

Preparing for New Solar Cells through Integrated Research: Challenges in Translating Social Robustness into the Selection of Materials

Heidrun ÅM¹ and Knut H. SØRENSEN²
*Department of Interdisciplinary Studies of Culture,
Centre for Technology and Society,
Norwegian University of Science and Technology, Norway*

Abstract. Research policy and research councils increasingly demand responsible innovation and socially robust knowledge. But what does that imply? Theories say little about how to translate social robustness into practice. In this chapter, we report from an integrated project on solar cells where Ethical, Legal and Social Aspects (ELSA) oriented scholars interacted with material scientists. The aim of the project was twofold. First, to achieve social robustness in the selection of materials for new solar cells. Second, to enact socially robust research. This chapter shows how considerations for novel solar cell materials widened from toxicity and efficiency considerations to a broader set of considerations. The latter contributes to the Science and Technology Studies and ELSA communities. In particular, we suggest transgressing laboratory-based engagement studies by introducing a use perspective through methods such as what we call dialogue meetings. For this, we have drawn on Latour for theoretical inspiration and for suggestions of practical implementation.

Keywords. Social robustness, solar cells, new materials, dialogue meetings, integrated research.

Introduction: assembling an integrated project

Increasingly, science policy strives for responsible innovation and for enhancing public deliberation related to emerging techno-scientific developments. In the course of such efforts, the Research Council of Norway funded four Ethical, Legal and Social Aspects (ELSA) projects in 2011 (see, also, Nydal et al., 2012), marked by close collaborations between former separate research communities, such as—in the case of our project, ‘Socially Robust Solar Cells’ (SoRoSol)—materials sciences, industrial economy, science and technology studies (STS), and philosophy.

¹ Corresponding author. Email: heidrun.aam@ntnu.no

² The research has been funded by Research Council of Norway (grant no 203503/O70). We have received very useful comments from Margrethe Aune, two anonymous referees, and the editors, for which we are grateful. We also want to thank SoRoSol project manager Turid Worren Renaas and the rest of the team for a rewarding and friendly collaboration.

This chapter reports on this integrated project: how did we approach the integration issue, what worked, and what lessons may be drawn? It should be noted that the concept of integration in the call for grant applications was fairly open. The projects were to stimulate a balanced, interdisciplinary cooperation between scientists, humanists and social scientists, to create a mutual learning arena and to raise awareness about the co-production of science and society. The only concrete guidance was that the project should provide for reflection about values as well as monitoring of these reflections.

SoRoSol—funded by the Norwegian nanotechnology research program—responded to this challenge by aspiring to build a platform for socially robust development of high-efficiency solar cell technologies as a way of shaping the planned interaction within the interdisciplinary team, to trigger learning and change attitudes of the team members. The selection of materials to analyze was the main concern. The participating materials scientists would attempt to identify and assemble untried materials that would increase the efficiency of solar cells. The selection of such materials to be measured in terms of their efficiency to transform solar energy into electricity was to be influenced by considerations brought forward through exchanges within the project team. In this regard, our project responded well to calls for more context sensitivity and specificity in ELSA research. It is argued that future ELSA studies should distinguish between general ideas of nanotechnology and concrete applications (Nordmann and Rip, 2009). Such a focused approach is expected to provide for more meaningful interactions with scientists (Nordmann and Rip, 2009; Shumpert et al., 2014).

The initial project team consisted of seven professors, one research scientist, and two postdocs³ Material scientists—two professors and one postdoc from the Department of Physics—were at the core of the SoRoSol project. Their research goal was to develop so-called third-generation photovoltaics from appropriate materials. The physics professor managing the project had worked on the topic for many years, and her interest in advancing solar energy made her enthusiastic about high-efficiency solar cells. Also on the team were a professor (Sørensen) and a postdoc (Åm) in Science and Technology Studies (STS). The physics and STS postdocs were the only positions fully funded by the project. In addition, two philosophy professors specializing in applied ethics and two professors with a background in respectively system engineering and life cycle analysis participated. The latter two were to contribute to eliciting potential environmental, health, and safety (EHS) issues of new solar cells, but resources proved too sparse to allow much activity on this front.

While it was clear that the materials scientists' task in the project was to identify materials for high-efficiency solar cells, the roles of the remaining disciplines were less developed. The motivation of the ELSA scholars to engage in the project was to probe what the theoretical idea of socially robust research could mean in practice. In the context of analyzing the properties of new materials that could potentially be used in solar cells, how could social robustness emerge from interdisciplinary encounters within the project? In this chapter, we—the project participants from STS—show how an interdisciplinary exchange process could lead to (moderate) changes in the

³ All SoRoSol participants worked at the Norwegian University of Science and Technology (NTNU), except one research scientist from Stiftelsen for industriell og teknisk forskning (SINTEF), the largest independent research organization in Scandinavia, headquartered in Trondheim. However, this person left the team after the first year.

understanding of research problems when selecting materials for future solar cells. We start by introducing the theoretical framework underlying the integration efforts of the SoRoSol project and the sources for the subsequent analysis of the efforts to achieve social robustness.

1. The meaning and implications of social robustness

As implied in the project title, SoRoSol should lead to socially robust solar cell research. What was meant by social robustness, and how was it to be achieved?

