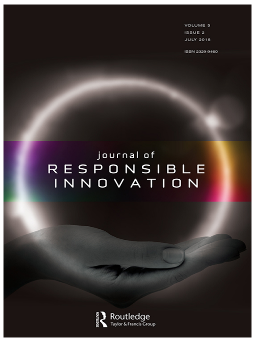

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A comparative, sociotechnical design perspective on Responsible Innovation: multidisciplinary research and education on digitized energy and Automated Vehicles

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ABSTRACT

This study develops a comparative, sociotechnical design perspective for interdisciplinary teams of social scientists and computer scientists. Sociotechnical design refers to identifying both technical and governance challenges and to understanding the ways in which the two types of problems affect and define each other. Approaching design as an open-ended, iterative process, the study develops a triple comparative perspective to problem finding and solutions: across two types of technological systems (the smart grid and connected and automated vehicles), three areas of societal implication and values (safety, equity, and privacy), and two continents (North America and Europe with a focus on the U.S. and Germany). The study then describes the implementation in an international collaboration of research and teaching. The collaborative experience and comparative research provide insights into the salience of the values across technological systems, portability of solutions across technological systems, and potential for policy harmonization across countries.

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Introduction

In comparison with the analog systems of the twentieth century, twenty-first century technological systems are often connected digitally across a large spatial scale. The digital transition is now evident across diverse technological systems, including

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energy, water, transportation, buildings, finance, healthcare, biotechnology, and communication. The change in technological systems offers many advantages, including increased levels of economic and technical efficiency and the potential for enhanced environmental sustainability. To achieve these goals, system designers are increasingly turning to new technical means, such as real-time information processing at a global scale, the analysis of big data, and machine learning.

However, the increased complexity of technological systems has generated risks and unanticipated consequences, which have led to public concern and in some cases to opposition. Awareness of the potential for public concern has motivated governments, firms, researchers, funders, and public-interest advocates to pay increasing attention to the problem of designing systems in ways that address broad societal values and implications (Taebi et al. 2014). Interest in 'responsible research' (Owen et al. 2021; Owen and Pansera 2019) or 'sociotechnical' perspectives (National Science Foundation 2015) has been growing, even if it is plagued by deep challenges. (Responsible innovation, or RI, is distinguished from RRI, or responsible research and innovation, which represents a European policy perspective; see Owen and Pansera 2019).

This study contributes to the literature on RI and sociotechnical perspectives by developing a framework that can facilitate their inclusion in open-ended multidisciplinary education and research teams. The approach developed here is not prescriptive in the sense of developing rules or ethical guidelines. Rather, it builds on the tradition of 'agile software design' and the open-ended, iterative, and recursive approach found in the design professions (Beck et al. 2001; Bronet et al. 2003; Nieusma 2018). It also draws on the idea of building partnerships between social scientists (or humanists) and those in the technical professions (engineering, computer science) that has been articulated in the RI and STS (science and technology studies) literatures on sociotechnical integration and related concepts (e.g. Fisher and Schuurbiers 2013; Flipse and van de Loo 2018; Guston and Sarewitz 2002). In this study, the emphasis will be on examining the opportunities for collaboration in the process of identifying problems (and possible solutions) in the contexts of teaching, policy outreach, and research.

An important question at the outset is for whom such approaches are intended to benefit. Engineering, product, and software designers often work for companies or governments (either directly or via grants and contracts), and their degrees of freedom are limited by goals established by their funders, who often prioritize profitability or national security. In contrast, attention to RI implies a different type of 'client': the broader public and the effects of innovation on the public interest. In the RI and engineering ethics literatures, these considerations often include discussions of values or societal implications (Boenink and Kudina 2020; Taebi et al. 2014). One way of implementing RI is direct engagement with stakeholders, users, consumers, citizens, civil society leaders, policymakers, and others who can be tasked with speaking for a broad public interest (Felt et al. 2016, Taebi et al. 2014). This study will focus instead on the parallel approach of embedded social scientists in research and education teams, with the goal of having them represent societal implications, values, and public interests based on their research and knowledge.

