly discuss the findings from these four studies here.

Beyea (2010) sees as the main benefits of smart grid its potential to save energy, its capacity of shaving peak electricity usage and reduction of risks of black-outs (note that Zio and Aven 2011 also consider the possibility that smart grid technology increases the risk of black outs). The main concern in Beyea’s paper in terms of risk transformation is the issue of privacy in relation to access, storage and mining of data collected by smart meters. Such data are useful and interesting for many possible purposes and can serve a wide range of interests that extends far beyond the proclaimed purposes (mainly: optimization of the matching between energy demand and supply) for which these data are collected. Given that the EU is planning to install 245 million smart meters between 2010 and 2020, the amount of data will be tremendous and so will be the possibilities of data mining. Privacy protection is important because from high resolution smart meter data personal habits can be inferred. Even while these issues can be resolved by regulation, technology and obtaining consent for legitimate uses, some privacy risks will always remain.

Pearson (2011) argues that vulnerabilities linked to increased reliance of smart grids on ICT may undermine the potential gains that this technology can bring. This requires recognition that cyber security should become an essential part of EU energy policies. Early action is required and Pearson advises that the European Commission appoints a cyber-security coordinator and recommends collaboration with the US on this issue. Interestingly, recognizing the increasing reliance on ICT, in October 2012 a group of Dutch knowledge institutes established a new European knowledge network: the European Network for Cyber Security (ENCS). Its mission is to protect vital infrastructure, including electricity, water and telecom grids (http://webwereld.nl/nieuws/112107/nieuw-kennisinstituut-moet-energienetwerken-beschermen.html). As far as we are aware the EC has not yet taken a leading role in coordinating the challenge of cyber security.

Pallotti and Bordini (2011) discuss the requirements for smart grid cyber security. They propose a code of technical practice to help companies in managing information security. The code covers 12 sections, see box 1.

Box 1 Code of technical practice for cyber security of smart grids (Pallotti and Bordini, 2011)

1) Threat modelling

Information infrastructure architects and consultant attempt to identify the potential attack vectors investigating Use case vs. abuse case.

2) Segmentation

For minimizing the impact of attacks, the utility companies have to use segmentation. For example if data traffics would be limited in a geographical location through a stateful firewall, an attack would be contained in that location only.

3) Firewall rules

A typical implementation in an IT environment is a deny all firewall rules with proxy server and continent filtering.

4) Signing

Software on smart grid device has to implement signing. It does validate the integrity of the code to be executed.

5) Honeypots

Used as trap attackers a honeypot can identify an attack, alerting the organization in time for countermeasures. Placed on smart grid environments and perimeters area it will be able to better understand the weaknesses of the infrastructure.

6) Encryption

Adopting encryption on transport layer, data archive and control network can safeguard sensitive information from compromises.

7) Vulnerability management

There's a control centre in the company to ensure that the security policies are effective and constantly upgraded.

8) Penetration testing

Exploiting, periodically, the weakness issue found in a vulnerability scanner test.

9) Source code review

It' s an important software quality development requirement especially oriented through code vulnerabilities and fixing patch.

10) Configuration hardening

Smart Elements on the grid have to be tested with vulnerability scanner and hardened before entering in production. CIS standard con be used for benchmarking.

11) Strong Authentication

The companies have to adopt at least 2 authentication methods between (password - hardware key – biometric id)

12) Logging and monitoring

Logging and Monitoring provide information to identify attacks or reconstruct events in case of natural calamities. Interesting researches are still in progress in signal processing analysis, mixing typical data-mining technique with multiresolution analysis of wavelet transform. Analyzing and mine the data security log can detect a larger numbers of attacks on different time scale.

Zio and Aven is the only study so far that has attempted to systematically assess the risks, vulnerabilities and uncertainties of smart grids. They argue that the hazards, risks and vulnerabilities relate to the hardware of the network itself and the communication and information systems within and around that network. These can include:

- Mechanical failures
- Natural events (storms earthquakes, natural fires etc.)

- Intentional attacks (sabotage or terror by conventional means)
- Control failures
- Control hijacking
- Cyber/internet attacks

They emphasise that the future smart grid system is complex and uncertain where uncertainty and complexity stem from a range of characteristic aspects such as the context of system definition, design, development, deployment, operation, adaptation and evolution. On top of that all kind of technical issues add to the complexity and so do societal issues such as globalization, competitiveness, financial issues, political issues, etc. This makes assessment of risks of a future smart grid very complicated because the functioning of the components and systems implemented in a smart grid will depend on the operational context in the large sense (technical, environmental, social, economical, political), whose boundaries are difficult to frame with certainty and are dynamic on the spatial and time scales considered. This is why critical reflection on uncertainty and assumptions in Technology Assessment of emerging technologies such as smart grid technology is so important.

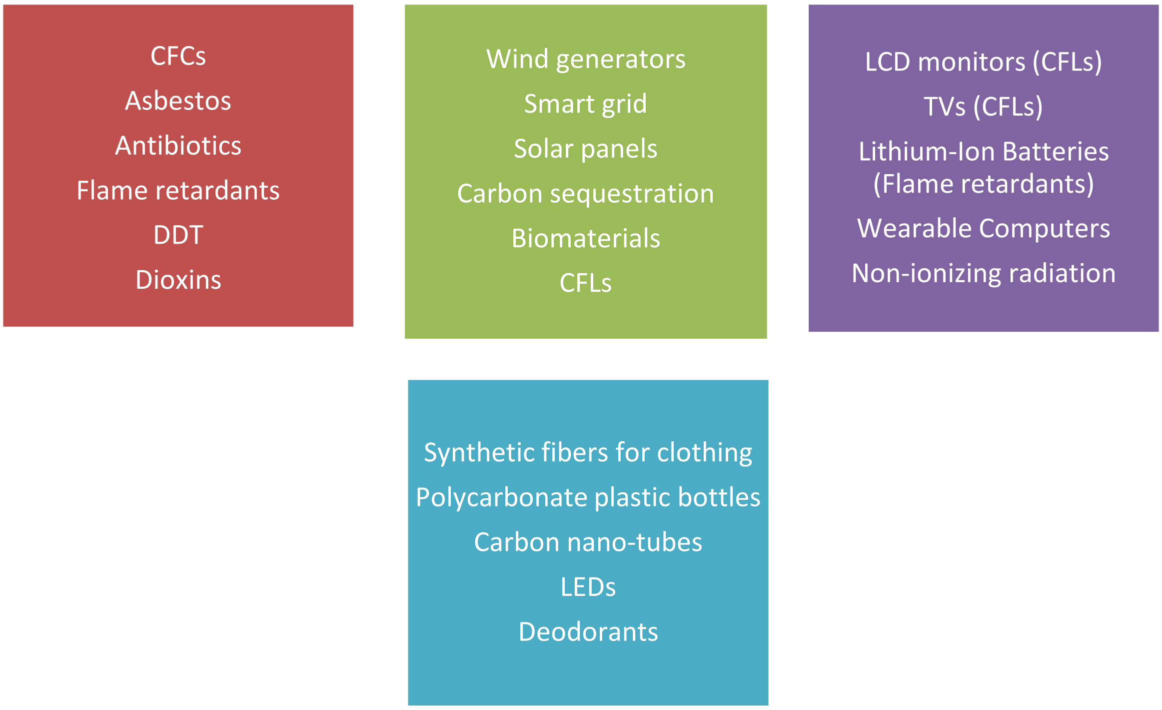
3. Results from interviews

A series of interviews with key people in the field of innovation, policy-making and sustainable products was held. The outcomes of the interview are described in detail in a separate report (Kouloumpi 2012).Experts with different expertise in the field were interviewed in order to discuss their own experiences of relevant cases of risk migration and real life innovation practices and regulations.

3.1 Cases of risk migration

Interviewees identified 22 cases of risk migration, which we grouped in four categories: classic cases, sustainable products; electronics and other (figure 3.1).

Figure 3.1. Cases of risk migration mentioned in the interviews divided in categories: Classical cases (Red), Sustainable Products (Green), Electronics (Purple), Other Products (Blue)



The green box includes any sustainable products mentioned by the interviewees as products that have the potential to cause negative side-effects because of some of their characteristics. However, those concerns are not fully verified yet, except for the risks related to CFLs (Compact Fluorescent Lamps), due to mercury. The wind generators were mentioned due to the hidden risks related to their manufacturing and especially to the extraction of the raw materials needed for their fabrication. Raw materials extraction is a highly energy intensive process and subsequently increases the hidden embodied CO2 emissions in the lifecycle of wind generators. The risks are expected to become bigger, since the extraction of raw materials will take place mainly in China, a country which does not comply with all necessary environmental and health precautionary measures. Another sustainable energy product mentioned for its potential risks was the smart-grid. Its digital nature and its interdependence on the internet, imply a risk of affecting vast amounts of the population in cases of sudden interruption of internet or unexpected disruptions of the system. Furthermore, there are also many concerns related to privacy ("Big Brother") because of the constant control and monitoring of individual energy consumption implied by smart grid systems and smart meters.

The purple box in figure 3.1 contains the electronic and computer products mentioned by the interviewees with either verified or potential unexpected risks. Many of the risks related to these products stem from the dismantling or wrong disposal phase of the products which was not taken into consideration during their design.
Finally, the blue box resumes other products mentioned in the interviews which do not belong to any of the categories above. Some of these were nanotechnology materials, like carbon nano-tubes, which have raised alarms due to their chemical molecule structure similar to the one of asbestos. Another product with unexpected risks - as mentioned in the interviews - is the synthetic fibres (polyester and acrylic) used for clothing. The problem relies on the fact that these fibres get rinsed by the washing machine and via the wastewater they accumulate on shorelines worldwide and in marine species. In fact, one cycle can strip as much 1,900 fibres off each piece of synthetic clothing (Browne et al, 2011). Research also shows that the pollutants are eaten by mussels and locusts, which can then work their way up the food chain to humans.
Finally, on the table below one may see an overview list of all products, mentioned in the interviews, with a potential to cause unexpected risks. A short description of the risks as presented by the interviewees is given in the column ´Other relevant risks´.

