

Dealing with uncertainty in sustainable innovation: mainstreaming and substitution

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Abstract

In this paper, innovation is studied as a set of activities that seeks to deal with uncertainty. It is argued that the very idea of innovation contains the assumption that the future is, in principle, open to change. Moreover, since innovations compete with other innovations and with existing solutions as well, the outcome of innovative activities has to remain uncertain. Innovation theories, in the course of their development away from the linear models, have introduced elements that allow for certain degrees of fuzziness, randomness, and circularity. However, if the concern for impacts of an innovation is introduced into innovation theory, even more uncertainty is generated. This is, for instance, the case in sustainable innovations. Therefore, a fundamental shift in the thinking around innovation was promoted toward open-endedness and reflexivity. After a discussion of these conceptual efforts to incorporate uncertainty, the innovative actors' own strategies are studied in two empirical cases: advanced daylight systems and technologies that use CO₂ as working fluid for heating and cooling. These cases employ two different strategies to overcome uncertainty – mainstreaming and substitution – which are discussed in the light of innovation models in the last section.

Introduction

The flying car, a stock ingredient of classic visions of 'the world of tomorrow,' never really took off and nobody wanted to provide teens with a new way of socialising when mobile text messaging was invented. Stories of innovation are always also stories of unexpected failures and surprising successes. That innovation has to deal with a certain amount of uncertainty is one of its defining characteristics, since innovative activities are always directed toward an uncertain future.

Unlike innovators, scholars of innovation can choose to deal with innovation ex post. In hindsight, successes and failures often seem necessary so that reasons and obstacles can be analysed. This was, already in the 1960s, the goal of the aptly called Project Hindsight, funded by the US Department of Defence (DOD) (1963–1967) and has been a major strand within innovation research since then.

However, there are situations in which hindsight as a research strategy is not feasible. Innovations can span many years (as also Project Hindsight found out) and empirical research, which is done on emerging innovations, seldom has the opportunity to follow the process to its end in order to be able to look back. But, there are also more fundamental reasons to abstain from the wisdom of hindsight. Already, the DOD's Project Hindsight was criticised for its 'certainty bias' because it ignores "the failures, blind alleys and perplexing alternatives which are so much a part of the innovative process" (Kreilkamp, 1971, p.56). Indeed, how do we know whether the measures appear successful because of the success of the innovation or the innovation became successful because of the measures? And, even if we could distinguish between cause and effect, do we not ignore an important aspect of innovative actions, which is its perplexing uncertainty, when we analyse innovation only in hindsight? Moreover, what are the criteria for determining that an innovation has reached its closure so that it can be studied ex post? What about examples in which things and processes are constantly developing?

In this paper, I take these doubts as the starting point for a study of uncertainty in sustainable innovation. The goal is to discuss innovation theory on par with the knowledge/ignorance of the innovators and their strategies to deal with uncertainty.

Innovation theory leaves us not unprepared for this task. I will start with a brief recapitulation of those innovation models that attempt to get uncertainty under control. Leaving the unrealistic assumption of linearity behind, they have dealt with that which cannot be planned by injecting more and more elements of uncertainty into their models. These contributions promise to regain control by acknowledging and defining certain areas of randomness and complexity. With the concern for sustainability as extrinsic motivation for innovation, an even more fundamentally open approach was advocated, which, as I will argue, challenges the very idea of innovation as being a process that is controllable in the last instance.

I will then discuss two sustainable innovations: advanced daylight systems and the so-called Shecco technology, cooling/heating based on CO₂ as working fluid. Neither

of them can be called groundbreaking in any sense. They reinvent the wheel, meaning that they do what other technologies already do, but they do it in a more energy-efficient way. In this situation, which is typical for sustainable innovations targeting existing infrastructure, they indeed encountered uncertainty as a major obstacle – especially when compared with the certainties of the status quo. And they employed different strategies to deal with this uncertainty, which I will call

mainstreaming and substitution.

The scholar of innovation and the innovator encounter similar problems if the scholar is not able or willing to construct certainties from an ex post perspective. In the conclusion of this paper, I will discuss how the innovators' strategies can inform models trying to deal with uncertainty in innovation.