The approach to the integration or embedding of social scientists in the collaborations is described here as 'sociotechnical design' because it involves the integration of social science (and humanities) perspectives with engineering and natural science perspectives in shared projects of problem finding, defining, and solving. In both cases, the idea of design refers to an iterative, open-ended, and exploratory approach. We build on this sociotechnical design perspective by introducing an additional component: we show how sociotechnical design that is anchored in collaborations of social scientists, scientists, and engineers can be improved by including the multiple comparative perspective of different technological systems, societal values, and political jurisdictions. Thus, we develop an argument for, and an example of, a comparative, sociotechnical design perspective. We do so in the context of the collaborations of an international team of researchers who work on advanced digital technologies, and we discuss the team's experience in education, policy outreach, and research.

Background

Responsible research and innovation and its problems

Current discussions of RI build on more than half a century of efforts to develop the governance of innovation, which emerged primarily in North America and Europe (Von Schomberg and Hankins 2019). During the 1970s and 1980s, the U.S. Office of Technology Assessment provided advice to Congress on technology policy. Although the organization was defunded in 1995 because conservatives perceived it as anti-innovation, other efforts were emerging. The developments included various forms of public engagement in governance processes (such as consensus conferences) and funding for research on ethical, legal, and social implications/aspects (ELSI or ELSA) of new technologies. Some of these developments involved more open-ended processes that focused on mutual learning and early-stage engagement. Table 1 provides some examples of the main approaches. Although the sources provided are relatively recent, the bibliographies can provide access to more historical overviews.

In Europe, policymakers and researchers developed a systematic approach under the rubrics of 'responsible science' and later RRI (De Saille 2015; Owen and Pansera 2019). The European Commission (2014) developed RRI to bridge the perspectives of European citizens and innovation actors. Funding from the European Commission supported a wide range of research projects that included public engagement, gender equality, open access, ethics, and science education (European Commission 2020). National

Table 1. Examples of Models of Responsibility in Innovation Processes

Type of Engagement or Assessment	Description (Reference)
Government-based technology assessment	Government agencies for technology assessment, such as the U.S. Office of Technology Assessment (Ely, Van Zwanenberg, and Stirling 2014)
Ethical, legal, and social implications (ELSI) funding	Dedication of a portion of research funding on large initiatives (e.g. genomics, nanotechnology) for societal implications research (Balmer et al. 2016)
Constructive technology assessment, participatory technology assessment, upstream public engagement	Inclusion of multiple stakeholders through workshops, citizen reports, etc., to assist with anticipation of problems and social learning (Ely, Van Zwanenberg, and Stirling 2014; Rip 2018)
Real-time technology assessment, anticipatory governance, sociotechnical integration research	At an early stage, integration of social science and policy perspectives in funding and in natural science and engineering research projects and programs (Fisher and Schuurbiers 2013; Guston 2014; Guston and Sarewitz 2002; Radatz et al. 2019)

governments also implemented programs. For example, in Germany, the NanoKommission provided a platform for responsible nanotechnology research (Coenen and Grunwald 2017), and in the U.K. the Engineering and Physical Sciences Research Council funded RI research (Owen et al. 2021). Researchers in Europe have also called on the Commission to encourage interdisciplinary collaboration and to include the social sciences and humanities (Gerber et al. 2020).

Stilgoe, Owen, and Macnaghten (2013) identified four main dimensions of RI: anticipation (improved foresight), reflexivity in governance and design (the inspection of the values that orient innovation and the institutions that govern it), inclusion (the development of new forms of public participation and governance), and responsiveness (the design of institutions so that RI concerns are not ignored and instead become embedded in innovations). At its best, RI brings public interest concerns into both technology policy and the technical processes of design and innovation. However, Stilgoe, Owen, and Macnaghten (2013) and other researchers have also identified deep challenges and problems with the vision of RI and similar approaches. One problem is that the new forms of research and governance do not provide a crystal ball about future societal implications or a guaranteed route to more responsible and acceptable design. Especially for software-intensive systems, complexity is so great that it is impossible to predict all outcomes. (The lead author was engaged in one such exercise at the U.S. National Science Foundation during the early stage of the Internet, and it was impossible to foresee some of the implications twenty-five years later, such as the effects of social media on politics.) Nevertheless, by at least thinking about the issues, it may be possible to identify some problems that can be caught in early stages.