Table 3.2: Properties of cases of (potential) risk migration, as presented by the interviewees

	Case	Type of product or innovation	Aimed sustainability improvements	Potential risks introduced	Other relevant aspects
1.	**Compact Fluorescent Lamps**	New lighting product	Environmental (energy saving, materials savings)	Ecological (mercury) Human health (mercury, light frequency)	Risks mainly appear during waste phase of the product- not proper recycling or accident during dismantling
2.	**Wind generators**	Renewable energy product	Environmental (greenhouse gas emissions reduction) Human health (air quality)	Ecological (embodied emissions during wind generators´ construction due to extraction of rare earth metals)	Rare earth metals´ extraction is a highly energy intensive and polluting process and takes usually place in countries with insufficient environmental regulations
3.	**Solar panels**	Renewable energy product	Environmental (greenhouse gas emissions reduction) Human health (air quality)	Ecological (heavy metals, GaAs) Human health (heavy metals, GaAs)	The toxicological properties of GaAs are not thoroughly investigated; it contains Arsenic which is considered highly toxic and carcinogenic. GaAs and heavy metals could come in contact with human body during the production or dismantling phase of solar panels
4.	**Smart grid**	New type of energy distribution network	Environmental (energy savings)	Human health (no electricity due to internet disruption- danger for hospitals) Safety (hacking/terrorist attacks) Issues of privacy	Due to its interdependence on internet, smart grid might cause huge risks in case of a sudden internet disruption. Moreover, constant monitoring of energy use challenges ´Big Brother Issues´
5.	**Carbon sequestration**	Novel technique for reducing CO_2 emissions	Environmental (greenhouse gas emissions reduction) Human health (air quality)	Ecological (GHG emissions) Human health (GHG emissions)	The fluid used to inject CO2 into the ground has the potential to provoke very powerful GHG emissions
6.	**Biomaterials**	Novel materials which are bio-degradable	Environmental (material saving, waste saving) Human health (replace toxic alternative)	Ecological (interactions under certain conditions) Human health	Novel materials may not have been thoroughly investigated. Not enough information is available about their properties and how they behave under

	Case	Type of product or innovation	Aimed sustainability improvements	Potential risks introduced	Other relevant aspects
					certain conditions
7.	**LCD monitors**	New design computer monitors	Environmental (energy saving, materials saving)	Ecological (mercury) Human health (mercury)	LCD monitors contain CFLs. During dismantling, the product breaks and mercury is released
8.	**Lithium-Ion Batteries**	Rechargeable batteries used for consumer electronics	Environmental (energy savings, material saving) Ecological (replace nickel cadmium-toxic alternative batteries) Human health (replace toxic alternative)	Ecological (accumulation of flame retardants) Human health (bioaccumulation of flame retardants)	Lithium-ion batteries are not always properly disposed, hence flame retardants get into the ecosystem streams
9.	**Wearable Computers**	Novel types of electronics integrated into clothes	Environmental (energy saving, material savings)	Environmental (waste)	Wearable computers are expected to be cheaper and hence to have a shorter lifetime, which will subsequently increase the amounts of total waste
10.	**Artificial fibres for clothing**	New types of clothes materials containing plastic fibres (e.g.nylon)	No	Ecological (micro-plastic debris accumulation along the shorelines) Human health (micro-plastic debris)	Micro plastic debris<1mm are being accumulated in marine habitats. An important source of microplastic is sewage contaminated by fibres from washing clothes.
11.	**Polycarbonate plastic bottles**	Reusable plastic bottles	Design and shape moulding	Ecological (bisphenol A release) Human health (bisphenol A release)	Polycarbonate plastic contains bisphenol A, a toxic substance which can release into liquids under certain temperature conditions
12.	**Carbon nanotubes**	Novel material (small solid particles) with special properties (due to small size and structure)	Environmental (material saving, energy saving)	Human health Environmental (ecosystem health) Functioning of societal systems (waste water treatment)	Special material properties (small size, persistence). Some particles have similar form with asbestos molecules, so there is suspicion that they could cause similar risks Rapid spread to large scale application. Existing risk assessment frameworks & tools insufficient
13.	**LEDs**	New lighting product	Environmental (energy saving)	Human health	Toxic stress to the eye´s retina and the risk of glare. The blue light hazard, hormonal disorders Low-intensity LEDS exhibit significant cancer and non-cancer potentials due to the high content of arsenic and lead (Wilson, 2011) Mass production: use of cheap quality materials
14.	**Deodorants**	Cosmetic product	No	Human health Environmental (ecosystem health)	Contain nano-particles with unidentified effects on human health
15.	**CFCs (Halocarbons for refrigeration)**	Novel material (gaseous) with special properties (low reactivity)	Safety (replaces aggressive alternative)	Environmental (ozone layer, climate change)	Special material properties (low reactivity, i.e. environmental persistence) Rapid spread to large scale application
16.	**Asbestos insulation**	Novel material (small solid particles) with special properties (due to small size and structure).	Environmental (energy saving). Safety (fire-resistant)	Human health	Special material properties (small size, persistence in body) Rapid spread to large scale application

Case		Type of product or innovation	Aimed sustainability improvements	Potential risks introduced	Other relevant aspects
17.	**Antibiotics**	Compound or substance that kills or slows down bacteria	No	Human health	Increase bacterials´ resistance
18.	**Flame retardants**	Chemicals that inhibit or resist the spread of fire	No	Human health Ecological Environmental	Bioaccumulation Persistence
19.	**DDT**	Insecticide	No	Human health Ecological Environmental	Persistence, bioaccumulation suspected to cause cancer
20.	**Dioxins**	Toxic substance of herbicides	No	Human health Ecological Environmental	Municipal waste incineration is another source Chemical manufacturing as well Fat-soluble, accumulation in the food chain

Some of the cases brought forward by the respondents are well known classical examples of risk migration and others are products that may raise certain new concerns. Nevertheless, there are many similar aspects and commonalities between the cases mentioned in the interviews. Firstly, many of the risks presented were caused by a novel material, whose special properties have not been thoroughly examined. One may notice that the innovative characteristics of new products are more likely to create risks. More specifically, persistence and bioaccumulation are some common aspects in the cases of risk migration. Furthermore, another issue that is common in almost all mentioned products is the sudden massive scale of their production. At an earlier stage of product application, the risk is not obvious or might not even exist. However, when the product becomes suddenly widespread, the induced risk becomes huge and the impacts very divergent and difficult to manage. Another common aspect among various cases is persistence and bioaccumulation. These seem properties that are likely to cause high risks. In many cases incomplete assessment of the whole lifecycle of the product during its design phase has been a major factor in overlooking the risks. As mentioned in the interviews, the neglect of use and waste phase of the product, at the early phase of design, appears to be one of the strongest commonalities between the cases risk migration. Most of unforeseen risks seem to be caused either from non-standard/unexpected use or improper disposal of the product; facts that had not been taken into consideration when the product was being designed.

3.2. Barriers to early detection of risk migration

One of the main characteristics of the risk migration phenomenon is the fact that risks become usually apparent only after a technology or product has become widespread and the threats to the environment or human health are already very serious or irreversible. One of the key ways to prevent risk migration is the early detection and awareness of any unforeseen risks. Hence, one of the questions that were addressed to the interviewees was: ´Are there any practical constraints preventing early detection and prevention of risk migration?´

One of the first barriers to early detection of risk migration, frequently mentioned in the interviews, was that there is a clear information problem to face with the phenomenon of risk migration: Impacts cannot be easily predicted until the technology is extensively developed and widely used. It is very difficult to identify unintended side effects in the beginning, because there is very little evidence and knowledge about them. In the later phase, when information and proofs are available, the risks have already emerged and have often become socio-economically irreversible.

Furthermore, the complexity of risks´ nature relies also on the fact that there is no linear cause-effect relationship between risks and their cause; a small cause may cause a very big impact. Hence, it becomes very difficult to early predict the exact consequences of certain choices and detect any potential risks.
Another issue that appeared often in the interviews as one of the main barriers to early identification of risks was the incomplete assessment of the whole lifecycle of the product during the design phase. More specifically, as it came up from the interviews, many unanticipated side-effects of products are related to the use phase or the waste phase of the products. However, these stages are not taken into consideration during the design at the early phase of the product development.

As far as the use of the product is concerned, the problem relies on the fact that the innovators cannot think of all possible use and thus cannot foresee all inventive possibilities of the customers/clients and how they might use the product. Moreover, sometimes risks are not created from the product itself, but from the new social practices that the product creates. An example of this notion is the new product that is under development for medical self-testing, the ´lab-on-a chip´. The product will give the opportunity to users to measure their own blood pressure at home. The dangers, in that case, might pop-up from the fact that the use of this technology transfers from the lab- where professionals use it- to the private sphere, where it is used by individuals which are not trained to use it. Hence, the product itself might be safe, but the risks are transferred, migrate from the professional realm to the realm of private citizens. Therefore, it might be difficult to early identify these risks, since they are not related directly to the product, but to the behaviour induced by the product.

The waste phase is also considered by many interviewees to be a crucial stage of the lifecycle of the product for potential risks. Many risks related to the waste phase of the product are caused either due to accidents during the dismantling phase (a broken piece which releases toxics) or due to wrong disposal (e.g. instead of being properly recycled, products might end up to normal waste streams). However, these risks are not detected early because the disposal of products and the waste phase is not yet taken into consideration during their design.

Furthermore, the way the market functions was also mentioned as one of the main barriers preventing early detection of risks. Almost all interviewees mentioned the very short time demanded for a product to get in the market because of extreme competition. In fact, in order to identify any potential unexpected negative side-effects of a product, thorough research of the lifecycle of the product and long-term monitoring should be conducted at the early stage of the product´s development. However, the pressure of the market and the competition do not leave any time and space for precautionary attitude. Hence, usually innovators just try to comply with the existing regulations since there is no time to examine and predict unexpected risks.

In addition, comprehensive precautionary assessments imply very high costs for companies which might be inhibiting for innovation. As it was reported at the interviews, in order to identify and foresee any potential risks that the product might cause in the future, the company should have a testing facility like the ones used by pharmaceutical companies for testing medicine. Such a provision would imply extreme costs for the company, a fact that creates a barrier to early detection of unforeseen negative side-effects of the products.

Moreover, another topic mentioned as a constraint to early detection of risks was the fact that, very often, the key actors for the new products are not aware of any possibility of unforeseen risks that the products might cause, but they are also not aware of their role in creating these risks. One could also see a psychological factor in this kind of behaviour, since it is common that technology developers and innovators are so fascinated with their product -their creation- that they do not even want to think of any potential problems or risks.

Finally, respondents highlighted the role that the current social thinking plays in the phenomenon of risk migration. Public perception of science is that science is very powerful and that assessments and calculations are just a matter of applying the scientific method. There is a tendency to believe that every scientific question can be answered by science while in reality the ability of science to prove that something is safe or possesses a risk is sometimes very limited or requires an experiment of a scale that is impossible in practice. For instance Weinberg (1972) noted on the risk of low level ionizing radiation that an experiment that could prove at the 95% confidence level that a dose of 150 millirems would increase the spontaneous mutation rate in mice by 0.5 per cent, requires about8,000,000,000 mice. Weinberg concluded "*the number is so staggeringly large that, as a practical matter, the question is unanswerable by direct scientific investigation*" and proposed the term *trans-science* (Weiberg, 1972) for this type of problems. Most actors seem not aware of such fundamental limitations to the ability of science to establish whether new technologies are safe or dangerous and it seems to be very difficult to acknowledge and accept any ignorance or uncertainty and hence any unexpected risks.

3.3. Barriers preventing early action against risks

Apart from the fact that risks are, many times, detected very late, it is also common that action in responding to already known risks takes also too long. As it has also been commented in the interviews, it requires a long time for the system to acknowledge the risks and react against them. Thus, another question that was addressed to the interviewees was the following: ´Which are the practical constraints preventing early action against risks?´

Firstly, the experts mentioned the problem of vagueness of responsibility. According to the interviewees, it still remains unclear who carries the responsibility in case of the appearance of unexpected risks. In reality, the responsibility is often delegated to the next actor and any action against risks is constantly postponed; the designers are pointing at the engineers or the consumers; the consumers call for the government to take action; the government is waiting for scientific evidence of risks etc. Besides, the legal parameters are also complex and vague as far as responsibility for risks is concerned. The problem relies on the fact that it is difficult to blame the responsible producers of the product since they can claim ignorance and they cannot be accused and sued. Otherwise, the responsibility often passes on the consumers who become responsible for using the product while being aware that there might be some risks.

Secondly, interviewees mentioned the overload of information and the difficulty in filtering the sources. In cases of uncertainty, it is common that there are many predictions and contradictory results which make the right decision for action a very complex task. This concern is also known from the ´Late lesson from early warnings´ as the danger of paralysis by analysis where either information overload or lack of political will leads to a failure of timely hazard reduction measures. Besides, from the legal perspective, making a fair decision for action, in case of uncertainty and of conflicting scientific opinions, is also a complicated work. In fact, it is very difficult to legally claim the ban of a certain product when there is a lot of uncertainty and inconsistent scientific results, considering also the fact that there are examples of untrustworthy science.