The concept ‘social robustness’ as used in the grant application was taken from Gibbons et al. (1994) and Nowotny et al. (2001). It was born from the assumption that it is no longer sufficient that knowledge is reliable only according to scientific criteria. Indeed, in order to be able to trust scientific knowledge, society must have input into the science in one way or another:

‘Reliable knowledge, [...], will be tested not in the abstract, but in very concrete and local circumstances. [...] The reliability of scientific knowledge needs to be complemented and strengthened by becoming also socially robust. Hence, context-sensitivity must be heightened and its awareness must be spread. [...] One way to make science more context-sensitive is to bring in people’ (Nowotny et al., 2001:117).

Such ideas have a longer prehistory (see, for example, Rip, 2010), and they resonate with longstanding concerns with respect to science policy and technology assessment. A main issue is the relationship between democratic legitimacy and scientific authority (Guston, 2005). In the social contract between science and society emanating from World War 2 experiences, science and society were considered as rather separate spheres where communication and information first and foremost flow from science to society. In the new, socially robust contract that Nowotny et al. (2001) recommend, the opposite should also be true: society should talk back to science. To realize this idea, they introduced the concept of ‘contextualization’ (Nowotny et al., 2001). Contextualization transcends the immediate context of application; research activities should anticipate and engage reflexively with future, possible entanglements and imaginable social implications (Nowotny et al., 2001).

How contextualization may be achieved is not a straightforward issue. For example, Peter Weingart (2008) has criticized the idea of contextualization as vague and as ignoring the serious difficulties in actually achieving the underlying goals. He concludes that there is a need to search for new approaches to achieve the goal of changing the science-society relationship in the direction proposed by Nowotny et al. (2001:144):

‘The only escape from the difficulties of imagining institutional mechanisms of representing society vis-à-vis scientists would seem to be the implementation of a ‘socially responsible’ conscience in the individual scientist’s mind. Since that option is also not available (...) the focus must be on institutional mechanisms that process knowledge and values and interests at the same time’.

Weingart’s argument may be compared to Sheila Jasanoff’s (2004) idiom of co-production of science and society, and in particular to Bruno Latour’s (2004) proposal for a politics of nature. Latour’s idea is that scientific knowledge needs to proceed through a series of activities:

1. the development of issues or propositions to explore (Latour's term: 'perplexity')
2. broad dialogues to explore what may be considered an answer or solution ('consultation')
3. ranking of the answers or solutions ('hierarchy'), and
4. the establishment of a proposition as a fact ('institution').

These could be considered arenas where social robustness should be enacted in different ways. The shared idea of Weingart, Jasanoff, Latour, and Nowotny et al. is to find ways in which facts and values may impact each other, approaching the issue from the perspective of building new or reforming existing scientific institutions. Thus, integrated projects may be seen as experiments in developing new institutional mechanisms to such ends. The SoRoSol initiative, for example, was designed as a reform effort at the project level, to be based on an interpretation of primarily Nowotny et al. (2001), but also Latour (2004). Initially, socially robust technology was defined as 'technology that is transparent, socially acceptable and resilient regarding political and ethical scrutiny',⁴ Michael Gibbons (1999:C82) provides a compact outline of three main aspects of social robustness:

1. 'It is valid both within and outside the laboratory
2. Validity is achieved through involving an extended group of experts, including 'lay' experts, and
3. Because 'society' has participated in its genesis, such knowledge is less likely to be contested than that which is merely 'reliable'.

The SoRoSol project focused on the second aspect. The aim, as stated in the grant application, was to increase the reflexive capacity of the project team as a whole in the following manner:

'The goal is to make visible what, where and how choices are actually made, choices that are interconnected but could have been different. A distributed reflexive capacity would make the whole technology development process more socially robust in terms of being able to take broader sets of considerations and possibilities into account'.⁵

1.1 Method

How to achieve this aim? Two integration activities were highlighted in the grant application: first, the entire project group should meet monthly. The two STS scholars (Sørensen and Åm) attempted to shape project meetings into something like a trading zone (Galison, 1996), to exchange professional views on the issue and practice of selecting and measuring solar cell materials. With reference to Latour (2004), the exchanges were mainly concerned with perplexity and consultation. The monthly meetings were an important part of the initial strategy to achieve social robustness and increase the reflexive capacity of the whole research team. Second, the first author, Åm, was to work with the materials science postdoc in the laboratory. (We discuss our experiences with this ethnographic approach in another paper, Åm and Sørensen in preparation). The idea behind the laboratory study was that Åm should develop interactional expertise related to materials science (Collins and Evans, 2002) that

⁴ 'Integrated researcher project. Socially Robust Solar Cells (SoRoSol)', grant proposal, Trondheim: NTNU (2010:1).

⁵ Grant proposal (note 4) at p.7.

would enable the visibility and transparency of research choices as well as facilitating communication in the project. Åm recorded the activities of the project meetings and the collaboration with the materials science postdoc in field notes.

Åm further conducted a series of interviews with solar scientists in Norway and we also took part in a separately funded focus group study of the general public's engagement with low-carbon energy, where questions about solar energy were included. Some results from these studies were presented to the team, but with little impact because the results were not considered directly relevant for selecting materials. For example, the participants in the focus groups were more concerned with finding information on how to install solar panels or whether PVs could be connected to the grid in any kind of building.