Another major shortcoming is the potential for RI to clash with industrial and government priorities for rapid innovation and marketplace competitiveness. Fisher and Maricle noted that the vision of sociotechnical integration is not often realized in priorities for research because of ‘institutional norms that preclude integration and concerns that integration would compromise national competitiveness agendas’ (2015, 9). In a study of the implementation of RI funding in the U.K., Owen and colleagues (2021) identified various barriers to the institutionalization of RI, including political priorities that supported a market-oriented institutional logic for universities and researchers. Even at the level of university-based research teams, the integration of RI via multidisciplinary research and education that includes social scientists and humanists can be challenging (Bennett and Sarewitz 2006; Owen et al. 2021).

However, some categories of industry (e.g. consumer-facing firms) and some government and foundation funders do see the value of including RI in their priorities (Eastwood et al. 2019; Long et al. 2020; Steen and Nauta 2020; Taebi et al. 2014; van de Poel et al. 2020). Where the engagement with societal goals occurs early in the design process (such as at the proposal-writing and problem-definition stage), the outcome of these collaborations can be quite creative and can lead to changes in how both technical and social researchers think about their research (Blok et al. 2015; Koops et al. 2015; Radatz et al. 2019; Smolka et al. 2020; Van de Poel 2009). Nevertheless, working toward RI requires recognition of the tensions in the underlying values between, for example, the social sciences and computer sciences, and it also requires a steep learning curve for social scientists who do not have a technical background.

This study does not pretend to resolve the conflicts that play out in attempts to implement RI in multidisciplinary teams, nor does it suggest that even an open-ended, iterative approach to sociotechnical design is a panacea. But in the tradition of the approaches of RI that emphasize partnerships between scientists-engineers and social scientists-humanists, such as sociotechnical integration research, we begin with the fact that opportunities do open up. Wherever these opportunities emerge, it is useful to think about a strategy to make as successful as possible the 'trading zone' of interdisciplinary collaboration, which is a form of cross-cultural communication (Collins, Evans, and Gorman 2007). In the tradition of work in RI that focuses on the strategy of making these collaborations more successful (e.g. Balmer et al. 2016), this study examines a strategy for the mutual identification of problems and solutions through the lens of multidisciplinary, sociotechnical design.

A Sociotechnical design perspective

The 'sociotechnical' perspective emerged from the field of science and technology studies (STS) and gained currency in a wide range of studies of technological change and transitions, including studies of industrial transitions and sustainability (Hess and Sovacool 2020; Sovacool, Hess, Amir et al. 2020). Rather than view the social and technical as separate spheres that interact, the perspective views them as mutually defined, organized, coproduced, or constituted.

Research in STS during the 1980s and 1990s articulated several main sociotechnical perspectives. The social construction of technology approach focused on how social groups with a stake in a product or technological system engaged in negotiations. The process often begins with controversy, and it can lead to a stabilized design outcome (Pinch and Bijker 1987). Actor-network theory focused on the interconnections of human and non-human nodes in networks with distributed agency (Callon 1987). The study of large technical systems examined the development of infrastructure-based systems that included organizations, objects, rules, and different types of human actor categories (Hughes 1987). These three approaches influenced subsequent developments in the study of technological systems, such as the multilevel perspective, which emphasized the relationships between emerging niche technologies and the existing regime in the context of broader societal or 'landscape' changes (Geels 2007).

The term 'technical' is used here to refer to knowledge, practices, and objects associated with modern technology. Researchers who study technology, society, and policy sometimes distinguish between technology as a broad category and subcategories within it. With respect to scale, the term 'object' will be used here for specific, small-scale forms of technology such as a computer or smart meter and the software programs associated with the object. Since the 1980s, the terms 'large technical system' and 'technological system' have been used to define a larger unit of analysis that is generally associated with infrastructure (Sovacool, Lovell, and Ting 2018). The term 'technological system' is used here to refer to a complex network that connects infrastructure and technological objects, cultural or institutional systems associated with the objects, social organizations and social relations, and the natural environment. Examples of technological systems include electricity, water supply, and transportation systems (roads, rail, sea, air). These systems undergo periods of stability and change, and the study of change is generally understood as a transition, such as from horse-drawn vehicles to internal combustion engines (Geels 2005). The type of transition of greatest interest here is the digital transition of the early twenty-first century.