Thirdly, one of the most important outcomes from the interviews was the recognition of the complexity of global chain market, as one of the main obstacles to action against risk migration.

Apart from the fact that products have become more complex, the whole chain of product creation has become much more complicated than in the past. Nowadays, there is a huge number of suppliers, many producers and brands responsible for the same product, which makes it very difficult to monitor the process and impose on them common laws. Furthermore, in the last decades there has been a tremendous change into the manufacturing industry. At the moment, almost no brand is responsible for its own production; manufacturing of products is utterly done by the Originally Equipment Manufacturers, companies which reside in many different places in the world, like in China, Taiwan, Indonesia. These companies are responsible for so many different producers that they end up becoming even bigger companies than the brand names. As a result, even if companies try to act against a certain risk and change some features of the product, they may find obstacles to pass their decisions to the real manufacturers. A typical example mentioned in the interviews was the case of Philips. In the past Philips had more production in their own hands, which was also located in the Netherlands. During the years, more and more shares of the production were delegated for manufacturing to OEMs in different parts of the world and now the biggest part of their production is done by OEMs. One of them, FOXCOM, is one of the biggest companies in the world, since it is responsible for manufacturing products for all well known computer brands. When Philips tried to change the design of LCD monitors in order to avoid risks related to CFLs, the plans got rejected by the manufacturers. Last but not least, products are being designed for different markets in the world, where there are different national regulations. Hence, it is difficult to impose general rules and laws and set a common agenda for action against the same risks.

In the same context, the large size of modern companies was also mentioned as a barrier to early action against risk migration. Companies nowadays, are so big that internal communication between different departments becomes a highly complicated task. In fact, the reason for not setting or not applying environmental benchmarkings or taking action against risks might usually be the lack of internal communication within the company (e.g. from the energy consultancy department to the designers etc).

Interviewees further mentioned practical and real-life barriers preventing the substitution of the products that induce the risks. What was mostly stressed was the big difference between the theoretical/systemic approach to the risk migration problem and the real life barriers. As a matter of fact, one may agree on a theoretical/societal level that, in order to avoid some risks, there should be a substitution of certain products. On that level, the substitution might seem logical and give a solution to the society against the potential risks. However, on the individual practical level, the costs are tremendous both for the industry and for the employees and in fact no industry will close down only because of some suspicions.

Apart from the socio-economic practical constraints, there are also many legal implications and barriers that prevent action against risks. In the way society works and the political system is constructed now, the government and the societal actors are allowed to act against a risk only when there is an emergency, a crisis, i.e. when the risk has already appeared and the damage has already been done. However, when there are some vague assumptions or suspicions about potential risks and in general the case is uncertain, it is very difficult for the societal actors to intervene. In fact, they are not authorized to make decisions upon uncertainty and the law does not foresee any action in vague cases. The problem relies also on the way the legal system is constructed at the moment, since it relies only on the public law for tackling risks. However, the public law is not flexible enough to be modified fast and respectively to each risk case and as a result it is always applied too late and only when the hazards are already there.

One of the interviewees with expertise in law and especially in cases of risk migration and precautionary measures gave a deeper insight in the way law, currently, deals with risks. First of all, the general line is that in a case of risk, the employers are responsible for the employees, e.g. if a worker is exposed to asbestos, then the employer is liable. However, this implies that the risk is already known and verified. Furthermore, an industry is liable for a risk when it has deliberately done something wrong or when it has not informed their employees and the users for the potential risks related to the product. On the other hand, the industry is not liable if it has taken the necessary precautionary measures to avoid the negative side-effects and if it has informed the users of the potential dangers and has taken protective action. Moreover, the producer company does not have liability when the risk is caused by non-expected use of the product (e.g. when the asbestos insulation is covered in a safe way and no user can reach it and come in contact with it, then the building industry is not liable).

However, every case of risk is different and one has to consider various parameters and their combinations in order to draw conclusions for the liability of each case. One of the crucial issues to be examined, though, in cases of risk, is the availability of alternatives. The interviewee stressed the necessity to observe whether there is an alternative product/way that could substitute the product which causes the risk and if yes, which are the costs and the potential risks also included in the alternate option. The existence of a possible substitute would increase the responsibility of the industry that did not consider the fact. In contrast, if the conditions do not permit another choice and, besides, the risks of not using the product at all would be even higher, the liability needs to be reconsidered.

All the above mentioned examples refer to cases where the risk has already been known. In these cases the responsibility of the industry mostly relies on taking the necessary precautionary measures and communicating the risk. The problem, though, is far more complex when the risk is not yet known or is very uncertain and the hazards appear only after many years. These cases are especially intricate for the law since it is very difficult to accuse someone for the way he/she acted at a different time and under different conditions and conclude that he/she would have had an alternative option. The complexity from the legal point of view relies on the difficulty not to be predisposed and examine objectively the case and the conditions of the past, while the risk is already known.

According to one interviewee, there is a high possibility that one is biased when trying to identify the conditions of the past, while being already aware of the existence of the risk. It is often the case that, while observing the knowledge that was available in the past and the alternative options, one cannot easily be objective and is tempted to assume that there was more information about the risk available at that time. In fact, even if one has to use the requirements of the past while examining the case, it is humanly impossible. One of the major examples of this complexity is the case of asbestos; although it is easy now to blame the industry, the truth is that when asbestos was vastly produced it was the best, the cheapest and the most easily available product and even governments were promoting its use, despite the potential risks. Hence, it is very difficult now to fully know the conditions of these times, the available knowledge about the risks of asbestos and the exact social context in order to address responsibilities.

In order to avoid unforeseen risks, the law obliges the industry to take precautionary measures and perform their ´information duty´, i.e. to do thorough research about risks and to give transparent information about potential dangers. However, if the information duty is not properly followed by the industry and facts and information about the products have been hidden, as for example the use of certain substances that have the potential to cause risks, the industry is liable. Nevertheless, it is impossible to accuse them if no one is aware of the risk. In these cases of non-transparency, the government is the responsible societal actor for accusing the industry and formulating public laws that ban the use of hazardous products or substances. The process, though, is very time-consuming and cannot prevent the negative impacts of the risk.

However, even in cases when the industry had withheld valuable information about the risks and had not warned for the dangers, they were judged as innocent because of the responsibility of the consumers who used the product. The tobacco industry is a primary example of these cases; it has been accused many times by smoking victims, for not properly communicating the risks and for using addictive substances. Yet, most of the times, the industry ends up to escape from any accusations, because of the responsibility of the smokers who choose to continue smoking and take the risk. The main claim in these cases is that, no matter what warnings the industry would had given, the smoker would continue the harmful habit.

3.4. Early identification of unexpected risks

Regarding the question how to tackle the problem of risk migration, the interviewees made a number of suggestions. First of all, taking into consideration the fact that many risks result from incomplete lifecycle assessments of the products, it has been generally concluded that the industry needs to think beyond the developing stage and consider the application, usage and waste stage of the product at the early phase of its design. Nowadays, it is obvious that it is not sufficient to think only of the foreseeable use of the product since there are so many different behaviours, characters and lifestyles that differ from the decided baseline for products´ use. Hence, many interviewees agreed on the importance of experimenting the products beforehand with user groups or creative people that might invent new uses of the product and may give a better insight into what people can do with this product.

For major innovations, it would be useful to create experimental learning spaces where the product is being tested before it goes to the general market; places where people can experiment in isolation and while knowing that they work with a new product. This idea has also been brought forward by developers of social robots and intelligent ICT. Undoubtedly, experimentation should be within reasonable limits, but still it would bring a new perception of the unforeseen ways that people might use the product.

Furthermore, in the same context, a more extensive analysis of how to deal with waste should be necessary for all products. The current methods for preventing risks only work when the risk is known and the focus is already given on known pollutants discarded with the product. Besides, it is essential also to include research for the worst case scenario already from the design phase, e.g. in case the product is not properly disposed of.

In general, all interviewees stressed the necessity of adopting a comprehensive ´system view´ while designing new products. It is important that the industry starts thinking differently while designing a product and try to include the whole system: how the product is functioning, how the consumers will use it, behaviours induced by the product, business issues related to the production and distribution, legal compliances etc.

The development of screening tools which could identify potential risks at the early phase of product development is recommendable. For this reason, an alternative use of Lifecycle Analysis Method has been suggested. At the moment, LCAs are highly time-consuming processes that only happen when the product is already in the market. However, the focus should be given on using LCAs as screening tools, which would make a fast, rough checking during the design phase of the product in order to assess which are its components, examine the ways it is going to be used and discarded and identify any ´alarm issues´.

To reduce the blind spots in knowledge, research should focus on the ´newness´ of the products - its innovative characteristics. This is crucial because often it is these new features that create new dangers. It was generally agreed that it is the newness of the product that should be taken into consideration as a trigger for conducting dedicated research on potential effects of exactly these new properties in order to assess potential risks.
A further suggestion is to make companies accountable for the consequences of their products. If it becomes clear that the industry e.g. might have to close down all their plants in case of a risk, there is an incentive to adopt a more precautionary strategy.

Furthermore, one of the interviewees mentioned that the only way to tackle the problem of risk migration, taking into consideration the current global chain market, is to establish an international research platform; a network of research facilities that exchange information as fast as possible. Nowadays, with the global trade, every country imports loads of products from all over the world and it is impossible to track their sources and identify all unforeseen risks for all of them. As technological innovation increases, the problem is expected to become bigger in the future. According to the interviewee, there is no single country or single institution that could tackle all the development and information. Therefore, despite the complexities of implementation, the only way to deal with the problem is to have an international research network (controlled e.g. by UN), since the exchange of information and the communication of potential risks are necessary for earlier reaction against them.

Finally, the important role of society in tackling the problem of risk migration was mentioned. One can never guarantee that all risks will be excluded. Even with the best predictions, there is always the chance that a new unforeseen risk might appear. Moreover, precise predictions will always be limited by the time (the product needs to get to the market), the money (they are very costly) and the nature of innovation itself (it is dangerous to prevent anything, because that would kill innovation). Hence, next to the normal safety assessments, it is important to develop the social context in which the product will land i.e. to create a knowledge base in the society for those who are going to use the product. According to one of the interviewees, there is no good innovation that does not pay attention to the context where the product is going to land and this is not merely a responsibility of the product developers; it is a responsibility that the whole society needs to take. Therefore, one of the main ways to tackle the problem of risk migration is to realize and emphasize the importance of social learning in regards to innovation in order to keep the latter within a sensible frame in society. In general, apart from very precise predictions and precautionary assessments, the most crucial part for risk management is to create a grown up and mature social environment, that can receive the innovation and is prepared to see any potential risks and give feedback. To that point, emphasis was given on the necessity to stimulate open and transparent communication and broad awareness about potential risks. The co-evolution of risk management with innovation is the main way, according to the interviews, to tackle unforeseen risks.

3.5. Promoting early action

A common characteristic in the cases of risk migration is that any response and action against risks comes, often, very late, when the hazards already exist and the impacts might already be socio-economically irreversible. It is important, hence, to find ways to overcome the burdens in the process in order to be capable of responding earlier to any alerts. The interviewees brought up advices about changes in the innovation process and governance which could allow a faster reaction against risks.