We then decided to try to bring in other professionals working with the use of solar cells in various contexts to see if this would make use-related issues of selecting materials more tangible, extending the problem horizon as well as helping the translation between properties of solar cell materials and their potential social effects. The rest of the team also thought this was a good idea, and three such dialogue meetings between the team and solar cell application experts—one at a time—were conducted. In addition, a fourth expert was interviewed by Åm and the results presented to the team. These use focused and expert-based dialogue meetings are the main focus of this paper. However, we begin by providing details about the interdisciplinary dialogues in the project meetings and during Åm's fieldwork at the laboratory. Thus, the next section describes how we tried to explore the fairly general framework of socially robustness: what practices did we try out, and what did we achieve?

2. In search of social robustness

Let us begin by considering the point of departure of the materials scientists. Their work had two main aims. First, they wanted to demonstrate improved efficiency from using a new concept of intermediate-band solar cells. Second, they had to identify materials that could compose such an intermediate band. For the purpose of the SoRoSol-project, they had chosen to work with combinations of zinc. The kind of zinc combinations selected for further scrutiny should depend on the outcomes of the interdisciplinary cooperation in the project, as described in the grant proposal:

‘Depending on input from HSE considerations and the social and ethical aspects to be studied as described in sections 2.2.2. and 2.2.3., respectively, we will then focus on either the more problematic ZnSe:Cr (or ZnTe:Cr) or the less harmful, but more complex CZTS’.⁶

Hence, the selection of materials was already in the grant proposal presented as a nodal point for interdisciplinary cooperation, and the quote mentions that some of the materials under consideration could have harmful properties. Further, the quote shows that HSE and ELSA perspectives should be considered in the selection of materials. In order to be able to make this happen, we first had to study our materials scientists' existing strategies for selecting materials. Åm did this through the laboratory ethnography, but we also devoted a project meeting explicitly to this question. This meeting provided some important clarifications but also raised some new issues.

⁶ Grant proposal (note 4), p.3.

The goal of this June 2012 meeting, eight months after the project had started, was to discover moments of choice in the materials science research in order to find potential space for intervention. To structure the discussion, we tried to apply a protocol of four decision components developed through so-called socio-technical integration research (STIR) (Fisher, 2007; Fisher and Mahajan, 2006): define opportunity, define selectors/considerations, define alternatives, and define outcome. We drew on this protocol by coincidence. Åm reviewed the literature on integrated projects at that time and the protocol's focus on decision-making concurred with our wish of outlining how our collaborators usually set out to decide on new materials. That said, we used the protocol differently than intended by its developers. For us, it provided a tool to structure one discussion at one meeting, helping us map the possibilities for cooperation in the team. The outcome is illustrated in Figure 1.

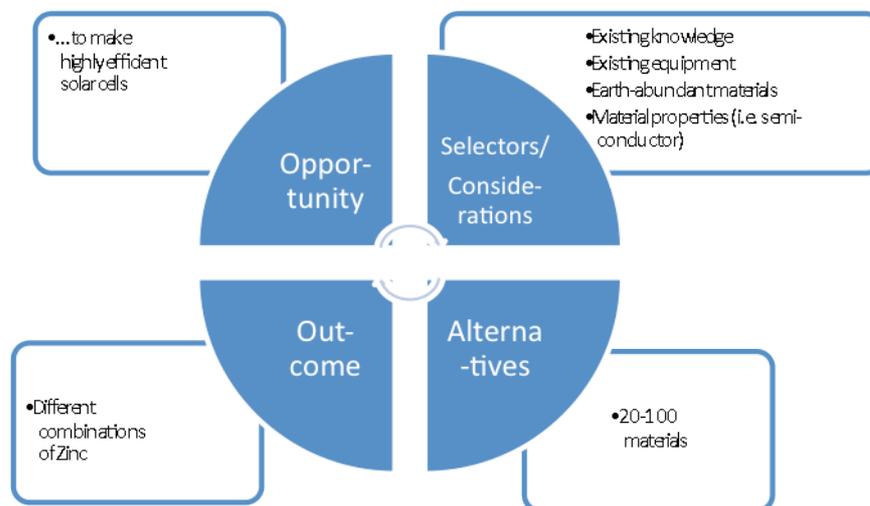


Figure 1. Components in the process of selecting materials.

The materials scientists presumed that the problem to be solved was low efficiency rates of existing solar cells. However, this framing disregarded that 'improving efficiency' might be an insufficient strategy for successfully implementing solar technology (Åm, 2015). Also, the criteria applied in the selection of materials were predominately technical. For example, potential candidates would need to display certain physical properties in order to be suitable for solar cells. Above all, they had to be semiconductors. Besides, existing laboratory infrastructure had a strong bearing on the selection of materials since the expensive equipment tends to be linked to a certain class of materials. Thus, the selection of experimental instruments limits the choice of materials for many years. Accordingly, people working with these instruments and the kind of materials that fit the experimental profile gain extensive knowledge about their instruments and about a limited group of materials that may create a path dependency with respect to future choices.