The term ‘design’ is understood broadly as the intentional shaping of demarcated aspects of the social and material worlds. Because design is intentional and conducted with a goal or purpose in mind, it has a normative dimension, even if the norms are not always explicit. The term ‘design’ is valuable for cross-disciplinary communication because it is used and understood (albeit differently) across a wide range of disciplines. The term can serve as a boundary object or connector, particularly if social scientists note that the applied social sciences also face design challenges with respect to improving the governance of technology. The approach of sociotechnical design emerges from traditions in the design professions (e.g. community-based, human-centered, participatory, universal, user-centered, and value-sensitive) that attempt to broaden the goals of the design process from technical considerations that are necessary for a system to function effectively (such as efficiency, functionality, and cost effectiveness) to include societal and public interest goals (Nieusma 2018; Scacchi 2004). Achieving the opening up of goals often includes a design process that considers the perspectives of users, affected communities, and the policy context of technology but goes beyond usability testing at the prototype stage. Instead, the focus is much more on how the iterative, open-ended process of design requires ongoing redefinition of problem-solution packages.

The sociotechnical design perspective involves two, connected design challenges. First, engineers, computer scientists, and other technical experts may gain insights into how to design technical objects that are based on awareness of societal implications and are adaptable to different cultural and policy contexts. Second, the collaboration can help social scientists (and engineers and scientists, when they engage in policy advising) to improve recommendations for governance, policy guidance, regulations, user interfaces, and standards. We refer to these two dimensions as technical design and policy design. Although some might argue that this approach to design is too broad, the scope of this approach is valuable in the context of multidisciplinary collaboration because it signals how social science and policy researchers share a common set of challenges with engineers and computer scientists, and it also signals how the two types of design can be interconnected. Although these two processes do not always occur on the same time scale because governance may take some time to catch up with technological change, attempts to have the conversations during early stages of technological development may make it possible to improve both the readiness and the technological sophistication of policy guidance.

In summary, the sociotechnical design perspective recognizes that the design of technical objects is embedded in broader technological systems, social practices, and policy regulations that are coproduced with laws, regulations, cognitive categories, practices, routines, and organizations (Miller and Wyborn 2020). On the one hand, part of what engineers and inventors do is to affect policy design because their design choices for objects and technological systems have social and political implications. In this sense, technology is legislation (Winner 2010) or, for software, code is law (Lessig 2006). Especially for infrastructure-based technological systems such as a road transportation system or the electricity grid, the design and implementation of the system involve lock-in and have political, cultural, and social implications for long periods of time. On the other hand, part of what policymakers and public-interest advocates (and their advisors) do is to affect the design of technological systems by providing guidance, regulations, nudges, and incentives. When policy makers develop programs, agencies, and public engagement processes, their innovations also reverberate across the technological system and steer it in some directions rather than others. Thus, although we can say that technology is legislation, it is important not to miss the symmetrical idea that policy is engineering. For example, with respect to the user interface, social science and applied policy fields routinely contribute to design of incentives and user behavior for technological systems and objects.

Because innovation often has unintended consequences, there are limits to what can be achieved in the design process. Nevertheless, as the review of sociotechnical and RI perspectives has suggested, there is also recognition among funders and some governments that support for the embedding of sociotechnical perspectives and multidisciplinary collaborations in the design process can help to produce both more policy-aware technology and more technology-aware policy.