One of the first topics mentioned was the importance of developing a system to deal with the risks as soon as they appear. The suggestion was based on the already existing system of post-marketing surveillance. Post-marketing surveillance is the practice of monitoring the safety of a pharmaceutical drug or device after it has been released on the market and is an important part of the science of pharmaco-vigilance. Post-marketing surveillance further refines, or confirms or denies, the safety of a drug after it is used in the general population by large numbers of people who have a wide variety of medical conditions. Similarly, a monitoring system for products should be developed in order to check their safety after their release on the market. The interviewees have agreed that such a mechanism would be too costly to be developed only by the industry. Therefore, the definition of the exact functions of the system as well as the share of responsibilities for its development, still remains an issue open for discussion.

Furthermore, another important component of the system that would deal with risks faster is the relevant regulation. It is important to develop regulations about how to deal with risks when they already there, but also regulations for compensating those suffering from the negative impacts.

More to the point, the interviewees emphasized the importance of changing the current legitimacy state and underlined the necessity to act proactively. According to them, it is essential to change the current idea that politics need to react only upon crisis. A certain balance should be set by giving legitimacy into action even if the situation is still vague.

Moreover, the law specialist that was interviewed drew the attention to the contribution of the private law as a key way to deal with risks faster and more effectively. As it has been noted above, only the public law is currently used in order to tackle risks, namely everything that concerns risks is regulated from the government. However, the regulations from the public authorities are not flexible for change and as a result they come always too late or they are not enough to solve the problem. The interviewee remarked that there is also too much lobbying against public law and laws that are imposed from above are not always taken into consideration. For this reason, the advice was, next to the public law, to make, also, use of the private law in order to eliminate risks. The difference with the private law is that it comes from the private domain as a self-regulation; hence it also embraces the interests of the industry and it has bigger chances to be respected and applied. The interviewee pointed out that in order to ensure that the industry will focus more on avoiding risks, there should be a shift, a behavioural change; this shift will only be possible if the industry has also a profit and an interest in preventing any unforeseen risks. It is important, hence, to find the nudges that bring about a different behaviour from industries and trigger them to use the knowledge they already have about their products in order to eliminate risks. It was generally concluded that only if the regulations are within the interests and profits of the industry, they are likely to bring real changes and that can only be achieved with private laws and self-regulation.

Finally, apart from legal advices and changes in the regulation system, some more practical hints were also suggested in the interviews. One of the interviewees recommended that in order to involve more the industry, the environmental performance of the product should become part of the management structure, i.e. to make the environmental performance of the product part of the bonus key for the managers. In that way, the focus in management would shift from how to sell the product to how to take into consideration the environmental hazards. Another suggestion that might bring a different behaviour within business companies was the option of leasing. The idea relies on the fact that if companies do not sell their product, but they lease it instead, they might remain responsible for it and for any induced risks until the final phase of the disposal and dismantling.

3.6. Reflections on real life innovation practices

The professional experiences of the interviewed experts in different fields of innovation brought valuable insights on real-life practices and how the problem of risk migration is considered in reality. First of all, the current rules of market impose the way industry works and how innovation is created. As mentioned earlier, the high pressure in time and the competition do not leave space for any precautionary assessments. In reality, innovators struggle to make the product work and bring it to the market faster than their competitors. Most of the interviewees agreed that in real life there is no luxury of time to fully assess the lifecycle of the products and investigate for any unintended negative side-effects. In fact, producers mostly try to comply with already existing regulations so that the product is legal and could not be blamed and they do not aim to improve the product´s environmental performance beyond the required standards. Obviously, innovators give priority to deal with clear risks, which are reasonably easy to identify and they prefer to have a practical checklist of issues that they need to take into consideration.

Some of the interviewees commented that sustainability still remains a marketing trick for the companies, i.e. a way to sell their products and ´green´ their profile and any kind of efforts in avoiding environmental risks is not a primary goal for the industries. As an example, companies are using ´buzz´ words as recycling, sustainability, eco-design, but no clear action is taken to avoid risks. In some cases, it is even common that already known risks are not even discussed for fear that interest of consumers might drop tremendously. An interviewee, with experience in the field, mentioned that in many cases materials of nanotechnology are avoided to be declared as nano-materials, but they are renamed as new materials instead to avoid any public reactions. Furthermore, it was also added that it might be easier for nanotechnology industries to invest in lobbying activities in the legislation process or marketing rather than implementing risk prevention measures.

Real life innovation does not acknowledge ignorance and uncertainty. It mostly relies on environmental assessments and calculation with the certainty that there is always only one solution for each problem. That is the reason, according to the interviewees, why it is very difficult to include any precautionary mentality and it is the main constraint in taking potential risk migration into account.

3.7. Reflections on the EEA´s “Late Lessons“

Reflecting upon the discussions and the main findings of the interviews about the various barriers that still prevent actions against the problem of risk migration, one may wonder whether the already known lessons from past cases are taken into consideration. The European Environment Agency (EEA) report ´Late Lessons from early warnings: the precautionary principle 1896-2000´, published in 2002, summarized cases of risk migration, drew conclusions about commonalities and patterns and closed with a suggestion of 12 lessons (Box 1 chapter 2) that should apply to innovation in order to avoid similar risks in the future. However, according to the interviewees, ´real life´ innovation practices do not take these lessons into account, either because they might not be aware of them or because the conditions do not a allow precautionary attitude. Taking into consideration the practical and legal barriers against detection and reaction to risks- as they were brought up during the interviews- one may remark that the EEA´s 12 ´Late Lessons´ do not fully account for the complexity of real-life innovation. Despite the value of the lessons, the report was written 10 years ago and the lessons could be characterized as naïve since they underestimate the multiple burdens of the current social and economic global system.

Reviewing all the barriers preventing action against risk migration- as explained in the interviews- and the advices the experts gave as possible ways for solving the problem, one may discover many links with the EEA´s ´Late Lessons´; on the one hand, the practical constraints give an explanation about the reasons for the lessons have not been applied so far in ´real life´ innovation, while the advices seem to be in accordance with many points of the 12 lessons. This contradictory point might imply the complex nature of the problem of risk migration, but also the necessity for finding ways to bridge the gap between the theory, systemic analysis and the real life practice.
More specifically, browsing the lessons one by one, it can be figured out what barriers hinder their implementation.

The first lesson, ´Acknowledge and respond to ignorance…´ has as main ideological barrier the current social way of thinking, which gives emphasis on assessments and calculations presuming that there is always a solution for each problem. This mentality, as explained above, does not recognize any uncertainty in knowledge.

Moreover, the following lessons (2,3,4), which have as general tenor ´to know more´ by providing long-term monitoring and reducing the blind spots and the interdisciplinary obstacles to learning, seem to not fully take into account the current economical conditions and the rules of the global market. Comprehensive assessments and thorough monitoring of products imply testing facilities and practices like the ones used by pharmaceutical companies, the cost of which can be catastrophic for innovation. In addition, the extreme competition imposed by the global production and the high time pressure for putting the product on the market do not allow in depth and long-term research for identifying and preventing unforeseen risks.

Furthermore, the complexity of the global chain market also becomes a burden for the application of the 5th Late Lesson referring to the accountability for real world conditions. In fact, it is almost an impossible task to have a full overview and control of the whole production chain. Nowadays, products are produced and manufactured by so many different companies in various parts of the world that any attempt to fully know all real life conditions and the risks that might generate, seems almost out of question. Additionally, it is often assumed that technologies will perform to the specified standards. Yet real life practices can be far from ideal. In fact, this lesson remains still up-to-date since the interviews revealed that non-expected use or social behaviours induced by the product are not yet taken into consideration during its early phase of development.

The 7th lesson of EEA´s report refers to the importance of constant evaluation of alternative solutions. Indubitably, it is very crucial to constantly investigate for alternative solutions that could possibly substitute any products that cause risks. However, as it has been commented in the interviews, real life practical barriers hamper any attempt for substitution. In truth, even if substitution might be desirable on a theoretical, social level, it implies tremendous individual costs for the industry that is going to close down and for the employees. In reality, no factory will close down when there is uncertainty about the risks and the process of substitution is being postponed to the numerous practical burdens.

Using lay knowledge and accounting for values of different social groups (Lessons 8 & 9), becomes also a difficult task due to the complexity of the global chain market. Products are intended for different markets and nations globally where conditions, knowledge and values vary strongly and are often not acknowledged. Any effort, hence, to account for local knowledge and value becomes more complex due to the global character of production.

Moreover, lesson 10, suggesting for maintaining the regulatory independence from economic and political special interests, seems to be quite naïve; it does not take into consideration the powerful role that big corporations can play by lobbying in order to promote their products. It also happens that companies are aware of the risks but choose not to make that information public, because they give priority to profit.

Lesson 12, suggesting action in order to avoid paralysis by analysis, does not account for the problem of legitimacy. As it has been explained by the legal expert in the interviews, the social actors are not authorized to take action upon uncertainty and usually all legal processes need a long time to be reformulated. On the other hand, apart from the difficulty to be implemented due to real life barriers, the 12 ´Late Lessons´ seem to still have strong validity since they have many similar points with the advices suggested by the various experts during the interviews.

The suggestion of lesson 2 for long-term environmental and health monitoring is in accordance with the idea of post-marketing surveillance that was mentioned in the interviews but also the suggestion for development of screening tools that would assess the lifecycle of the products and monitor their performance from the early stage of their development.

Furthermore, lesson 3, calling for reduction of blind spots and gaps in scientific knowledge, is consistent with the recommendation to focus the research on the ´newness´ of the products, their innovative characteristics, since they could be the features that create danger. Besides, lessons 3 and 4 seem to link well with the suggestion for development of an international research platform that would exchange knowledge and information about risks. In general, the advice of open and transparent communication about risks was mentioned often in the interviews and is a possible way to overcome interdisciplinary obstacles and gaps in scientific knowledge.

Moreover, lesson 5 emphasizes the importance of including real world conditions, a fact that was also mentioned as one of the key issues in the problem of risk migration in the interviews. All experts stressed the necessity to take into consideration the use and waste phase of the product, worst case scenarios, but also social behaviours that might be induced by the product.

Lesson 7 refers to the importance of evaluating alternative options which is in accordance with the issue of responsibility that was brought up by the legal expert during the interview. The industry carries a bigger responsibility and is liable when an alternative option that could substitute the risky product, was available.

Lessons 8 and 9, on the other hand, have a clear link with the call in the interviews for creating a grown up and mature social environment that that can receive the innovation and is prepared to see any potential risks and give feedback. The advices from the interviews and the ´Late Lessons´ seem to fully agree on the important role of the society in tackling the problem of risk migration. Moreover, the issue of regulatory independence of interested parties was also mentioned by one of the interviewees, who suggested the establishment of independent research entities that could provide valid information about potential dangers.
Last but not least, the suggestion of the legal expert to include the private law could be a solution for the issue of legitimacy and could avoid the problem of paralysis by analysis according to the last lesson.

3.8. In summary

The interviews brought new insights in the problem of risk migration while, at the same time, they confirmed some of the issues already known. Our findings highlight the complexity of the phenomenon of risk migration and the various social, economic and legal implications that relate to it and most of all the necessity of a fully integrated and inclusive proactive approach to risk appraisal and out-of-the box thinking on potential scenario's and imagining possible surprises.

From the interviews we conclude that real life innovation practices do not systematically account for potential unexpected risks and the lessons known so far from past cases (such as the EEA Late Lessons from Early Warnings reports), are hardly taken into consideration and are not widely known to innovators, nor are they taken on board in the daily practices of innovation governance. Innovators mostly aim to deal with clear and known types of risks which are reasonably easy to identify with state of the art methods and try to make sure that they comply with existing risk regulations.