However, in our discussions, the materials scientists also presented criteria that resonated with social and economic concerns, for example that new materials should be abundant (not rare-earth materials). In addition, of course, the selection of materials was strongly guided by the leading research goal of improving solar cell efficiency. But

most interestingly, at this meeting eight months into the project, our collaborators announced that they would consider only nontoxic materials. How did that come about?

In the decision-making discussion during our June meeting, the materials scientists in the team denied that they earlier had considered toxic source materials. While the materials scientists did not make a big fuss out of this, the four ELSA scholars ‘encountered that funny feeling of finding an anomaly’ (Star, 2010:605). They felt that the materials scientists were now contradicting what they had said some months ago and what had been written in the grant proposal (see the quote of the initial statement above). At the meeting, the materials scientists presented this decision as a concern for safety in the laboratory and as a way to reduce safety equipment costs. They added that it probably was an advantage with respect to later marketing efforts. After all, solar panels are situated within the attractive theme of environmentally friendly energy; people would probably prefer a nontoxic version, even if the toxic materials were encapsulated. The ELSA scholars in the project saw a result of a learning process, mirroring the presentations previously given by them.

The materials scientists initially denied this, but the project manager changed her story after the philosophers in the team repeatedly challenged her on this in the following monthly group meetings. In October 2012, for example, a master student had started to work with the solar scientists. The aim of the student’s project was to identify materials for future projects. Her list excluded toxic materials from the beginning. Also at this meeting, the material scientists did not recognize ELSA’s influence on this change of attitude. A few months later, however, the project leader confirmed in an email to Åm that they had dropped toxic materials because of the discussions in SoRoSol. Eventually, the whole team—materials scientists and ELSA scholars—agreed that this change in attitude was a result of team cooperation. Still, this example shows that learning in integrated projects may be difficult to measure, since outcomes are not always straightforward and clear-cut.

The scientists discarding the use of toxic materials was a first concrete result of SoRoSol, but the ELSA scholars were not satisfied with this narrow focus on risk governance. For example, we doubted that raising efficiency was the single main strategy to pursue in order to increase the use of solar energy. Social robustness should imply further considerations. According to Nowotny et al. (2001), contextualization means bringing people into knowledge production by asking a simple question: ‘Where is the place of people in our knowledge?’ We assumed that socially robust innovations have to be embedded in socio-technical practices of users. Thus, the question arose of how usability issues could be translated into criteria for selecting materials. In this manner, we extended ELSA’s traditional focus on technology design by introducing considerations regarding future domestication and social shaping of (solar) technology by users (Sørensen, 2004; Williams and Sørensen, 2002).

Consequently, the need for a method to map and bring in usability issues emerged. Gibbons (1999) suggests that:

‘This [the contextualization] might be done by identifying areas in which significant implications of particular research projects are likely to arise without being pinpointed exactly, making it necessary to ‘prospect’ for these (presently unknowable) implications. Such a process might, for example, involve consulting other knowledge producers and users, as well as wider social constituencies, in order to carry out a form of ‘triangulation’ survey’ (Gibbons, 1999:C84).

In other words, the task ahead appeared to be to find a way to bring in diverse stakeholders concerned with new solar cell technology into future application settings (Williams, 2006). With Latour (2004), we responded to this question by extending the consultation efforts within the team to include a group of external experts that were specialists in the use of solar cells in various fields. In this manner, we wanted to develop social robustness by discussing application-oriented socio-technical criteria of selected solar cell materials through dialogues beyond the project team since the input from the focus group study proved insufficient. We chose to solve the conundrum methodologically by suggesting that the project team should undertake a series of what we called dialogue meetings with experts regarding applications of solar cell technology. This proposal was welcomed by the whole team as a way of proceeding with the integration issues. In the following section, we give an account of this part of the project and the achievements.

3. Dialogue meetings as a method for integrated research

We have so far argued that providing for socially robust solar cells could mean simply bringing general society into the process. However, this is only an abstract suggestion and our previous efforts of achieving this aim through internal discussion in the team had not, as already shown, been very successful. The alternative strategy, the dialogue meetings, was a way to explore how usability issues could translate into socio-technical criteria guiding the selection of materials for future solar cells. The idea was to create through these meetings a platform to engage experts with presumably different experiences—and thus diverse perspectives—on end use of solar power. The point was to explore potential alignments among stakeholders such as architects, energy companies, consulting engineers, policymakers, and industry representatives with respect to criteria for selecting materials for solar cells. Alignment refers to the eventual entanglement of actors and activities to secure mutual dependencies (te Kulve and Rip, 2011:703). The meetings should also increase the reflexive capacity of the SoRoSol team by introducing new considerations about future challenges to solar cell technology development, which could produce new restrictions—or opportunities regarding the selection of materials. In this way, we wanted to elicit reflections in the team regarding such mutual dependencies and the need to align relevant human and non-human actors when developing and marketing new technologies. The underlying idea was to make the concern for social robustness more productive by eliciting what other criteria than efficiency that might be needed for a successful translation of solar cell technology research into innovation. Three dialogue meetings were conducted by means of inviting one or more guests at a time into our monthly group meetings. The group decided collectively whom to invite. The criterion was that they should be experts on the usage of solar energy or solar technology. In addition, one interview was undertaken where the results were presented to the SoRoSol team.