Research problem and contribution

The use of multidisciplinary teams that include social scientists is not new, and government funders have increasingly recognized the value of integrated research that has a sociotechnical perspective. A sociotechnical perspective on both problem analysis and solution design can better address the complexity of social and environmental problems. Furthermore, because social scientists have methods for studying societal implications and public opinion, they can bring a perspective on RI into teaching, research, and design. We contribute to these developments by adding a triple comparative perspective to show how systematic comparison can be used to inform collaborations across the computer science, computer engineering, and social science disciplines. The perspective involves comparisons across technological systems, societal values, and political jurisdictions. Although the approach has some overlap with other strategies of sociotechnical collaboration such as value-sensitive design and socio-technical integration research (Fisher et al. 2015), it also develops a broader perspective of design thinking based on comparisons not only across values, systems, and jurisdictions but also across teaching, research, and policy outreach. In the next section, we outline the scope of the comparative method that is used to varying degrees in the collaboration, and in the section that follows, we describe some of the projects that emerged from the collaboration where different angles of comparison were used.

The Comparative method in sociotechnical design

This study reports on the comparative dimension of some of the projects that emerged from a collaboration that involved an international team of university-based researchers who work on software-intensive technological systems, with funding from both the U.S. and German national science foundations. The network of researchers provides cross-disciplinary training for students, engages in policy outreach with industry and government actors, and engages in multiple collaborative research projects. Not all projects in the collaboration involve sociotechnical design or a comparative perspective; this study focuses on a subset that do involve such considerations.

A comparative perspective is important because effective sociotechnical design, as with best practices in design in general, requires the careful inspection of problems and the identification of underlying assumptions. As the fields of cultural anthropology and other comparative disciplines have shown, one of the best ways for gaining insights into nonintuitive assumptions is by developing a comparative perspective (Hess 1995). For example, an important line of research in comparative STS shows how scientific research in physics or biology may seem universal until we include the perspectives of research communities in other countries, such as Japanese physicists, and the perspectives of historically excluded groups in scientific research fields, such as women or indigenous people (Harding 2015; Traweek 1992). Thus, a comparative perspective can provide a source of new ideas and innovations, and it can reveal hidden assumptions and even biases. Moreover, in the context of system design that will be used internationally and potentially across different technological systems, a comparative perspective also has practical value because software and hardware systems design can face implementation barriers when extensions are made across different technological systems and countries.

The strategy of comparison that is developed here works in three dimensions: across technological systems, across societal concerns and values, and across political jurisdictions. A multiple comparative perspective of the scope outlined here can easily become a massive undertaking. Consequently, this study focuses on a limited range of comparisons that emerge from the expertise of the participants in the collaboration.

Comparison across technological systems

Comparison across technological systems can identify new possibilities of how problem-solution packages in one system may be unique to the system or portable to another, and we will come back to the findings that we have about portability in the results section. The sociotechnical design dimension of the projects that will be described in the next section focuses on two technological systems: electricity and transportation. The researchers selected these two systems because they have existing expertise in these systems and because both systems are undergoing substantial digitization transitions. These systems were also selected because the societal implications are already under discussion in governments, industry, universities, and civil society.

Within electricity, the focus is on the consumer interface with digital electricity platforms that enable real-time pricing to integrate digital demand management (DDM) programs and distributed renewable energy. DDM is the use of pricing schemes and incentives to help utilities to control the electricity load, especially the fluctuations within the daily load. One important type of DDM is transactive energy, which refers to the use of pricing structures and automated control systems to bring about greater energy efficiency and to improve the load management for utilities (Chen and Liu 2017). The problem of load management has become particularly acute with the development of distributed renewable energy (e.g. rooftop solar) and the ‘prosumer’ (a consumer who is also a producer). Digital systems with advanced metering infrastructure enable utilities or other electricity service providers to manage their loads more efficiently by using the resources of digitized electricity systems (the smart grid) and the consumer interface of those systems (the smart meter).

Within transportation, the focus is on the development of connected and automated vehicles (CAVs). Although terminology is inconsistent, we use CAV for a vehicle that is equipped with driving automation and that also has communication capability with remote human monitors, other vehicles on the road, and the road infrastructure. The communication capability usually involves wireless transmission using microwave technology, LIDAR, and radar. CAVs are defined as having various levels of automation, from driver assistance to vehicles with no human driver monitors (SAE International 2018). Because many vehicles on the market now have basic driver-assistance automation and connections to the Internet, they can be considered connected with a low level of automation. In most countries, vehicles with full automation (no human driver or safety monitor driver) are in limited use, usually within a carefully described operational design domain. For general users, the main automation technologies involve driver assistance such as automatic emergency braking and lane monitoring. Vehicles with higher levels of automation, including vehicles with no human monitor driver in the car, are currently being tested on the roads of some countries.