As far as unforeseen and unidentified types of risks are concerned there is either ignorance or sometimes even a tendency to actively ignore any discussion about them, driven by fear that openness about unknown impacts could drop consumers´ interest and hamper innovation. In fact, the main barrier to precautionary measures and action to cope with new and emerging risks, as it has been brought up by the interviews, is the current economic system and the global chain market. Firstly, the very short time demanded for the product to release to the market and the extreme competition, do not leave any space and time for individual firms for precautionary assessment: it would harm the competitive position of the company unless all firms would have to go through such thorough explorative appraisal of new and emerging risks. Secondly, the chain of the product creation has become rather complex; various producers and OEMs (Original Equipment Manufacturers) are responsible for the same product, which is designed for different markets in the world. The production of parts is also distributed over the world and not all countries will follow the same regulations. Of course, import regulations can prevent some problems from occurring here. However, it might also cause risks locally: e.g. environmental damage in countries producing parts or collecting the waste. This could be interpreted as risk migration from one country to another. Monitoring becomes very difficult, while sometimes strategies and policies against risk might be rejected at different stages of the production chain.

Furthermore, the interviews revealed also the key importance of legal barriers in the problem of risk migration. Policy makers are reluctant to act upon uncertainty, the legal frameworks and risk assessment methods are lagging behind and not fit for the novel aspects of new materials, new substances and new products with unknown new properties, so the law comes always too late, when the novel risk manifests itself and the damage is usually already done. Emphasis was given on the inclusion of the private law (liability and the obligation to prevent harm) and self-regulation, next to the public law, as a way to tackle the problem of unforeseen risks.

Finally, from the different interviews a main lesson was gained; that the responsibility for risks is shared across all the actors: industry, government and society. The industry should adopt a more integrated system-view and think beyond the production stage, exploring the potential impacts in the full life cycle and including the long term fate and potential behaviour in the environment. It is essential, based on the outcome of the interviews to include the realistic use and application of the products, the disposal as well as the unanticipated novel social behaviours that they might provoke. In addition, focus should be given on developing screening tools, making alternative use of LCAs (Lifecycle Analysis), which could identify early any potential dangers.
The government on the other hand, could invest on more extensive and thorough research in order to reduce the blind spots in knowledge, by giving focus on the ´newness´ of the product. Moreover, it seems essential, according to the interviews, to create experimental learning spaces where the products can be tested by user groups who may give a better insight into what people can do with this product. Furthermore, the interviewees brought up an interesting topic for further consideration: the creation of an international research platform that could exchange information

about risks as fast as possible. In that way, an international knowledge base could be created that could deal with the overload of information about all products coming from the global chain market. It remains however an open question who should take the lead in establishing such a platform. Besides, governments should consider the idea of post-marketing surveillance and develop a system of regulations about how to deal with risks and how to compensate the ones who suffer from the impacts.

All interviewees agreed upon the important role that society can play in tackling the problem of risks. Next to very precise predictions and precautionary assessments, the most crucial part for risk management is to create a grown up and mature social environment, that can receive the innovation and is prepared to see any potential risks and give feedback. According to the interviews, there is no good innovation that does not pay attention to the social context where the product is going to land and this is not merely a responsibility of the product developers; it is a responsibility that the whole of society needs to take.

4. Results of the electronic survey

Of the 108 experts invited to the survey, 12 experts (names listed in appendix) completed the survey (response rate: 11%). In the following we present the results from the survey. Note that the information and opinions described in sections 4.1.1 to 4.1.24 primarily come from the survey respondents, in their own words. In some cases we added information from the literature which can be recognized by the literature references provided. Some of this literature was provided by respondents.

4.1 Cases of risk transformation

The respondents identified 24unique cases of risk transformation which are described below. Some of them overlap with the cases from the interviews and the historic cases in the previous chapters. Some cases are not examples of transformation of a sustainability risk to another risk; the respondents have interpreted sustainability in a broad way. For each case we address the following items:

a. Case description
b. What did the product aim to achieve in terms of sustainability?
c. What were the unanticipated side-effects/introduced risks?
d. How were these side-effects discovered?
e. Could these unintended side effects have been anticipated earlier? How?

These points correspond to questions in the survey.

4.1.1. Compact Fluorescent Light bulb

a. Case description

Leaving normal incandescent light bulbs for energy-saving compact fluorescent lamps containing mercury. Workers handling returned light bulbs were exposed to mercury due to un-safe handling. Also consumers may be exposed.

b. What did the product aim to achieve in terms of sustainability?

- Improved energy efficiency;
- Increased product life time;

Compact fluorescent bulbs use 70% less energy than a traditional, incandescent bulbs and last up to 10 times longer than a standard incandescent bulb.

c. What were the unanticipated side-effects/introduced risks?

- Risk of mercury exposure;
- Risk of mercury pollution during processing or recycling (or lack of recycling);
- UV emission suspected to increase risks of skin and retinal damages;
- Electromagnetic fields from transformers may affect electro-hypersensitive people;
- High frequency flashing of the light can trigger migraine and epileptic reactions/seizures in sensitive people (see also SCENHIR, 2012);

d. How were these side-effects discovered?

Mercury: Workers were surveilled.
Seizures and migraine: Personal and anecdotal evidences.

e. Could these unintended side effects have been anticipated earlier? How?

Mercury: Yes, this is basic toxicological knowledge.

4.1.2. Flat screen for computers and televisions

a. Case description
Introduction of flat screen televisions led to massive increase of the strong greenhouse gas NF_3.

b. What did the product aim to achieve in terms of sustainability?
Reduce energy consumption.

c. What were the unanticipated side-effects/introduced risks?
NF_3 used during processing is a strong greenhouse gas (missing in the list of the Kyoto Protocol of the United Nations Framework Convention on Climate Change).

d. How were these side-effects discovered?
NF_3 world production increase.

e. Could these unintended side effects have been anticipated earlier? How?
Make an extensive list of greenhouse gasses for which emission reduction policies are needed, and not just emissions-trading oriented policies.

4.1.3. Spray Urethane Foam (PUR)

a. Case description
Spray Urethane Foam (PUR foam) is widely promoted and used for floor insulation in houses. One of the ingredients Methylene Diphenyl Diisocyanate (MDI) can cause sensitisation by inhalation and skin contact. In some cases, inhabitants of houses became sensitized and had to be permanently evacuated from their house and leave behind all their belongings, because the traces of MDI they contain trigger severe acute allergic reactions in sensitized persons.

b. What did the product aim to achieve in terms of sustainability?
- Energy saving;
-Greenhouse gas emission reduction;

c. What were the unanticipated side-effects/introduced risks?
When ground-floors of houses are insulated with Spray Urethane Foam (PUR), a mixture of Methylene Diphenyl Diisocyanate (MDI), polyol and a propellant is injected into the crawl space below the floor. The chemical reaction to form PUR can take 24-72 hours to complete. When the floor does not seal well and the mixing conditions are not perfect, high concentrations of MDI can build up in the house. Methylene Diphenyl Diisocyanate (MDI) is a dermal and inhalation sensitizer classified both as R42 (May cause sensitisation by inhalation) and R43 (May cause sensitisation by skin contact) as defined in Annex III of the European Union Directive 67/548/EEC: Nature of special risks attributed to dangerous substances and preparations. As a consequence, inhabitants of the house exposed to MDI have developed in several cases over-sensitivity to MDI. When this occurs the only remedy is to completely and permanently evacuate the sensibilised inhabitants from their contaminated house. They have to leave all their belongings behind, including their car and their clothes, because once sensitized, the trace-concentrations of MDI in all their belongings are enough to trigger severe acute allergic reactions.

d. How were these side-effects discovered?
The risk is well known, but the branch maintains that if good practice is met, risks are negligible. Experts of the Expertise Centre Environmental Medicine of Rijnstate hospital in Arnhem, The Netherlands rang the alarm bell after many cases occurred.

e. Could these unintended side effects have been anticipated earlier? How?
The regulation failed to account for real life conditions and assumed that good practice is always met and assume for instance that all floors seal well.

4.1.4. Styrofoam (polystyrene)

a. Case description
Styrofoam turned out to have several health effects. Styrene has been classified as a possible human carcinogen.

b. What did the product aim to achieve in terms of sustainability?
Though not specifically intended at sustainability in the direct sense, styrofoams were created for their reusability and versatility. They are widely used for insulation.

c. What were the unanticipated side-effects/introduced risks?
Styrofoams are non-biodegradable, it has been claimed they cause several human health effects. The EPA and the International Agency for Research on Cancer have established styrene as a possible human carcinogen.

d. How were these side-effects discovered?
Predominantly research has identified the several risks associated with this product

e. Could these unintended side effects have been anticipated earlier? How?
May be not.

4.1.5. Ceramic tiles with (radioactive) zirconium

a. Case description
Ceramic tiles with zirconium have thermal properties that make them favourite in near zero energy buildings. However, they can be radioactive, and be a source of indoor ionizing radiation exposure.

b. What did the product aim to achieve in terms of sustainability?
Energy efficiency.

c. What were the unanticipated side-effects/introduced risks?
The risk of exposure to ionizing radiation in indoor air and related health risks especially in children. Health risks are also increased for subjects working in warehouses.

d. How were these side-effects discovered?
It has long been known that naturally occurring zirconium contains a fraction of radio active isotopes. The amount can vary from mine to mine. Producers of tiles are not measuring radioactivity of products, even though this could be done by routine methods.

e. Could these unintended side effects have been anticipated earlier? How?
By interdisciplinary collaboration

4.1.6. Offshore wind power

a. Case description
Offshore wind power, planned to produce renewable energy, met opposition from fishermen.

b. What did the product aim to achieve in terms of sustainability?
Renewable energy.

c. What were the unanticipated side-effects/introduced risks?
Offshore wind farms create a new dangerous zone for fishermen.

d. How were these side-effects discovered?
Fishermen's opposition during public participation processes.

e. Could these unintended side effects have been anticipated earlier? How?
The respondent indicated that this would be possible but that it requires that we stop trying to manage marine environment as an extension of terrestrial planning.

4.1.7.Windmills and bio fuels

a. Case description
Renewable energy policies have promoted windmills and bio fuels but this has led to loss of biodiversity and landscape values.

b. What did the product aim to achieve in terms of sustainability?
Renewable energy production.

c. What were the unanticipated side-effects/introduced risks?
Loss of biodiversity and landscape values.

d. How were these side-effects discovered?
Listening opposition from interested parties/NGOs.

e. Could these unintended side effects have been anticipated earlier? How?
By consultations.

4.1.8. Biomaterials

a. Case description
Increased use of agro-resources for replacing oil as raw material for chemicals (one of the aspects of green chemistry) such as plastic made from maize has led to competition with food production and further intensification of agriculture.

b. What did the product aim to achieve in terms of sustainability?
Replace non-renewable resources by renewable ones. An example is plastic made from maize instead of oil.

c. What were the unanticipated side-effects/introduced risks?

Reduced surface of land available for food production, increased risk from intensive agriculture (which is usually the production pattern for agro-resources). The effects are not unanticipated, but not taken in consideration, i.e., ignored.

d. How were these side-effects discovered?
They are quite obvious but this does not prevent policy and industry from investing in such innovation without considering farming patterns and larger issues related to food production (chemicals produced from agro-resources need specific ways of synthesis, different from chemicals produced from oil).

e. Could these unintended side effects have been anticipated earlier? How?
This is an ongoing controversy, oil replacement by agro-resources in chemical innovation and industry is recent.