The first dialogue meeting was held in November 2012. We had invited Professor Anne Grete Hestnes, architect and professor of building technology at NTNU. She is a renowned expert in the use of solar cell technology in building design and a long-standing contributor to the field of sustainable buildings. The guiding question for this conversation was:

- What kind of properties of materials is important to consider for the use of solar cells in buildings?

In March 2013, we met Bjørn Thorud from a large Norwegian consulting engineering company, Multiconsult. Formerly an employee of Scatec Solar, Thorud was responsible for solar energy at Multiconsult and is renowned for his engagement and expertise in Norwegian solar energy use. The guiding question for the meeting with him was:

- What properties of materials promote the increased end use of solar power?

In May 2013, we met with representatives of Enova, a Norwegian publicly owned enterprise that promotes energy-efficient consumption and production of renewable energy. Enova plays an important role in the user implementation of Norway's policies for environmentally friendly energy. The meeting was set to explore:

- What role may new solar technology play in the Norwegian energy system?

At that time, Norway had no energy policy to advance the generation of electricity by means of solar cells. Thus, the meeting with ENOVA explored the possibility—or rather, as we experienced through the meeting, impossibility—of a future national home market for new types of solar panels.

In December 2013, Åm interviewed Alf Bjørseth. An icon of the Norwegian solar industry, he has funded and managed a range of renewable energy companies, among them the first Norwegian company to produce wafers for solar panels. As the incumbent solar industry was based on silicon solar cells, the interview aimed to elicit how willing (or unwilling) companies would be to alter the existing production infrastructures in order to use new materials as those the SoRoSol materials science group was developing. Thus, the interview focused on the question:

- What marketing aspects must scientists consider when they introduce new materials for solar cells?
- The results were reported and discussed at the subsequent project meeting. What was achieved through these meetings? Did they work as a vehicle to improve social robustness?

In analyzing the notes taken from the talks and discussions during our dialogue meetings, including the interview and how that was commented upon, four main themes emerged. Unsurprisingly, costs and efficiency proved to be important topics in most meetings, but this did not add much to the exchanges in the project team prior to the dialogue meetings. However, the additional themes did add a great deal. These were:

- Potential markets and market potential
- Sustainable and environmentally friendly materials, and
- Design and aesthetics.

In the following, we discuss how these themes contributed to increased reflexivity in the SoRoSol team.

First, the analysis of the outcome of the dialogue meetings pointed to the importance of the envisioned application context to understand the usability issue. The invited experts indicated that a promising, large future market for solar cells was in building-integrated photovoltaics (BIPV). Several Norwegian policy documents

indicated that a passive house level requirement might be part of future Norwegian building regulations. The 2012 Norwegian government white paper on climate policy proposes, for example, tightening the technical requirements for new dwellings to a passive house standard by 2015 and to nearly zero-energy buildings by 2020 (Meld. St. 21, 2012:13). Other countries and the European Union have similar regulation scenarios. Thus, building-integrated photovoltaics (BIPV) might become a large market also in Norway because it appears difficult to reach zero-energy building goals without local energy production by means of solar cell panels. An advantage of integrating solar cells in buildings is also that this can be cheaper than using other building elements, for example, for facades or roofs. Thus, solar panels as integrated building elements change the cost perspective for materials because solar panels can supplant some building materials.

Thus, building-integrated photovoltaics could make it easier to market new solar cell materials. More generally, dialogue partners recommended that R&D efforts in the solar cell area should provide solutions to problems—like making buildings produce energy—not be solutions searching for a problem. In other words, solar scientists should have in mind a client who would be interested in buying the product. This included aiming at niches or for producing solar cells for solar power plants. To engage with niche solutions might mean to engage in creating niches by identifying new areas of application. For niche products, higher costs might be tolerated, which reduces requests for materials to become more cost efficient. Of course, considering the dominance of silicon in the current solar cell technology market, one may ask whether there is a place for new materials such as those sought in the SoRoSol project. Whether a solar industry company invests in new materials will depend on its management's willingness to take risks. Regardless of whether one is going for BIPV or niches, we were told, the key is to develop a product with a particular market (inclusive producers and costumers) in mind and to adjust the innovation accordingly.

A second theme was the potential need for environmentally friendly materials, which the SoRoSol team interpreted to mean safe and abundant materials. The dialogue partners concurred that solar cells should not contain toxic materials. Environmentally friendly materials have a competitive advantage in green technologies and in an increasingly environmentally conscious building sector, as well as in other industries. Materials for solar cells that can be used in buildings will be easier to market if they fulfill the environmental assessment requirements of the building sector. The British Building Research Establishment (BRE) developed in 1988 an environmental assessment method (EAM). This is one of the most renowned environmental certification systems in the building market, applying a holistic user-perspective in order to evaluate how environmentally friendly a building is. BREEAM is Europe's leading environmentally classification tool for buildings, and many countries are adapting the standard to national conditions.⁷ BREEAM also lists problematic materials not to be integrated in buildings such as certain compounds of chromium and the ones used in SoRoSol's research could fall under this regulation. Although BREEAM is only a voluntary standard, it is prestigious. We were told that it seems unlikely that BIPV that are incompatible with BREEAM standards would stand a chance on the market.