Comparison across societal values and goals

The second dimension of comparison involves societal goals. Rather than defining responsibility and societal challenges a priori as general ethical principles or predefined values, we adopt a more empirical approach based on public concerns, societal values and goals, and societal implications that are already identified and under discussion in civil society, industry, the government, and/or the media (Boenink and Kudina 2020; Taebi et al. 2014). The salience of societal values and goals (e.g. the relative importance of safety versus other values) varies widely across technologies and social contexts.

Of the societal implications, the research described below will focus on safety, equity, and privacy, which have emerged as salient for the technological systems under study. The values also present interesting opportunities for comparative analysis both across the technological systems and across countries. In the educational portion of the project, other societal values are also addressed, including security, sustainability, and democratic governance.

Comparison across political jurisdictions

The third aspect of the comparative perspective includes different political jurisdictions with an eye on how the different policy cultures can be harmonized. Harmonization can improve RI by distilling best practices from different countries and synthesizing them; it can also make beneficial technology more accessible by reducing barriers in a global industry. The emphasis here is on a cross-national comparative perspective, and the approach draws on a wide range of comparative work in the social sciences (e.g. Ragin 2014), science and technology studies (e.g. Hughes 1993; Jasanoff 2011), and sociotechnical transition studies (e.g. Geels et al. 2016). Cross-national comparison is important because it can identify opportunities for harmonization of policy across political jurisdictions (Macnaghten 2016; Schneider 2006). The comparisons can also alert software systems designers to cross-cultural differences that can be anticipated as systems diffuse across countries, and therefore it can point to opportunities for early-stage flexibility and innovation in design. We recognize that other types of comparative analysis across political jurisdictions are also of interest and value, such as multiscalar analysis, and some of the projects described below include subnational, national, and supranational (European Union) levels of policy guidance and regulation.

In the collaboration described below, the study focuses on the U.S. and Germany. These countries are selected because of the advanced state of their industries and the relative importance that the two countries have in establishing global directions for policy, standards, and system design. As the first and fourth largest economies in the world, the U.S. is the dominant economy in the North American free trade area (Canada, Mexico, and the U.S.), and Germany is the dominant economy in the European Union. Together, the two trading blocs represent nearly half of the global economy. Consequently, agreements on standards and harmonization of policies in the North Atlantic region will likely influence standards and policy in other world regions.

Prior to the development of the European Union, comparative studies of North America and Europe tended to operate at the country level. However, with the increasing role of the E.U. in setting policy directions for member countries, and with our choice to focus on two countries with federal governments, multiple levels of jurisdiction can be important. Although this study focuses on the U.S. and Germany, a necessary asymmetry also emerges because discussion of policy in Germany requires some reference to E.U. guidance. Likewise, although some of the relevant policies in Germany are devolved to the federal states (the Bundesländer), in the U.S., the federal government in this area tends to devolve much more policy to the states, and it becomes more necessary to include state-level policy as well.

Results: project summaries

This section reviews how a comparative, sociotechnical design perspective was used in the projects that emerged from the research collaboration. It includes three main domains in which the collaboration was configured: teaching, policy outreach, and research.

Teaching

Each year a seminar introduced students to the general approach. The seminar was conducted in the U.S. for students who would later join summer internships in either the U.S. or Germany. It involved faculty from the computer science, computer engineering, and social science fields. Readings and classes introduced students to technical and policy problems and solutions.

The course used a matrix structure that brought the triple comparative perspective to problems of both software and policy design: across five main societal concern areas (privacy, safety, security, equity, and sustainability), two broad categories of technological system (CAVs and DDM), and jurisdictions in North America (the U.S. and Canada) and Europe (with a focus on Germany). The readings and classes also included issues of public acceptance, public opinion, and the role of political civil society in shaping opinion. As the seminar transitioned to remote during the pandemic, it included participation by German students and faculty.