Uncertainty in innovation

Lane and Maxfield (2005) distinguish three kinds of uncertainty: truth uncertainty, semantic uncertainty and ontological uncertainty. Uncertainty about the truth or the semantics of a statement can in principle be reduced by deliberation or method: actors

can agree about sticking to certain standards for truth and meaning. The third kind, ontological uncertainty, however, goes deeper touching actors' beliefs about "what kinds of entities inhabit their world; what kinds of interactions these entities can have among themselves; how the entities and their interaction modes change as a result of these interactions" (Lane and Maxfield, 2005, p.10). In certain situations, entities and their relations change that rapidly that these beliefs become inherently unstable. Lane and Maxfield suggest that innovation is one of these situations: by creating new entities and/or new relations between entities, it is inescapably dealing with ontological uncertainty. Innovation theory has from early on struggled to provide innovators with tools and knowledge that enable them to know which entities and relations will be relevant in the future. In this section, I present some examples of these.

Certainty despite uncertainty

Linear innovation models – no matter if they were actually once widespread or not (Asner, 2004; Edgerton, 2004) – deal with uncertainty by simplifying innovation into unrealistic cause-effect relations. It is therefore not surprising that the history of research on uncertainty in innovation processes starts with a departure from the linear models of innovation.

Kline's chain-linked model (Kline and Rosenberg, 1986) and Leonard-Barton's (1988) adaptation cycles defined themselves explicitly against the supposedly linear nature of older models. They introduced feedback links, recursions, and mutual dependencies of the various institutions/actors involved in innovation. In this way, they hoped to provide tools to manage the complex processes of innovation. In Leonard- Barton's model, for instance, a successful innovation is characterised by growing alignment between technology and organisation, a process made possible through large and small adaptation cycles. Kline's chain-linked model is held together by a 'central- chain-of-innovation', which leads from design and development to marketing. For both Kline and Leonard-Barton,

complexity produces uncertainty. By proposing models that acknowledge the real complexity of innovation and that contain practical advice on how to decrease complexity, they seek to regain control.

This also applies to Reinertsen's 'fuzzy front end', popularised during the early 1990s (Smith and Reinertsen, 1991), which describes activities that take place prior to more formalised innovation activities as being characterised by a high degree of uncertainty. The promise here is that controlled openness and informal approaches produce a better starting point for an innovation process, which then allows to be controlled more effectively in later stages and consequently shows higher success rates (Kim and Wilemon, 2002). A typical activity located in this preparatory stage is the initial choice of a promising new product (Zhang, 2001).

Specifically studying the relation between order and randomness in innovation, Cheng and Ven (1996) tested two widespread but contradictory assumptions: innovation as (a) a periodic sequence of stages and as (b) a series of events that follow blind random. They concluded that neither order nor blind random is prevalent, but something, which is neither orderly and predictable nor stochastic and random. Again, they found that uncertainty was particularly high only in the beginning of the innovation journey (Cheng and Ven, 1996, p.607).

Similarly interested in the relation between random and systematic change are evolutionary approaches (Nelson, 1995; McKelvey, 1997). Here, random variation provides the grounds for the selection of successful 'species' (firms, innovations, etc.), i.e. both systematic events and random ones occur: the "systematic ones act by winnowing on the random ones" (Nelson, 1995, p.55). However, as Nelson acknowledges, the hope to be able to explain or even to predict successful selection of innovations rests on the possibility of a systematic theory of selection events.

Sustainability and open-ended innovation

In the last instance, innovation is a goal in itself for the innovation theories presented so far. The innovation journey is finished when the innovation is implemented. What happens then does not matter. This is different in discussions that add extrinsic motivations for innovation. A desire to achieve sustainability, for instance, has to focus on what an innovation does after it has been implemented. After all, the unintended consequences of past innovations are one major reason to reach for more sustainable technologies in the first place.

This focus on consequences introduces a more specific meaning of uncertainty: unintended consequences connected to ecosystems and human-environment relations. To deal with these uncertainties, flexible approaches were proposed, which treat sustainable development as an open process instead of a predefined goal (Folke et al., 2002; Newman, 2005). To achieve this, reflexivity (Voss and Kemp, 2006) and open interaction (Sørensen, 2002) were advocated, which anticipate

that an innovation strategy may change fundamentally by reacting to emerging conditions.