Life cycle analysis (LCA) is—also beyond the building sector—increasingly becoming integrated decision tools (see, for example, Hertwich, 2010). Therefore,

⁷ Available at: <http://www.ngbc.no/?q=content/om-breeam>

nontoxic and environmentally friendly products with positive life cycle assessments are needed. Within LCA, lifetime is an important criterion because it influences the environmental effects of photovoltaic tremendously. To comply, it was explained to us, materials should be durable and robust in different weather. Generally, waste disposal was argued by the dialogue partners to be an important issue, and good recycling routines should be considered also with respect to solar panels.

Design and aesthetics emerged as the third important topic in the dialogue meetings. It was stated that architects' concerns about solar cells are mostly on the module level (size and shape) and thus not directed at the properties of the material used in the cells. However, scarcity of space is a major issue, at least in cities. This may produce a preference for high conversion efficiency in BIPV because it increases their area efficiency, dialogue partners said. Concern about size and shape implies a need for variety; for example, architects would like to have more choices on design features.

Our dialogue partners told us that solar cells on curtains or solar cells that operate window blinds might be considered aesthetically cool. Apart from that, architects may need to carefully consider the siting of solar panels on buildings, which depends on the surroundings, particularly with regard to shadows that could reduce the output of solar panels. For this reason, solar cells with wider angles are very interesting. In the future, translucence and transparency might also be attractive module properties, according to our dialogue partners.

From a design perspective, the SoRoSol project received the crucial information that concentrator PVs (which use optics to increase light intensity), such as the ones that the SoRoSol materials research group had been aiming for, were considered ugly. These kinds of solar panels might, however, still have a role in areas where land is inexpensive and the weather conditions sunny.

3.1 Summary

Which of the nontechnical criteria that emerged from the dialogue meetings could influence the future selection of solar cell materials of the materials scientists? The materials scientists concluded that their attention was in particular drawn to the opportunity of BIPV; previously, they mostly had considered solar power plants. In addition, the materials scientists became aware of what kinds of materials that could not be used in buildings when they learned about BREEAM and similar environmental assessment regimes. They also observed the need to consider such regimes before selecting materials for research projects. For example, their existing strategy to increase the efficiency of solar cell prototypes by using chromium appeared as potentially problematic since BREEAM does not allow for the use of certain chromium compounds in buildings. Consequently, the dialogue meetings confirmed the soundness of the previous choice to reject potentially toxic materials from the SoRoSol project.

Thus, the dialogue meetings succeeded at least to some extent in increasing the reflexive capacity of the SoRoSol team, above all by extending and diversifying the concerns recognized as relevant by the whole team to consider with respect to the selection of materials. This was achieved because the invited experts helped introduce in an authoritative manner more specific contexts of use into the discussions about selecting materials. While the ELSA scholars in the project previously had raised several of the arguments made by the dialogue partners, the arguments proved in subsequent discussion in the team to clearly have been more convincing when made by people recognized by the materials scientists as experts with respect to the potential use

of solar cells. In retrospect, taking the initiative to the dialogue meetings was probably the most effective move made by the ELSA scholars.

However, the impact of these meetings should not be overrated. Challenges of translating between social aspects and criteria for selecting materials for solar cells remained, even if we had made some progress. The main difficulty was the issue of relevance with regard to solar cell materials. What social and ethical concerns could be considered pertinent in the context of the SoRoSol project besides efficiency in transforming solar energy to electricity? Apart from toxicity, the dialogue meetings helped to show that some design issues with respect to future applications of solar power technology could be translated into selection criteria. The most important example was that of the concentrator PV, which according to the invited professor of architecture architects might not use because of its problematic aesthetic qualities. The materials scientists in the SoRoSol team accepted this message, and this profoundly changed their search strategy with respect to materials. The materials scientists treated other important design concerns, such as flexibility, bendability, softness, and color, to be less relevant to the process of selecting materials. Rather, they considered such issues to depend on the engineering of the cells (e.g., one could perforate cells to achieve transparency) rather than on the material used in the cells.

4. Conclusion: social robustness as a goal for integrated research

The aim of the SoRoSol project was integration between materials science, HSE, and ELSA scholars to achieve increased social robustness of solar cells, based on an understanding of social robustness of a technology as making it “transparent, socially acceptable and resilient regarding political and ethical scrutiny”.⁸ To what extent did we succeed?

In general, the project led to an increase in the reflexive capacity of the team above all through the emerging acknowledgement that the selection of new materials for solar cells has to consider the future socialization and marketization of such solar cells. We believe that this awareness initiated new ways of thinking about selecting materials, and that the extended range of criteria for selecting materials might be consolidated among the participating materials scientists. These assumptions were supported by the fact that the materials scientists explicitly expressed the wish for disseminating results of the SoRoSol project to other research groups working on solar cell development. Furthermore, we observed that, to some extent, the project had made the materials science research more transparent to the ELSA scholars, whereas the issues of social acceptability and political and ethical resilience had become more tangible for the materials scientists. Thus, the goal of mutual learning and reflection was at least partly achieved.