4.1.9.Tetrapak/ Tetra Recart

a. Case description
Tetra Recart claims to have lowest carbon footprints of all non-reusable rigid packaging systems. However, this claim critically depends on the assumption that recycling occurs. In the real world this hardly happens and the product is not sustainable.

b. What did the product aim to achieve in terms of sustainability?
Tetra Recart, produced by Tetra Pak, is made from FSC-certified "paperboard" and, it is claimed that it has less impact on the environment over its life cycle than a "tin" can. Recart cartons "have been shown to have one of the lowest carbon footprints of all non-reusable rigid packaging systems in life-cycle analysis studies across the world".

c. What were the unanticipated side-effects/introduced risks?
The key issue I have with TetraPak cartons, is the ease of recyclability. Very few local authorities offer kerbside recycling for TetraPaks. I suspect that most people are just throwing their TetraPaks out either with the rest of their card and paper recycling or in their general rubbish where it will likely end up in landfill and add to emissions.

d. How were these side-effects discovered?
Personal experience.

e. Could these unintended side effects have been anticipated earlier? How?
Yes definitely, this could have been anticipated.

4.1.10. Computers and electronic communication

a. Case description
Computers and electronic communication is sometimes claimed to contribute to sustainability by reducing paper and travel. However, it leads to generation of toxic waste in developing countries that produce and recycle electronics.

b. What did the product aim to achieve in terms of sustainability?
Reduce paper use.
Reduce travel.

c. What were the unanticipated side-effects/introduced risks?
Toxic waste generation, especially in developing countries where production happens.

d. How were these side-effects discovered?
Civil society and media investigation.

e. Could these unintended side effects have been anticipated earlier? How?
Yes - through systemic or life cycle assessment of production and disposal.

4.1.11. Douche gel of Neutral

a. Case description
Douche gel of Neutral claims to be free of hazardous chemical additives. Some users show allergic reactions.

b. What did the product aim to achieve in terms of sustainability?
Fragrance free.

c. What were the unanticipated side-effects/introduced risks?
Possibility of allergy / severe eczema.

d. How were these side-effects discovered?
Respondent's skin was changed into field with severe eczema when using douche gel of Neutral.

e. Could these unintended side effects have been anticipated earlier? How?
No, respondent bought the product because respondent is hypersensitive to perfumes.

4.1.12. Health impacts of UV Filters

a. Case description
UV protection and some other cosmetic products with UV filters protect from UV (with questionable efficiency)and cause breast milk contamination (Schlumpf et al., 2010).

b. What did the product aim to achieve in terms of sustainability?
Current cosmetic products are frequently declared as being produced in an environmentally friendly way.

c. What were the unanticipated side-effects/introduced risks?
Bioaccumulation in breast milk.

d. How were these side-effects discovered?
Breast milk analysis.

e. Could these unintended side effects have been anticipated earlier? How?
By close collaboration with pharmaceutical and cosmetic industries which in their classified files and archives possess side effects that are not allowed to be publicly available.

4.1.13. Bottled water

a. Case description
Bottled water led to depletion of groundwater and increased toxicity of groundwater.

b. What did the product aim to achieve in terms of sustainability?
Reducing water-borne diseases.

c. What were the unanticipated side-effects/introduced risks?
Depletion of groundwater increasing toxicity of groundwater.

d. How were these side-effects discovered?
NGO investigation.

e. Could these unintended side effects have been anticipated earlier? How?
Through lifecycle assessment of product development.

4.1.14. Recycling of waste

a. Case description
Recycling of waste.

b. What did the product aim to achieve in terms of sustainability?
Saving of material.

c. What were the unanticipated side-effects/introduced risks?
Attacks of fever and respiratory symptoms in waste-collecting workers.

d. How were these side-effects discovered?
By referral to occupational medicine department.

e. Could these unintended side effects have been anticipated earlier? How?
Yes, endotoxins are formed.

4.1.15. TriCresylPhosphate (TCP) in jet-oil

a. Case description
The life time of jet engines is prolonged by the use of the lubricant tricresyl phosphate (TCP). This neurotoxic substance is a prime suspect of Aerotoxic Syndrome in aircraft passengers and aircraft crew. The aircraft cabin and flight deck ventilation are supplied from partially compressed unfiltered bleed air directly from the jet engine. Worn or defective engine seals can result in the release of engine oil into the cabin air supply. Aircrew and passengers have complained of illness following such "fume events". (Liyasova et al., 2011)

b. What did the product aim to achieve in terms of sustainability?
TCP is used as lubricant to prevent wear inside jet engines. It prolongs the lifetime of the engines.

c. What were the unanticipated side-effects/introduced risks?
Respiratory problems known as “Aerotoxic Syndrome” (Schopfer et al., 2010)

d. How were these side-effects discovered?
Aerotoxic Syndrome was first described in the late 1990s (Schopfer et al., 2010). TCP has been a main suspect from the beginning. Liyasova et al. (2011) showed that exposure takes place: of 12 jet airplane passengers tested, 6 had a detectable amount of a major metabolite of TCP.

e. Could these unintended side effects have been anticipated earlier? How?
Yes. The toxic properties of TCP have been known for long. Early warning signals that these substances pollute the indoor environment of airplanes have been around for more than a decade. Respondent reports that for some new airplanes (e.g. the new Airbus that has the ventilation air intake separated from the engine air intake) the problem is solved.

4.1.16.Plastic soup

a. Case description
Plastics, becoming a waste problem at sea including build-up in large fish and mammals.

b. What did the product aim to achieve in terms of sustainability?
Packaging to protect high-value goods; fish nets to provide income, reduce costs for the industry and last longer than traditional materials. These are two example aims.

c. What were the unanticipated side-effects/introduced risks?
Accumulation in particular areas of the oceans and impact on marine wildlife through the persistence of the plastics.

d. How were these side-effects discovered?
Monitoring of fish and mammals; catch.

e. Could these unintended side effects have been anticipated earlier? How?
Yes, not least through common sense, but these are externalities so it's a classic example of the beneficiaries of innovations exporting their costs on to others and the natural world.

4.1.17. Nanoparticles

a. Case description
Nanoparticles (all uses) have unknown effects in the environment and ultimately for human health

b. What did the product aim to achieve in terms of sustainability?
Promises of nanotechnology related to energy include: material savings; prolongation of product life time, and efficiency improvements.

c. What were the unanticipated side-effects/introduced risks?
Unknown to date but parallel research with very fine particulate air pollution suggests possible long term cardiovascular and respiratory effects.

d. How were these side-effects discovered?
Discovery of side-effects is in progress, just beginning in animal systems.

e. Could these unintended side effects have been anticipated earlier? How?
Yes, there are clear parallels with ultra fine particulate (UFP, PM0.1) air pollution

4.1.18. Neonicotinoid systemic insecticides

a. Case description
In the last 15 years neonicotinoid pesticides replaced organophosphates and carbonates and became the most widely used insecticides world-wide. They were assumed to be safer for human beings - but turned out to end up in pollen and nectar of treated crops and wild flowers and are extremely toxic for pollinators, contributing to honeybee colony losses and wild pollinator decline.

b. What did the product aim to achieve in terms of sustainability?
Reduce the quantity of active ingredient brought into the environment and, in theory, reduce the risk for the environment (a major preoccupation in the '90s was that only a small quantity of the sprayed pesticide was reaching its target). Assumed safer for human beings, mammals and birds. Higher efficiency in pesticide use.

c. What were the unanticipated side-effects/introduced risks?
In the end, the neonicotinoids turned out to be much less effective than promised: only 4-20% of active ingredient enters the crop to protect it, the remaining 80-96% leaches to soil, surface water and ground water (Van der Sluijs *et al.*, in press). High persistence in soil and water. Translocation to pollen and nectar. Uptake by wild vegetation from contaminated soil and water. Extremely toxic for pollinators and aquatic organisms, but the main harmful effects do not occur via acute or 10 day toxicity, but via sublethal neurotoxic effects that make the exposed pollinators vulnerable to all other causes of death, and a special chronic toxicity profile: the toxicity is reinforced by exposure time, implying that exposure below detection limit when sustained of a long period can be mortal. These mechanisms of action on pollinators are completely overlooked by the present risk assessment protocols that are designed for contact insecticides with classic chronic toxicity profiles.

d. How were these side-effects discovered?
Following the first application to sunflower and maize, French beekeepers observed strange behaviour of their bees. Together with independent scientists it was found that the industry studies used for the authorization were completely flawed and in practice the use of neonicotinoids has a negative impact on colony performance. (Maxim and Van der Sluijs, 2013)

e. Could these unintended side effects have been anticipated earlier? How?
Yes, envisaging the potential toxic effects associated to the mechanism of action instead of applying blindly the regulation for pesticide risk assessment, which had been developed for sprayed pesticides with a different way of action. New generations of chemicals should be assessed for their effects associated to their new properties (ex.: systemicity) and mechanisms of action (ex.: neurotoxicity, which also gives their utility for the use envisaged), in addition to standard evaluation methods. This might apply generally to results of innovation, their properties making them useful is also the properties creating their risks. See also the detailed analysis and lessons drawn by Maxim and Van der Sluijs (2013).

4.1.19. Bio-accumulation and persistence of chemicals

a. Case description
Bio-accumulation and persistence of chemicals

b. What did the product aim to achieve in terms of sustainability?
Greater crop outputs; protection of e.g. seed from fungus etc.

c. What were the unanticipated side-effects/introduced risks?

Health impacts on wildlife and humans. The effects are extremely hard to trace and to create dose-response evidence to inform policy and/or legal proceedings, so it seems likely that the impacts and externalities are much greater than normally acknowledged.

d. How were these side-effects discovered?
Particular extreme cases of reactions to certain chemicals such as weakening of egg shells.

e. Could these unintended side effects have been anticipated earlier? How?
Maybe not, but they can now. Still, many chemicals remain largely untested for these effects due to policy unwillingness to revoke licenses or insist on re-testing - so the onus of proof remains on others and not those who stand to gain from the innovation.

4.1.20. Phosphate free washing powder

a. Case description
Phosphate free washing powder turned out to contain substitutes that are endocrine disruptors.

b. What did the product aim to achieve in terms of sustainability?
Reduce eutrophication of rivers and lakes, successful. Success, but not valued: reducing resource consumption of phosphorus.

c. What were the unanticipated side-effects/introduced risks?
The substitutes turned out to be endocrine disruptors.

d. How were these side-effects discovered?
Rather incidentally, no systematic screening. The problem seems to be not entirely solved yet as the character of being an endocrine disruptor is hard to predict from the chemical structure or from standard laboratory experiments.

e. Could these unintended side effects have been anticipated earlier? How?
If (a) a regulation like REACH had been in place, but different from REACH in that it (b) better covers small scale productions and (c) the degradation products, with (d) special emphasis on the disturbance of biological regulation mechanisms and (e) synergetic effects, it might have been avoided.

4.1.21. Scrubbers reducing SO_2 emissions from power plants increase CO_2 emissions

a. Case description
Scrubbers reducing SO_2 emissions from power plants

b. What did the product aim to achieve in terms of sustainability?
Reducing air pollution, stopping forest decline

c. What were the unanticipated side-effects/introduced risks?
They decreased the energy efficiency of such plants, thus increasing the emissions of CO_2 per kWh

d. How were these side-effects discovered?
They were know all the time, but considered as cost issues rather than as environmental problems as long as the climate issue did not dominate the public discourse. Still today the failure has neither been recognized nor addressed politically.

e. Could these unintended side effects have been anticipated earlier? How?
Of course; alternative technologies were available, not even much costlier, but requiring closure of some old plants, and a decentralization of power generation: big corporations did not want this kind of control loss.