Sartorius (2006), in the same vein, introduced the concept of second-order sustainability, which is defined as the flexible ability to innovate. He distinguishes between “specific problem-solving capacity of certain innovations” which may be sustainable “in specific circumstances and for limited periods of time” and an adaptive flexibility which “brings about sustainability in more general terms – in the long run and in dynamic contexts” (Sartorius, 2006, p.278).

An example for how adaptive flexibility, open-endedness, and reflexivity can be achieved was described by DeLaet and Mol (2000). In their account of the Zimbabwean bush pump, they describe in depth how the technology is kept in a ‘fluid’ state by its inventor-engineer. For instance, all technical details are open to modification by its users and fed back into the development process. This ‘fluidity’ is not only the result of these feedback loops, which were also present in the discussions recapitulated above. It is also produced by the active inclusion of the technology’s material and social context. By designing into the pump extensive user participation in implementation, the technology can become subject to unexpected adaptations.

The accounts presented in the previous section tried to reincorporate loops, adaptation, fuzziness, and random variation into a more steady flow of time from the object’s non-existence to its existence as a fully developed innovation. The idea that sustainable innovation has to be reflexive, adaptive, ‘fluid’, aware of its consequences, and therefore open-ended represents a departure from the hope that the uncertainties of innovation can eventually be controlled.

Studying uncertain futures

The doubt concerning the ‘certainty bias’ of ex post studies leads to a focus “on the knowledge actually used in the course” (Faulkner, 1994, p.435). This entails a rigid agnosticism concerning the future of the innovation under study. In fact, whether a technology becomes an innovation or not is not particularly relevant, when one studies activities that are meant to innovate. The second methodological principle that follows from what was said so far is a strict adherence to induction instead of deduction. To decide into which category the studied phenomena belong, for instance, whether they are incremental or radical innovations (Hellström, 2007), is impossible, since this depends on characteristics which these technologies in their emergent state cannot have – yet. However, we can study the respective ambitions of the actors trying to innovate. For this study, I have selected two (sets of) technologies, advanced daylight systems and CO₂- based heating and cooling technologies (then marketed as ‘Shecco Technology’). These share a couple of characteristics:

- Both promise to be more energy-efficient alternatives to existing technolo-

gies in buildings.

- Both claim to offer additional environmental benefits.

They are clearly the brainchildren of engineers and architects, who want to make a difference in environmental terms: they want them to become sustainable innovations, correcting unintended consequences of earlier innovations. Three further commonalities make these technologies particularly interesting in the context of the present paper:

- Both have been around for quite a while but have been replaced by less energy-efficient alternatives in the course of the 20th century.
- Both have been rediscovered by enthusiasts during the 1970s and 1980s.
- Both have already been employed broadly but are still awaiting their final breakthrough (at the time of the field work: 2006), which may or may not come.

These characteristics placed them in a field of emergence, which made it impossible for the observer (in fact, for everyone) to decide whether these technologies will become successful innovations. They may as well become failures and give way to competing technologies.

The actual data collection took place in 2005 and 2006. Besides the usual analysis of technical and marketing documents, I have also interviewed 14 experts from four countries (Austria, Denmark, Germany and Norway), who were all involved in the implementation of one of these technologies, either as researcher, lobbyist, or company man. Additionally, I visited three daylight laboratories in Germany and Norway. Snowballing was used in order to find and get into contact with experts. This method is particularly useful when studying small populations, which can be expected to be closely connected. Usually, the goal of snowballing is to study the entire population defined by the sampling frame (Sudman and Kalton, 1986, p.413). Because of the principally open character of the present inquiry, the sampling frame had to remain open as well.

CO2 in the twilight zone: substitution

The story of sustainable innovations in the field of working fluids used for heating and refrigeration starts with a marvellous success for sustainability: in 1987, shortly after scientists had discovered a growing ozone hole over the Antarctic, the Montreal Protocol saved the ozone layer. This was achieved by substituting chlorofluorocarbons (CFCs) with hydrofluorocarbons (HFCs), now the most usual working fluid. There is one problem with HFCs though: they are greenhouse gases, i.e. they contribute to global warming (Kroeze and Reijnders, 1992).