Nevertheless, we experienced that the challenges of translating between ethical and social aspects and criteria for selecting materials for solar cells remained considerable throughout the project, above all with respect to identifying relevant such aspects. This made interdisciplinary integration fairly challenging. While we established a ‘trading zone’ (Galison, 1996) and reasonably effective ways of communicating, actual trades in knowledge and perspectives were few and modest. The main experience from the fieldwork in the laboratory and the project meetings was that the participants in the

⁸ Grant proposal (note 4), at p.1.

project struggled to trade knowledge in a way considered meaningful and relevant by all participants, with one important exception—the decision to exclude toxic materials from the current and future projects. This could be considered an important outcome, but we (the authors) experienced this as a low-hanging fruit, having hoped to achieve more results. Therefore, we brought on board experts in the potential use of solar cells, but even if we had some success from this effort in contextualizing the materials science issues, the trading of knowledge remained limited in light of the efforts put into the project.

Consequently, the experiences from the SoRoSol project illustrate some limitations of integrated research strategies as a way of making research and innovation socially responsible. First, in general, there is no simple recipe for making ethical and social interpretations of basic science and to identify relevant concerns. The grant proposal suggested mainly two concepts to deal with ethical and social issues. One was toxicity, which came to influence the outcome of the project. The second was efficiency in terms of transforming solar energy to electricity. However, the emphasis by the materials scientists on efficiency as their main criterion for the selection of materials actually represented a challenge when the ELSA scholars tried to introduce alternative socio-technical concerns.

This is related to a problem with integrated research in emerging technosciences—the challenge of contextualizing basic research that is far removed from potential future applications. In this regard, the introduction of the idea about BIPV was an improvement. However, as it turned out, it remained unclear whether new criteria, like flexibility or transparency, really were relevant with respect to the selection of materials. Furthermore, one may ask about the resilience of the expert accounts of future use. For example, highlighting issues of efficiency and costs, the experts from the energy efficiency agency Enova claimed that, in Norway, photovoltaics would not be competitive with other forms of renewable energy. However, the other dialogue partners were of a different opinion. Trying to foresee the future development of the building industry has to be considered problematic.

The dialogue meetings with invited use experts as a method for integrated research proved to be a fruitful experiment for us. The meetings made the team more dynamic and were an important step toward building a platform for socially robust solar cells. From the point of view of Latour's (2004) politics of nature, these meetings could be considered a consultation effort, maybe also involving some input to a ranking of research outcomes (hierarchy). Introducing the context of use successfully brought values and interests into the search for scientific facts about new, potentially more efficient solar cell materials. In this sense, the dialogue meetings worked as a tool of increased social robustness as well as reinforcing the idea that social robustness involves a concern for fairly concrete contextualization of the research in question. On the other hand, we experienced the goal of increased transparency as more challenging, at least with respect to a future public audience.

Further, in terms of social robustness, the paper is a reminder that integrated research cannot be confined to laboratories, since a laboratory is just a moment in a series of displacements (Latour, 1983). An effective STS intervention,

'requires one to ask about how the laboratory, as the selected key site [...] is situated in the wider range of activities, actors, interests, and relationships which constitute science and its distributed networks of stakeholders and innovation funders, practitioners, and affected publics' (Wynne 2011:794).

An earlier discussion at S.NET asked if integrated research meant that social sciences and humanities (SSH) would turn into mere auxiliary sciences. Nydal et al. (2012) suggested that SSH should not retreat into a facilitator role in integrated projects but instead should contribute as a discipline on its own terms. In a sense, we STS scholars adopted such a facilitator role by initiating the dialogue meetings that enabled the exchange among solar experts. However, it is wrong to conclude from this that we did not enact our discipline. Without our competence in user studies and public engagement, the idea of such dialogues and how to organize them would not have been known. One should not underestimate the importance of such SSH knowledge. Furthermore, we have made our own research within the SoRoSol project, as evidenced by this paper.

Nevertheless, the outcome was moderate in terms of social robustness even if our experiences modulate Weingart's (2008:137) fairly critical assessment of 'social robustness':

'It should not escape attention that the very vagueness of the terms involved explains their popularity among scholars of Science, Technology, and Society (STS) and practitioners of science policy because such vagueness creates the illusion that the dilemma [of representing society vis à vis scientists] can be solved. If the concepts were more concrete and if they had a better empirical grounding, the message would be more disappointing'.

We agree about the vagueness of the generic concept. However, in the SoRoSol project, the ELSA scholars tried to make it more concrete, above all by facilitating a fairly concrete contextualization in terms of future applications of solar cells. The paper provides evidence of this claim. Whether our message is disappointing or not depends on the expectations. There may be a tendency to claim that integrated research is vital to achieving socially responsible research and innovation. From our experience, this claim is too strong. However, the SoRoSol project was modestly successful in increasing transparency within the team, providing for somewhat greater reflexive capacity, and improving political and ethical resilience. SSH scholars may be able to mediate social and ethical concerns into laboratory settings, but the integrated research model is fairly demanding and may easily become a source of frustration (Åm and Sørensen, in preparation). There may be better ways of enacting such mediation. We suggest, based on the findings in this paper that to use and further develop the concept of social robustness may be helpful in this respect.