Each summer after the seminar, U.S. students were selected to participate in additional research projects under faculty supervision. Some of the U.S. students went to Germany prior to the pandemic or participated remotely with a German team during the pandemic. A few German students also joined U.S. groups during the summer months. Because students were integrated into existing research software and engineering projects, the capacity to utilize a sociotechnical design perspective in the design projects occurred only in some projects. One example that came close to this perspective was a project that developed algorithms for assessing security risk and threats to digital electricity systems. Another project translated consumer and public demands for safety into an approach to reducing the risk of collisions in CAVs, and another modeled system structures that tilted agent-based decisions either toward individual driver benefits or toward system-level traffic benefits of congestion reduction.

Policy outreach

As part of the collaboration, a workshop was held in Washington, D.C., hosted by the German Aerospace Center, which included policymakers, social scientists, engineers, computer scientists, and industry representatives (for a report, see Lemmer et al. 2018). The workshop involved representatives from both Germany and the U.S., and it focused on the need to coordinate policy development with rapid technological changes. This workshop involved sociotechnical design in the sense of bringing together diverse perspectives into defining the policy challenges that lie ahead for the regulation of CAVs when they are widely used on public roads. The different regulatory cultures of Germany and the U.S. were evident, especially for safety, which was the most salient societal value. The workshop was successful enough that additional workshops with German and U.S. leaders were planned for 2020 and 2021. Although the 2020 workshop was canceled due to the coronavirus pandemic, a virtual workshop was held in 2021 for a similar approach to unmanned aerial vehicle transportation. This workshop brought together the research team, additional researchers, policymakers, and industry leaders.

Research 1: sociotechnical system design

The most developed integration of social sciences and computer scientists in the research involved two social scientists (one faculty, one graduate student), a computer scientist (faculty), and undergraduate computer science students.

The first project reviewed real-world experiments with transactive energy that had been written from a technical perspective, and it resulted in a joint publication by the social scientists and the computer scientist (Lee, Hess, and Neema 2020). The project identified potential future implementation problems that would need to be anticipated in current system design of both hardware and software. The project also examined various societal values that were relevant to the assessment of the design of the systems and the consumer interface. The values included sustainability (e.g. the problem that DDM can encourage on-site diesel electricity generation as a result of load shifting), safety (e.g. cases of damage to equipment and wear-and-tear on equipment due to frequent on–off cycling), and equity (e.g. lack of price benefits for some categories of users and the potential for cost increases). In particular, our survey of transactive energy implementation projects showed that even if a particular implementation was found to be technically feasible and solid, the deep social values identified in the paper could fundamentally make or break a proposed solution.

After additional conversations, the team decided to develop a second project on virtual power plants (Neema et al. 2021). The project goal was to provide solutions, at a local level, to the integration of transactive energy with distributed energy resources (e.g. rooftop solar panels and local battery energy storage). This development was identified as occurring in both Germany and the U.S. in areas where high levels of distributed renewable energy are being integrated into the grid. The social scientists helped to define the research problem, that is, to define the challenge of using transactive energy to build a local virtual power plant to assist local power organizations to enable more efficient generation of distributed renewable energy. The social scientists gathered some of the data and helped to define the model parameters, and they helped to validate the modeling by bringing in the social context within which the proposed solution must work. For example, they helped to set up the model and its parameters in ways that respected local laws of energy pricing and privacy as well as corresponded to the typical *localized* energy usage patterns.

The computer scientists designed the simulation model and a set of design parameters to investigate their effect on the daily demand curve and power costs for consumers. The modeling tested a wide range of parameters, including the following: real-time pricing versus time-of-use pricing, wattage of the solar systems on customer buildings, battery storage presence or absence, solar penetration rate in the community, and pre-cooling in advance of price changes. The project developed a novel approach to real-time pricing and tuning it for reducing peaks in demand and smoothing the daily demand curve.

This project achieved a collaboration and experience in sociotechnical design, and it provided cross training of both the social scientist graduate student and the computer science students. The project helped to show the conditions under which local transactive energy systems could be used to facilitate the integration of distributed renewable energy into the grid by smoothing the aggregate demand curve, and it attracted interest in the U.S. from researchers in the National Institute of Standards and Technology.