4.1.22. Passenger air bags increase child death

a. Case description
Passenger air bags.

b. What did the product aim to achieve in terms of sustainability?
Reduce fatal traffic accidents.

c. What were the unanticipated side-effects/introduced risks?
Child death through injuries to head

d. How were these side-effects discovered?
Statistical data reported to highway safety authorities.

e. Could these unintended side effects have been anticipated earlier? How?
Yes - through diversifying choice of "model passenger" to include non-adults.

4.1.23. Genetically engineered plants undermines food security

a. Case description
Large scale use of genetically engineered plants led to competition for fertile land, undermining food security.

b. What did the product aim to achieve in terms of sustainability?
Alleviating poverty, overcoming world hunger.

c. What were the unanticipated side-effects/introduced risks?
Scaling-up resulted in competition for fertile land, thus undermining food security.

d. How were these side-effects discovered?
Only after the large scale production began to materialize, not taken seriously before food riots emerged

e. Could these unintended side effects have been anticipated earlier? How?
The results of pilot projects are often linearly extrapolated. However, large scales have risks of their own: mass production can be mess production. This quality change is often ignored in ex ante impact assessments, but could be taken into account by scenario development.

4.1.24. Composite dental fills

a. Case description
Composite dental fills (bisphenol A-glycidyl methacrylate (BISGMA)) lead to exposure to the endocrine disruptor bisphenol A.

b. What did the product aim to achieve in terms of sustainability?
Reduce mercury exposure from amalgam dental fills, both occupational and in patients.

c. What were the unanticipated side-effects/introduced risks?
Chronic exposure to the endocrine disruptor bisphenol A

d. How were these side-effects discovered?
In a randomized trial, Maserejian et al. (2012) found that greater exposure to bisGMA-based dental composite restorations was associated with impaired psychosocial function in children, whereas no adverse psychosocial outcomes were observed with greater urethane dimethacrylate–based compomer or amalgam treatment levels.

e. Could these unintended side effects have been anticipated earlier? How?
Yes, it has been known for long that BPA is an endocrine disruptor. All endocrine disruptors should be on a black list and be phased out and replaced by safer substances that can perform the same function.

4.2.Factors that hamper early detection of unintended negative side effects

Respondents were asked what they see as the main factors that hamper early detection of unintended negative side effects of new consumer products. We grouped the results into the following categories:

- lack of critical reflection on risks and benefits
- bias in appraisal of risks and benefits
- required level of proof
- inadequate risk assessment
- data gaps
- lack of monitoring
- institutional factors
- interests / power

The results are presented in table 4.1.

Table 4.1. Factors that hamper early detection of unintended negative side effects of new products.

Category	**Factor mentioned by respondents**
lack of reflection	Uncritical attitude of innovators and regulators;
	Not reflecting on validity of assumptions regarding safety and promises;
	Lack of recognition that higher system levels exhibit emergent properties, i.e. that linear extrapolation from small to large scale is not possible;
	Lack of imagination;
bias	Benefit bias - natural tendency to emphasize the benefits of innovations and reluctance to look at the dark side;
	Ideological blinding: theoretically expected impacts are tested and observed, unexpected ones ignored - fatal as the theoretical models tend to be less complex than reality;
	Constraining effects of mental models, incorporated into decision making tools
	Too small range of disciplines involved in the critical appraisal of potential risks and benefits / promises of new technologies;
required level of proof	Most side effects tend to be anecdotal evidences and not backed by research sufficiently, leading thus to a prolonged time period to establish/verify the claims;
inadequate risk assessment	Inadequate risk assessment;
	Not testing of new substances in a randomized controlled trial in human beings;

Category	Factor mentioned by respondents
data gaps	Lack of data on hazards associated with these materials (tox, ecotox and exposure/emissions);
lack of monitoring	Lack of a monitoring network for detecting new properties of results of innovation (which cannot be assessed with existing risk assessment methods);
	Lack of thorough all-purpose environmental monitoring;
institutional	Low interaction between political standardization of regulatory science and advances in academic science;
	Lack of incentives for private sector to do comprehensive risk assessment, especially when affected populations are poor or unorganized;
	The legislation is still very weak when it comes to chemicals in consumer products;
	Split political jurisdiction and authority
	Top-down management of needs and risks;
	General unwillingness to accept responsibility;
interests / power	Power of producers - lack of power of citizens;
	Political and economic interests inhibiting impact and damage assessment to avoid political or financial responsibility:
	Protection of industrial technologies and profit;

4.3. Barriers to early policy intervention

Respondents were asked which in their view are the main barriers to early policy intervention to reduce or constrain new risks once early warning signals are available. We grouped the barriers identified in the following categories:

- Vested interests
- Lacking sense of urgency
- Perceived level of evidence too low to justify intervention
- Limited expertise
- Institutional barriers
- Funding
- Reluctance to act / lack of courage
- Flaws in leadership

Table 4.2. Barriers to early policy intervention to reduce or constrain new risks once early warning signals are available.

Category	Barriers mentioned by respondent
Vested interests	Vested interests;
	Powerful stakeholders' interests (industry);
	Interconnected interests between industrial innovation and renewable policies;
	Financial;
lacking sense of urgency	Political issues are defined by the public discourse - whatever the damage, as long as the damage perception does not affect the public mood, the incentive to act is limited. And the public mood is shaped by media information which do not necessarily portray side effects properly;
perceived level of evidence	Policy intervention starts only with well backed research evidences, there is a significant time lag in terms of detection/early warning signals to action taken;
	Disbelief - unexpected means not credible, preoccupation prevails;
	Conflict over knowledge basis for decision-making;
Expertise	Bias in selection of experts by decision makers;
	Lack of proper education of policymakers in order to follow input from academia;
	Lack of multidisciplinarity;
institutional	Lack of protection of whistle blowers;
	Complicated and bureaucratic regulatory processes for risk assessment and management;

Category	Barriers mentioned by respondent
institutional	Under-use of academic research data in regulatory risk assessment;
	Diffuseness of regulatory authority;
	Inadequacies in monitoring (especially resource inadequacy);
Funding	Unbalance between public support and funding of research aiming at developing commercial innovation and public support and funding for identifying their risks (for nanotechnologies, a French report several years ago showed that the proportion was 5% for research on risks and 95% for developing new uses);
	Private funding of research on risks;
Reluctance	Lack of political will;
	Reputation - decision makers are often unable to admit failures or mistakes, as this could undermine their image of competence (and even their belief in their own competence);
Leadership	Poor leadership among risk-averse civil servants;
	Leadership, leadership, leadership!;
	"When the leaders lack vision, the people will die";

4.4. Responsibilities of producer, consumer and government

Respondents were asked what they see as the responsibilities of respectively the producer, the consumer and the government regarding detection of unintended side effects and action to reduce or constrain such effects. We categorized the responses according to descriptive and normative answers. The results are presented in table 4.3.

Table 4.3. Responsibilities of producer, consumer and government regarding detection of unintended side effects and action to reduce or constrain such effects.

Descriptive / Normative	Responsibility as identified by respondents
	Responsibility of producers
Descriptive	None at present. Regulation should define how these responsibilities should be identified and attributed;
	The legal provisions are limited in our legal system, as once a production has been allowed, the producer cannot be held responsible for the damages resulting from it (unless he received such information without disclosing it to the authorities);
	Depends on where the article is produced. REACH is applicable to things produced in the EU. There are also some product specific rules, e.g. for toys;
	Thinking at a short term range leads to only day-to-day profitability concerns;
	Unfortunately, there is always a way to avoid this. Even information on possible health effects for susceptible populations are written in small letters on product labels;
Normative	T is deep disagreement within society how the responsibilities for detection of unintended side effects are distributed over producer, consumer and government;
	The producer is liable;
	Producer must warrant sustainability of its products;
	When a producer gets permission to put new substances (chemicals, nanoparticles, GMOs) on the market, he should also get the obligation to make monitoring technology for these substances available to the supervising authorities;
	Producers have to investigate the issue through an unbiased study, and where possible recommend alternative means to tackle the issue temporarily;
	To take on unforeseen liabilities by insuring or contributing to a risk fund;
	Responsibility of consumers
Descriptive	None;
	Consumer has to read label on the product but in order to understand it, he/she has to be educated. Education of general public is paid by tax payers, means mainly industry. Industry prefer uneducated consumers;
	Consumers in many cases are easily mislead (mainly due to misinformation). They need to make a rational decision on the use of the product and refrain from it depending on the severity of the effect;

Descriptive / Normative	Responsibility as identified by respondents
Normative	Should not be regarded as a responsibility. Consumers need clearer information about how to detect such consequences, how to raise them to public visibility, and how to investigate possible reasons for failure to detect;
	Consumer must be ethical in his/her consumption behaviour;
	Promote corporate social responsibility as societal value;
	To take responsibility, think of the future, be well informed, ask difficult questions of the producers, say no when appropriate;
	Consumers should report side effects to officials;
	Consumer should improve knowledge diffusion of interests/flaws of products they use;
	Responsibility of government
Normative	Protection of citizens;
	The government may propose new legislation and work within the EU (and internationally) to improve the protection of human health and the environment;
	Governments should adopt more liberally the precautionary principle approach, as many of the risks are unknown and the severity of the risks are also unknown;
	Government must make producers accountable and warrant independence of risk appraisal and regulation;
	Monitoring is the second best option, the best being assessment procedures in the pre-market phase which minimize the risk of unintended effects;
	Govern in a way that pays more attention to the potential downsides of new technologies;
	The government must ask for reliable testing in human beings;
	Insist on proper liability insurance (viz. the whole structure of the 'limited liability company' - how suited is this to a risk society?);
	To have sufficient resources and expertise for adequate risk assessment, and when necessary to surveil risk management, for both consumers and workers;
	Government has to mobilize experts and educate its members;
	The responsibility of the government is closely related to that of producers. This has to do with the governing political economic ideology of the regulatory culture in question;

4.5. Lessons that can help to avoid future cases of risk migration

Respondents were asked what - in their opinion - are the most important lessons from past experiences that can help to avoid future cases of risk migration. The results are listed in table 4.4.

Table 4.4. Lessons that can help to avoid future cases of risk migration.

Lessons from past experiences that can help to avoid future cases of risk migration
Existing risk assessment methods are not made for identifying new risks. Some additional procedure able to identify new risks, different of those already known, should be imagined and added to the regulation of risks from innovation;
Science policy interface must adopt a post-normal approach: systematic critical reflection on knowledge quality, uncertainties and assumptions (e.g. van der Sluijs e.a. 2008);
For politics: make it a virtue to acknowledge mistakes;
Interim: an environmental Commissioner of the Parliament (not the government), like in New Zealand;
For business: change the liability regulations: Cover unexpected environmental impacts (not only fines, for delayed reporting also criminal prosecution);
For consumers: Not necessarily education, but communication possibilities, e.g. the opportunity to provide bad experience to public moderated black list web sites;
We should develop another burden of proof culture: make as sure as it is possible a product is safe before putting it on the market;
Lack of interdisciplinarity is still major problem which is recognized but is always lacking and knowledge application as someone calculated that only 7% of current knowledge is applied.
We need engineers and product developers that have basic training in toxicology and ecotoxicology. Enough to understand where there might be risks and apply appropriate risk assessment (and risk management) at an early stage in product

Lessons from past experiences that can help to avoid future cases of risk migration
development;
There is a risk that workers' safety is over-seen in the efforts to achieve sustainability for the environment;
With all new substances that will be introduced good research must be done including a randomized controlled trial. This gives also possibilities to find side effects that come much later;
Listen to the experiences of groups organized by concerned individuals to fight for protection from health and environmental risks;
As usually prevention is the best solution;
It is quite difficult to provide a simplistic answer to this as every case is different and needs to be tackled in a different manner;
See the Late lessons from early warnings: science, precaution, innovation report (EEA, 2013);

5. Conclusions

We explored the question to what extent the introduction of new, sustainable consumer products and technologies has led to unexpected, new or increased environmental and health risks and if so, under what circumstances this occurs.