References

- Åm, H. (2015) 'The Sun Also Rises in Norway: Solar Scientists as Transition Actors', *Environmental Innovation and Societal Transitions*. DOI: 10.1016/j.eist.2015.01.002.
- Åm, H. and Sørensen, K.H. (in preparation) *Innocents Abroad: Social Scientists Seeking Integration in the Laboratory*. Trondheim: Department of Interdisciplinary Studies of Culture, Norwegian University of Science and Technology
- Collins, H. M. and Evans, R. (2002) 'The Third Wave of Science Studies: Studies of Expertise and Experience', *Social Studies of Science*, 32 (2): 235-296.
- Fisher, E. (2007) 'Ethnographic Invention: Probing the Capacity of Laboratory Decisions', *NanoEthics* 1(2): 155-165.
- Fisher, E. and Mahajan, R.L. (2006) 'Midstream Modulation of Nanotechnology Research in an Academic Laboratory', *Proceedings of IMECE2006*, ASME International Mechanical Engineering Congress and Exposition, 5-10 November, Chicago.
- Galison, P. (1996) 'Computer simulations and the trading zone'. In: P. Galison and D.J. Stump (eds.) *The disunity of science. Boundaries, contexts, and power*. Stanford, CA: Stanford University Press.

- Gibbons, M. (1999) 'Science's New Social Contract with Society', *Nature* 402: C81-C84.
- Gibbons, M., Limoges, C., Nowotny, H. et al. (1994) *The New Production of Knowledge: The Dynamics of Science and Research in Contemporary Societies*. London: Sage.
- Guston, D.H. (2005) Institutional Design for Socially Robust Knowledge: The National Toxicology Program's Report on Carcinogens. In: S. Maasen and P. Weingart (eds.) *Democratization of Expertise? Exploring Novel Forms of Scientific Advice in Political Decision-Making*. Dordrecht: Springer, pp.63-79.
- Hertwich, E. (2010) *Assessing the Environmental Impacts of Consumption and Production, Priority Products and Materials*. Nairobi:UNEP.
- Jasanoff, S. (2004) The Idiom of Co-Production. In: S. Jasanoff (ed.) *States of Knowledge: The Co-Production of Science and Social Order*. London: Routledge, pp.1-12.
- Latour, B. (1983) Give Me a Laboratory and I Will Raise the World. In: K. Knorr-Cetina and M. J. Mulkay (eds.) *Science Observed: Perspectives on the Social Study of Science*. London. Beverly Hills: Sage Publications, pp.141-170.
- Latour, B. (2004) *Politics of Nature: How to Bring the Sciences into Democracy*. Cambridge: Harvard University Press.
- Meld. St. 21 (2011-2012) *Melding til Stortinget. Norsk klimapolitikk*. Available at: <https://www.regjeringen.no/nb/dokumenter/meld-st-21-2011-2012/id679374/?docId=STM201120120021000DDDEPIS&ch=1&q=> (accessed 15 February 2015).
- Nordmann, A. and Rip, A. (2009) 'Mind the Gap Revisited', *Nature Nanotechnology* 4(5): 273-274.
- Nowotny, H., Scott, P. and Gibbons, M. (2001) *Re-Thinking Science, Knowledge and the Public in an Age of Uncertainty*. Cambridge: Polity.
- Nydal, R., Efstathiou, S. and Læg Reid, A. (2012) Crossover Research: Exploring a Collaborative Mode of Integration. In: H. van Lente, C. Coenen, T. Fleischer, K. Konrad, L. Krabbenborg, C. Milburn, F. Thoreau and T.B. Zülsdorf (eds.) *Little by Little: Expansions of Nanoscience and Emerging Technologies*. Heidelberg: Akademische Verlagsgesellschaft AKA, pp.181-194.
- Rip, A. (2010) 'Social Robustness and the Mode 2 Diagnosis', *Science, Technology & Innovation Studies*, 6(1): 71-74.
- Shumpert, B.L., Wolfe, A.K., Bjornstad, D.J. et al. (2014) 'Specificity and Engagement: Increasing ELSI's Relevance to Nano-Scientists', *Nanoethics* 8: 193-200.
- Sørensen, K.H. (2004) 'Cultural Politics of Technology: Combining Critical and Constructive Interventions?', *Science, Technology and Human Values* 29(2): 184-190.
- Sørensen, K.H. and Williams, R. (2002) *Shaping Technology, Guiding Policy: Concepts, Spaces, and Tools*. Cheltenham: Edward Elgar.
- Star, S.L. (2010) 'This Is Not a Boundary Object: Reflections on the Origin of a Concept', *Science, Technology & Human Values* 35(5): 601-617.
- te Kulve, H. and Rip, A. (2011) 'Constructing Productive Engagement: Pre-engagement Tools for Emerging Technologies', *Science and Engineering Ethics* 17(4): 699-714.
- Weingart, P. (2008) How Robust Is 'Socially Robust Knowledge'? In: M. Carrier, D. Howard and J. Kourany (eds.) *The Challenge of the Social and the Pressure of Practice: Science and Values Revisited*. Pittsburgh: University of Pittsburgh Press, pp.131-145.
- Williams, R. (2006) 'Compressed Foresight and Narrative Bias: Pitfalls in Assessing High Technology Futures', *Science as Culture* 15(4): 327-348.
- Wynne, B. (2011) 'Lab Work Goes Social, and Vice Versa: Strategising Public Engagement Processes', *Science and Engineering Ethics* 17(4): 791-800.