Ups and downs

One of the possible alternatives is CO₂, which additionally offers improved energy efficiency in certain applications. While HFCs are produced specifically to be used as working fluids, CO₂ is generated in industrial production anyway and can be sequestered from existing emissions. This is similar to other technologies which promise carbon capture and storage with the added value that the CO₂ is actually doing useful work while being stored. In this sense CO₂ may even gain value in its own right while emission trading today is based on the premise that CO₂ is dangerous waste which has to be avoided. Here, my first empirical case comes in:

“At the end of the 1980s, Professor Gustav Lorentzen, from the Norwegian niversity of Science and Technology, took up the old idea of using CO₂ for heating and cooling. Previously, in the early days of refrigeration technology, CO₂ was a popular working fluid. It disappeared from the market in the 1940s mainly due to technical problems. Containing the high-pressure charge inside the system was not an easy task, and leaks were common. In the autumn of 1988, Professor Lorentzen got an idea for a new, simple, and efficient way of regulating CO₂ systems. This became the turning point in the reinvention of CO₂ technology.” (<http://www.shecco.com/about/history.php>, visited 06/04/2008)

This is how Shecco (Sustainable HEating and Cooling with CO₂), the main protagonist in my first story, described the prehistory of their ‘Shecco technology’. Lorentzen patented his idea in 1989 and, one year later, he sold the commercial rights to Norsk Hydro ASA, a Fortune 500 energy and aluminium supplier. According to Rolf Marstrander (2003), former senior vice president of Norsk Hydro, it was the aluminium branch of the company, which hoped to gain from the acquisition of the patent. Besides being a producer of aluminium, Norsk Hydro was involved in downstream activities, i.e. all kinds of business that involve the use of aluminium. Here, CO₂ with its larger pressure seemed to provide an opportunity in the ‘high risk – high profit quadrangle’. Shecco, now an independent company, was funded as part of various divisions within Norsk Hydro to exploit commercial potential of the patent.

The rest of the story according to Shecco is rather straightforward:

“The first commercial breakthrough came in the year 2000 with the introduction of Heat Pump Water Heaters in Japan, under the name of EcoCute’. [...] As CO₂ technology becomes a serious alternative in different applications and segments, Shecco is responding to the needs of its customers by offering a wider range of services to ensure a triple benefit: win for the industry, win for the consumers, and win for the planet.” (<http://www.shecco.com/about/history.php>, visited 06/04/2008)

Besides the backing of a major industrial player, another important factor in the CO₂ story is the close link to research, particularly SINTEF Energy Research in Trondheim. Even though Lorentzen's (re-)invention was not dramatically new, it still had to be realised, which was done for instance in a number of PhD theses since 1988 and in international research networks such as the EU-funded COHEPS (1995–1998) and COHEPS II (2000–2002). The researchers involved in these and similar activities told me about their early enthusiasm, when everything looked like they had the working fluid of the future in their hands.

However, this is not the whole story. At the end of the 1990s, it had become clear for Hydro Aluminium that the invention would not generate new business, “[i]t was even argued that the fact that Hydro Aluminium was working on the development of the Shecco technology was counterproductive to their present markets” (Marstrander, 2003, p.8). Around the same time came Norway's first commercial installation of a CO₂-based heat pump, which produced hot water for an egg plant in Larvik – and disappeared, because someone had used low-grade oil for maintenance, destroying the compressor. The other major use case, mobile air condition, did not develop as expected either: the CO₂-based system, in the beginning of the 1990s optimistically dubbed ‘MAC-2000’, is still waiting for its commercial breakthrough.

These and similar problems are not surprising at all. Very few innovations proceed in a linear fashion straight from invention to use – if they did, this text was obsolete. Moreover, Project Hindsight's successor, the Traces Project (Battelle, 1973) showed that innovative transfers from research to market – if they happen – take place within a timeframe longer than the 20 years of the CO₂ story.