Being largely based on expert interviews and a survey, results should be treated with some care. The sample of respondents is always a limited subset of the total expert-population and situational factors influence the composition of the group of respondents (e.g., who is well-known in the field, who has time to participate). Therefore, results are not necessarily representative. Rather, they give an approximation, and the responses provide valuable insights into the issue studied. In total, 20 experts participated in the interviews and survey. This is well within the range that is usually aimed for in expert elicitations; 6-12 participants (Knol et al, 2010). Given the broad coverage of relevant expertise and consistency with findings from the historic cases of risk migration described in existing literature, we consider the findings robust enough to support the general conclusions presented below.

First we made an inventory of findings from earlier studies. Key lessons on risk migration known from the literature include:

- Acknowledge and respond to ignorance as well as uncertainty and risk, in technology appraisal and public policymaking.
- Provide adequate long-term environmental and health monitoring and research into early warnings.
- Identify and work to reduce 'blind spots' and gaps in scientific knowledge.
- Identify and reduce interdisciplinary obstacles to learning.
- Ensure that real world conditions are adequately accounted for in regulatory appraisal.
- Systematically scrutinize the claimed justifications and benefits alongside the potential risks.
- Evaluate a range of alternative options for meeting needs alongside the option under appraisal, and promote more robust, diverse and adaptable technologies, so as to minimize the costs of surprises and maximize the benefits of innovation.
- Ensure the use of 'lay' and local knowledge, as well as relevant specialist expertise in the appraisal.
- Take full account of the assumptions and values of different social groups.
- Maintain the regulatory independence of interested parties while retaining an inclusive approach to information and opinion gathering.
- Identify and reduce institutional obstacles to learning and action.
- Avoid 'paralysis by analysis' by acting to reduce potential harm when there are reasonable grounds for concern.
- Update risk assessment methods to fit new risks.
- Assure adequate institutional capacity for efficient administrative procedures of risk governance.
- Broaden application of the principles of precaution, prevention and polluter-pays.
- Make government and business accountable.
- Broaden evidence considered (lay/local knowledge) and public engagement.
- Build resilience in governance systems and institutions.
- Reduce delays between early warnings & actions.
- Acknowledge complexity: multiple effects and thresholds.
- Rethink & enrich environment & health research.
- Improve quality & value of risk assessments.
- Foster cooperation between business, government & citizens.
- Correct market failures: polluter pays & prevention principles.

We found that the potential of these lessons is highly underutilized, because these lessons are not widely known and seem to have hardly been internalized by those working at the frontiers of technological innovation. Innovation is driven by competition between firms in a globalized economy and has drivers that are very different from the various aims of sustainability. Real life innovation practices do not systematically account for potential unexpected risks. Innovators mostly aim to deal with clear and known types of risks which are reasonably easy to identify with state of the art methods and try to make sure that they comply with existing risk regulations.
Bottlenecks in applying the lessons include: bias in appraisal of risks and benefits; required level of proof to justify interventions; institutional factors; vested interests and power structures that obstruct all attempts to intervene; lacking sense of urgency; limited expertise, reluctance to act/ lack of courage, and flaws in leadership.
In our interviews and survey we identified 40 examples of risk migration. In table 5.1 we list these cases and characterize them according to the circumstances/characteristics of the unintended side effects.

We identified amongst others the following new lessons:
- The old lessons are not well disseminated.
- System Analytical approaches to impact assessment should be promoted.
- Completeness of life cycle assessment is important.
- Science policy interface must adopt a post-normal approach: systematic critical reflection on knowledge quality, uncertainties and assumptions should be a central activity in the science policy interface;
- Incentives for ALARA are missing.
- Existing risk assessment methods are not made for identifying new risks. Some additional procedure able to identify new risks, different from those already known, should be developed and added to the regulation of risks from innovation;
- For politics: make it a virtue to acknowledge mistakes;
- For business: change the liability regulations: Cover unexpected environmental impacts (not only fines, for delayed reporting also criminal prosecution);
- For consumers: Provide communication possibilities, e.g. the opportunity to provide bad experiences with new technologies to public moderated black list / early warning web sites;

While many technological developments at first glance seem to be contributing to sustainability, this is not always the case. When we look better it is often not more than a promise whose validity is not established as we saw in the case of the Smart Electricity grid and in the Genetic Modified crops case. Promises related to sustainability include: alleviating poverty; overcoming world hunger; energy efficiency improvement; increase product life time; greenhouse gas emission reduction; reduced pollution; zero energy buildings; zero emission vehicles; renewable energy; renewable materials; reduced ecological footprint; increase yield; food security and increase safety. A related issue is issues that 'sustainability' tends to be interpreted very narrowly in the product design (e.g. reducing energy use), rather than the broader definition (systems view) that should have been applied for a concept such as sustainability.

The types of new and emerging risks include: health risks (carcinogenicity, endocrine disruptor, sensitisation, allergen, and mutagenicity); environment (pollution, bioaccumulation; pollinator loss, biodiversity loss, climate change, loss of landscape values); depletion of resources; increase of the problem that the technology aimed to solve; shifting effects to developing countries & future generations; pollution elsewhere in the larger system but outside the system boundaries considered. We could not find clear links between the type of sustainability promise and the type of new risk. Several historical cases involved innovations aimed at improving energy and material efficiency resulting in risks regarding human and ecological health.

Table 5.1. Examples of risk migration cases identified in interviews and survey and their characteristics/circumstances.

Case	Novel material / special unfamiliar properties	Persistence and/or bioaccumulation	Mismatch novel aspects and authorization tests / standards etc	Non standard situations	Lack of critical reflection on risks and promised benefits	Ignoring ignorance	Unreflective upscaling from small scale experiences	Incomplete life cycle assessment	Lack of systems analytic approach	No incentives to meet ALARA
Compact Fluorescent Light bulb			X					X	X	X
LED lamp	X					X			X	X
Flat screen for computers and televisions								X	X	X
Spray Urethane Foam (PUR)					X					
Styrofoam (polystyrene)					X					
Ceramic tiles with (radioactive) zirconium					X			X	X	X
Offshore wind power							X	X	X	X
Windmills and biofuels							X	X	X	X
Solar panels								X	X	X
Smart grid	X				X		X	X	X	
Carbon sequestration					X				X	
Biomaterials					X		X	X	X	
Tetrapak/ Tetra Recart					X		X		X	
Computers and electronic communication					X				X	
Douche gel of Neutral				X		X				
Health impacts of UV Filters	X	X	X			X		X	X	X
Bottled water					X				X	
Recycling of waste					X		X	X	X	X
tricresyl phosphate (TCP) in jet-oil			X	X	X	X		X	X	X
Plastic soup		X			X			X	X	X
Nanoparticles	X	X	X		X	X		X	X	X
Carbon nanotubes	X	X	X		X	X		X	X	X
neonicotinoid systemic insecticides	X	X	X	X	X	X	X	X	X	X
Bio-accumulation and persistence in chemicals	X	X	X		X	X	X	X	X	X
Phosphate free washing powder	X	X	X		X	X		X	X	X
Scrubbers reducing SO2 emiss. from power plants					X			X	X	
Passenger air bags increase child death				X					X	
Genetically engineered plants						X	X	X	X	
Composite dental fills		X	X		X	X		X	X	X
Lithium-Ion Batteries		X			X			X	X	X
Wearable Computers								X	X	
Artificial fibers for clothing		X			X	X		X	X	X
Polycarbonate plastic bottles		X			X				X	X
Deodorants		X			X				X	X
CFCs (Halocarbons for refrigeration)	X	X				X		X	X	
Asbestos insulation	X	X				X		X	X	X
Antibiotics									X	
Flame retardants		X			X			X	X	X
DDT	X	X	X		X				X	X
Dioxins		X						X	X	X

We identified a range of circumstances / characteristics that are more general across the cases. These were listed in the columns of table 5.1. When we rank the circumstances in table 5.1 according to the number of cases where they played a role, the following top 10 occurs (table 5.2).

Table 5.2 Top 10 of circumstances / characteristics of risk migration

Rank	Circumstance / characteristic	# cases
1	Lack of systems analytic approach	37
2	Incomplete life cycle assessment	27
3	Lack of critical reflection on risks and promised benefits	25
4	No incentives to meet ALARA	25
5	Persistence and/or bioaccumulation	17
6	Ignoring ignorance	14
7	Novel material / special unfamiliar properties	11
8	Mismatch novel aspects and authorization tests / standards etc	10
9	Unreflective upscaling from small scale experiences	9
10	Non standard situations	4

There is some uncertainty and ambiguity regarding the responsibilities that producer, consumer and government have and should have with regard to detection of unintended side effects and action to reduce or constrain such effects.

Regarding the producer, the legal provisions are limited in our legal system. Once the production and market introduction have been allowed, the producer cannot be held responsible for "unforeseeable" damages resulting from it (unless he failed to disclose key information to the authorities). One respondent suggested that when a producer gets permission to put new substances (chemicals, nanoparticles, GMOs) on the market, he should also get the obligation to make monitoring technology for these substances available to the supervising authorities. Note that the EU Product Safety Directive requires producers to monitor consumer products and producers should take action and inform authorities and the public when risks are identified. Another suggestion is to oblige companies to take on unforeseen liabilities by insurance or by contributing to a fund for (yet) unknown risks.
Other suggestions are (a) better accounting/testing/scanning for actual use, rather than an overly optimistic 'normal use', and for potential misuse; (b) account for diffuse responsibilities; (c) post-market surveillance.

As potential role for consumers, respondents suggested that consumers should promote corporate social responsibility as societal value. Further, consumers must be ethical in their consumption behaviour; should take responsibility; ask questions of the producers; say no when appropriate and report side effects they observe to producer and to authorities.

The government should develop adequate new national and international legislation to improve the protection of human health and the environment. Governments should adopt more liberally the precautionary principle approach, because many of the risks of new technologies are unknown and the severity of the risks are also unknown. Government must make producers accountable and warrant independence of risk appraisal and regulation. Monitoring is the second best option, the best being assessment procedures in the pre-market phase which minimize the risk of unintended effects. This requires an inclusive participatory approach of systematic critical reflection on both the validity of the promises and the possible risks of new technologies.
Still, systematic long term monitoring remains of key importance and should also involve monitoring of consumer experiences.

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Appendix

List of interviewees:

- Frans Brom
- Jaco Huisman
- Anne Keirse
- Andreas Koehler
- Frank van Rijnsoever
- Arnold Tukker
- Tom Verheijen
- Ernst Worrell

List of Respondents to the electronic survey:

- Maria Albin (SE)
- Scott Alister (UK)
- Iulie Aslaksen (NO)
- Josquin Debaz (FR)
- Lora Fleming (UK)
- Aleksandra Fucic (HR)
- Sheila Jasanoff (US)
- Janna Koppe (NL)
- Laura Maxim (FR)
- Christina Rudn (SE)
- Joachim Spangenberg (DE)
- SamarthiaThankappan (UK)