Of cars and bottles

The main problem of CO₂ as a substitute of less sustainable working fluids is that there are other alternatives. They all have their disadvantages: hydrocarbons and difluoroethane (HFC-152a) tend to burn and explode and ammonia is highly poisonous. Compared with them, CO₂, however, has one major disadvantage: Nobody earns money from selling it, whereas others, especially the so-called F-gases – hydrofluorocarbons (HFCs), perfluorinated carbons (PFCs), and sulphur hexafluoride (SF₆) – are backed by a powerful lobby. In January 2006, DuPont, one of the major producers of these synthetic refrigerants, announced completely new refrigerants with low global warming potential (GWP) and which additionally ‘are expected to be compatible with conventional hydrofluorocarbon (HFC) 134a automotive air conditioning systems with the potential for only minor modifications’.

Shecco supported the new technology in order to earn money in the future. Their gain, however, would mean losses for other even bigger actors. Such a situation,

in which a lot of money is at stake, is created by the logic of mass substitution: the cost of one unit may be small, but providing the refrigeration technology for Coca Cola's nine million bottle coolers, or for every new car sold in Europe, amounts to big business.

The struggle for the future's mobile air condition got heated in May 2006, when the European Parliament and the Council signed a Regulation 'on certain fluorinated greenhouse gases' and a directive 'relating to emissions from air conditioning systems in motor vehicles'. These ended the fierce battle about the ban of HFCs in Europe. For Shecco's CO₂ technology, the favourite of the environmentalists, the outcome was disappointing. Not only would the ban for HFCs in mobile air condition (which is particularly prone to leakage) not come before 2011, when some of Shecco's patents already have expired. Additionally, with a limit of 150 for the GWP of refrigerants, HFC 152a, one of the chemical contenders (GWP 140) is just acceptable, according to the new EU rules.

Around the different steps leading to this decision, PR firms, such as Hill & Knowlton, hired by the chemical industry, and a lobby group called 'European Partnership for Energy and the Environment' were working to get the f-gas industry's point of view across. On the other side, Greenpeace and other primary and 'secondary stakeholder' actors (Hall and Vredenburg, 2003) tried to move the parameters of the rules into their direction. Also, Shecco was there. As one representative (interview co7) told me, they drove members of Parliament around in Brussels in a prototype car air-conditioned by CO₂ to show its feasibility.

National governments or, in this case, supra-national bodies like the EU are in principle powerful enough to force an innovation into being (Schot and Rip, 1996, pp.258–260). In our story, however, the Parliament and its committees weighed economic, safety, and environmental concerns in a way that prevented change.

Greenpeace played an even bigger role in another application of CO₂ technology: bottle coolers. In 2000, before the Olympic Games in Sydney, pressed by Greenpeace, Coca Cola promised to replace HFCs in refrigeration by the Athens Olympic Games in 2004. By the end of 2006, 6000 units with CO₂ refrigeration had been placed in markets throughout the world – which is of course far from the complete phase out which was promised. In the case of a global player like Coca Cola, with some 9 million coolers and vending machines in the marketplace worldwide, its power could help to create de-facto standards, which are independent from national or supranational regulation. They could force the production of equipment and components of the new technology. Additionally, they are fundamentally dependent on the image of their trademark, which is why they are approached by Greenpeace and other secondary stakeholders. On the other hand, they have an obvious interest in avoiding the 'creative destruction' of rapid innovation by substitution. While switching from CFCs to HFCs involved a simple shift in chemicals, giving HFCs up would require a more expensive shift to new equipment. More importantly, it would place new actors in central positions and marginalise others. Therefore, it made sense for the company to wait and see how the overall market develops. In an interview with a senior

researcher at a major producer of components (interview co3), I encountered a similar description of dependencies. Asked for the state of the Coke story, he answered that they have the components ready. Now it would be up to the major producers of cooling cabinets to move. The way from a working prototype to a competitive product, according to him, is 95% of the whole innovation. Moreover, he vividly described how “in an industry segment, where firstly not much money is to be made and where secondly a technology exists, which works very well” incremental improvements of existing solutions are much more attractive than a bolder move, such as towards CO₂ technology.

Again, thus, the status quo was more resilient than one might expect. Who could move the substitution to its tipping point if not the huge actors of (super)state and transnational companies?

Actors in varying sizes

Whether CO₂ some day will be the ‘R2000’ of which SINTEFs researchers were dreaming is not up for this paper to decide. Potentially competing refrigerants are impossible to foresee in their developments. The struggles between technology, business, and politics continue. Connected to the expiration of the patent, in 2007, Shecco spun off from its powerful mother Norsk Hydro and became an independent consultancy promoting CO₂-related technologies. Thus, they now act as one actor of many within the web of mutual dependencies between business customers, politics, technology, component producers, and equipment manufacturers, which we have encountered in our study.

In 2009, a commercial building showcasing a CO₂-based heat pump is built in Norway. Substitution of R-132a with CO₂ would have replaced one well-functioning network with a new one, in which SINTEF and Shecco probably would have had key positions, while others would have lost their influence. Secondary stakeholders, like Greenpeace, in concert with politicians and those global players which are dependent on a polished trademark, stand in these struggles against the collective resistance of the status quo. The first story, thus, as it was presented here, is one of large potential profits, in terms of power, money, and environment, but also of how these profits were not realised. Instead, the innovation moved on, taking different shapes as a bottle cooler or a heat pump. It is now part of a larger ecosystem of competing solutions; it neither has disappeared nor has the large substitution made to happen. Uncertainty prevails.

Daylight in the twilight zone: mainstreaming

There are some 20 artificial skies in Europe, but one of the largest, the one at the Technical University of Berlin, is hardly ever used anymore. My informant, who gave me a tour of the structure, which fills a large hall blotched with cables,

told me with a smile that he and his colleagues already thought of using this half-spherical structure, with its thousands of light bulbs, to provide a service for jet-lagged business travellers (interview dl2). At other places as well, such as at the Technical Universities of Trondheim and Munich, artificial skies nowadays find themselves used more and more for teaching purposes and less for research.

This has not always been so. There were high hopes in the 1980s when they were thought to become a central tool within an imminent renaissance of daylight as lighting source in buildings. After many years of steadily escalating use of artificial lighting, the energy crises of the 1970s, a growing interest in ‘natural’ solutions, and a more scientific approach to daylight producing ‘advanced daylight systems’ were expected to create a backlash in favour of natural light. Artificial skies sought to capture the unique quality of daylight in controlled laboratory settings.

In German-speaking countries, an early proponent of advanced daylight systems was an Austrian engineer and entrepreneur, Christian Bartenbach, whose Licht-Labor (light laboratory) near Innsbruck over the years has trained a host of light consultants who are working all over Europe. Bartenbach’s approach, which combines innovation in individual projects, a strong emphasis on a scientific approach to light, and the conviction that holistic solutions which combine artificial and non-artificial light are needed, was shared by all my informants.

Contrary to the interviews with CO2 experts, the informants on daylight systems reflected less about external enemies, heroic events, or organisational history than about their own problems balancing three trade-offs.

The first trade-off, which was mentioned in the interviews, was between feeling and measuring. What has happened in Berlin and led to the demise of the artificial sky was that light technology research was merged with informatics around 2003, which shifted the focus to control technology and digitised simulations. In opposition to this, the irreducible quality achieved with physical models within the light dome was emphasised by the informants from Trondheim and Munich; both skies are located at the architectural faculty there, which seems to be beneficial to them. That a balance between measuring and feeling light was desirable was a topic in every interview, which was conducted with advanced daylight systems as topic. A light consultant called this balance to do both design (‘Gestalten’) and engineering (interview dl5). The overall tendency expressed in the interviews seemed to confirm the trend taking place in Berlin. As one senior manager of Bartenbach’s firm told me, the earlier focus on aesthetic qualities of daylight has, since 2000, made room for a stronger focus on measurements mainly in relation to energy consumption (interview dl4). He acknowledged that this was now a major driver for the implementation of daylight systems. But he also stated his discontent with this development, which according to him has shifted the focus away from the well-being of occupants. The renewed focus on energy conservation was also, in another sense, a blessing and a curse for daylight enthusiasts. Since a multiple of the energy saved by large light intakes may be lost as heat, the certainty and control gained by measurements comes at

the price of having to negotiate with other concerns which once were outside the daylight consultant's responsibility such as heat loss. Within these negotiations, according to my informants, the aesthetics of daylight is still mobilised but it now has to be balanced with a regard for energy measurements.

The second trade-off was encountered between tailor-made solutions and advantages from the reuse of components. The light consultants, often with a background in engineering, acknowledged the importance of the unique impression of illuminated space, which is a sum of materials, architecture, and artificial and non-artificial light. The common tenor was that a beneficial balance has to be struck every time a building is built. Bartenbach-trained consultants base their work on the premise that tailored solutions work best for a given building, which demands the involvement of a light expert in the early stage of the planning and building process. Here, a certain frustration echoed the demise of the artificial sky in Berlin: even though light and daylight are always mentioned prominently in architectural competitions, the expertise represented by the informants, according to the interviewed senior manager at Bartenbach, is less frequently contracted today than in the 1990s (interview dl4). He assumed that some of the reasons for this paradox lie in the success of Bartenbach's work, the advantages of conscious (day)light planning for both energy budgets and the occupants' well-being are common knowledge today; with increased cost pressure, however, the industry is not willing to invest in sometimes very expensive tailor-made solutions.

These tailor-made solutions were also mentioned in another respect as the source of a third trade-off related to advanced daylight usage. The informants agreed that, besides the cost, there is another problem with the components used: components are not mature and often prone to technical failure. A lobbyist for daylight use in Germany admitted that there have often been problems in electric motors driving advanced shading systems, which is because of the difficult and subtle mechanics used there (interview dl6). Teething troubles were mentioned also by other informants as one of the obstacles against daylight (dl5 and dl7). Similar problems exist with heat-absorbing windows, which still obstruct the natural spectrum of daylight. On the other hand, getting the components into the market is the only way of getting experience, reducing the price, and improving the quality. This lack of robustness may also be one of the reasons for so much 'science fiction' – technologies and components which are talked about but which do not exist in practice. The problem certainly is aggravated by conservative norms and regulations, which are based on proven technology. Therefore, two of the informants lobbied actively for daylight-friendly standards within national and international standardisation bodies.

Summarising the findings of this case study we can say that the informants described that they had to walk a narrow path between

- innovation and standardisation,
- success and watered-down results, and
- measuring energy savings and the occupants' well-being.

In this case study, central actors were less easily identified than in the first case. Bartenbach's business, according to one of his senior managers, owns hundreds of patents, which is in stark contrast to the one patent on which Shecco's innovation is based. The relation between implementation and idea is turned around: Bartenbach and his co-workers usually develop solutions for specific locations, which are patented afterwards.

The main actor encountered promoting advanced daylight usage were smaller businesses of self-employed light consultants. This matches the focus on holistic but tailor-made approaches to individual buildings. Collaboration and compromise with competing technologies, above all artificial light, but also HVAC engineers and structural designers were mentioned by all informants as desirable and necessary.

The use of daylight, I was told by two informants trained by Bartenbach, today is usually seen as a natural part of architectural design. These interviewees, however, were sceptical towards this 'success': architects who try to sell their buildings, they said, often only pay lip service to the positive associations connected to natural light. When the building eventually is built, the respect for daylight is the first thing sacrificed on the altar of economy and short-term thinking dominating the building industry (interviews dl4, dl5). Thus, at least, according to these informants, daylight systems – similar to CO₂ in the story told above – has neither realised the hopes nor disappeared. Uncertainty about the future prevails here, too.

Mainstreaming and substitution

The empirical study of innovative activities connected to Shecco technology and advanced daylight systems revealed different strategies, which I propose to call mainstreaming (daylight) and substitution (CO₂).

Mainstreaming is a metaphor borrowed from a specific set of successful strategies to achieve gender equality. Gender mainstreaming was characterised by placing women at places where decisions are made instead of making them the subject of decisions (Anderson, 1993). This entails a shift away from a particular focus on special 'women's issues' toward a more taken-for-granted inclusion of women's rights into the whole array of political issues. Gender mainstreaming has carried gender issues into national and above all transnational policies (True and Mintrom, 2001), and can therefore be called successful. At the same time, there is substantial criticism against mainstreaming as dilution of central issues of the original feminist critique of the status quo (for an overview, see Walby, 2005). The innovation strategy observed in the case of daylight systems resembled this kind of mainstreaming in both its strengths and weaknesses.

It tried to make the daylight consultant and his or her concerns a natural part of all building activities, accepting that the original efficiency goals become diluted

within all too many compromises and lip service.

Substitution, Shecco's strategy, did not compromise from case to case but sought to replace the worse with the better. Just as HFCs have replaced CFCs, CO₂ was expected to replace HFCs. However, as we have seen in our case, it met powerful opposition and did not succeed.

Both mainstreaming and substitution contained elements which helped to deal with the fundamental ontological uncertainty. They each contained elements which helped to deal with the fundamental ontological uncertainty described by Lane and Maxfield (2005) as well as with the more specific problem of unintended consequences posed within sustainable innovation.

Substitution was accompanied by the traditional power play, where both primary and secondary stakeholders, researchers, and politicians were enrolled in order to create predictable conditions for the impending change. In terms of technology, it promised to substitute only one component, leaving the rest of the system untouched, thus reducing the possibility for unintended consequences. In this way, it would act behind the scenes only, changing the component which is unsustainable, while providing the same or even better comfort. The Shecco case showed that this strategy, nevertheless, can produce severe resistance from actors who are to be replaced if the innovation succeeds.

Mainstreaming avoided unintended consequences through careful adaptation from case to case, seeking to achieve the best possible outcome in any given situation. Here, no great power play was involved. Instead, local negotiations were sought, which involved all relevant actors encountered in the respective project. Technologies employed here were much more open than in substitution; they consisted of many patents and open solutions instead of one patent and were adapted to local needs and conditions.

Conclusion

The observations presented here do not fit well with the innovation models discussed above. Compared with the back and forth of these two technologies, their shifting shape, and their precarious balances, the models still seem too orderly when they only allow for a certain degree of randomness and nonlinearity. This mismatch between empirical observation and model can be seen as a problem of the model or as the problem of the technologies which were studied here. From the latter perspective, both technologies have not managed to overcome episodes of fuzziness and chaos, resulting in failure as innovations. They are the error within the trial and error of innovation. They have lost the power struggles and left behind their identity in shifting alliances and local adaptation. From this perspective, the mainstreaming observed in the daylight case appears as misguided from the outset. Substitution, the strategy of Shecco, did at least try

to make a difference, whereas mainstreaming was content with getting limited impact on the local level of the individual building.

From the perspective of open-ended innovation as a flexible adaptation, however, mainstreaming is a viable strategy in its own right. Its careful work with balancing trade-offs on the local level may be as successful an innovative activity as the power play of substitution. Which one of these strategies is better suited to amend unsustainable infrastructure cannot be answered on the basis of the cases presented here. So far, both strategies may have been disappointing compared with the high hopes of the 1980s, but we have also seen that CO2 technologies and daylight systems have managed to challenge the status quo – at least up to a point.

On a more fundamental level the question of success may warrant a further qualification. De Laet and Mol (2000) conclude their text with the submission that ‘fluid’ technologies may not fit at all into the binary opposition of success and failure. After all, a technology may work in some respects and contexts and fail in others. The same can be said about ‘mainstreaming’ as innovation strategy. The local implementation of an advanced daylight system in a specific building, no matter how successful it turns out to be, cannot guarantee that the same system will work as well in another building. Thus, while substitution lends itself much to a judgement that determines its overall success or failure, mainstreaming has to be judged on a case-to-case basis.

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Appendix:

List of interviewees

Code co1 co2 co3 co4 co5 co6 co7 dl1 dl2 dl3 dl4 dl5 dl6 dl7

Function Researcher, NTNU, Trondheim, Norway Researcher, SINTEF, Trondheim, Norway R&D manager, component maker, Copenhagen, Denmark R&D manager, car industry, Stuttgart, Germany Researcher, Sintef, Trondheim, Norway Researcher, TU Graz, Austria Manager, Shecco, Norway Researcher, NTNU, Trondheim, Norway Researcher, TU Berlin, Germany Light consultant, Moosbach, Austria R&D manager, Bartenbach LichtLabor, Austria Light consultant, Hamburg, Germany Light lobbyist, Köln, Germany Light lobbyist, Ehningen, Germany

When 9/2005 10/2005 11/2005 12/2005 12/2005 01/2006 03/2006 10/2005
12/2005 12/2005 05/2006 05/2006 06/2006 06/2006