The project represented sociotechnical design in the sense of integrating social science and policy perspectives into the problem definition and parameterization of the model, and it was anticipatory in the sense of identifying a future world with higher reliance on local virtual power plants that use transactive energy to integrate high levels of distributed renewable energy and energy storage. This is a highly complex sociotechnical problem. Had we not integrated the social context into the research, the technological solution, by itself, would not have generated socially acceptable results. A few examples include social aspects such as: (a) realistically not less than five minutes are used for changing power pricing during real-time pricing, (b) smart meters are not to be attached to every load in the houses to protect the privacy of consumers, and (c) tradeoffs between socially acceptable monthly energy costs for consumers (both with and without solar panels) and load curve and total energy demand for utilities must be carefully considered.

Research 2: social science and policy research

The social scientists on the U.S. team also conducted various research projects that sought to bring a comparative, sociotechnical design perspective to problems of policy design. It was hoped that the German team would have social scientists, but the funding in Germany ended up not including social scientists. Still, the U.S. team was able to gain feedback and help from German social science and policy researchers for some of the projects. The discussion that follows will focus on the multiple comparative perspective across three societal value domains: safety, equity, and privacy.

With respect to safety, one of the research projects, which grew out of the policy workshop described above, focused on the potential for cross-national harmonization for CAV safety policy (Lee and Hess 2020). The comparative analysis of safety rules and guidance for on-road testing, which included Germany and the U.S., identified various areas of potential cross-national policy harmonization, including the licensing and training of safety drivers for testing, procedures for recording and reporting accidents, and penalties for non-compliance. The study found that although harmonization is possible for safety policy, there are also significant challenges. One problem is that European countries use an approach to vehicle safety standards that relies on third-party certification (known as type approval/homologation), whereas the U.S. approach uses self-certification by manufacturers (Canis and Lattanzio 2014; SafeTrans 2019).

With respect to equity, the differences in transportation systems between the U.S. and Germany also generated challenges for finding common policy approaches. Although equity and discrimination in transportation use are not absent in Germany, the issues are very salient in the U.S. because of the more automobile-dependent transportation system, the history of transportation racism that dates back to Jim Crow (segregation) laws in the U.S. South, and the existence of racially segregated ‘transit deserts.’ On the benefits side, CAVs could extend vehicle access to categories of persons not able to drive (Charness 2008), and they could also reduce transportation costs compared with taxi services and personal vehicle ownership (Bagloee et al. 2016; Fagnant and Kockelman 2015). However, on the negative side, CAVs could undermine the economics of public transportation (Buehler 2018), and CAVs could also cost more than conventional cars and reduce accessibility to vehicle ownership. A more technical dimension that emerged in our conversations is the lower capacity of present technology to detect darker skin color of human pedestrian figures as well as it does for lighter skin color (Wilson, Hoffman, and Morgenstern 2019; see also Williams 2020). Our research focused more on ridesourcing, which we viewed as an existing technological system that would likely be one of the first places where CAVs are widely used, and we included both survey research and spatial analysis (Lee and Hess 2021b; McKane and Hess 2021).

We found that equity-related issues are quite different for digital electricity. The primary equity challenge for DDM pricing is that it may have negative implications for second- and third-shift workers, who lack scheduling flexibility. Instead, they must complete essential domestic tasks like cooking, laundry, and cleaning at times of the day when prices are higher (Powells and Fell 2019). Furthermore, because lower-income households tend to use significantly less energy than wealthier households, there are fewer ways to cut energy use to lower their energy bills (Alexander 2007). Lower-income households are also less able to participate in the new programs and also tend to have older appliances and heating-and-air-conditioning systems. Because these equity-related issues are closely linked to household income levels, there may be greater similarities for equity challenges for electricity between Germany and the U.S. than for transportation. For example, policies in both countries could provide for price reductions for second- and third-shift workers who use electricity during peak hours, and policies could also enable subsidies for new equipment for low-income households so that they can more easily take advantage of DDM.

With respect to privacy, this area of societal values and concern is currently more highly emphasized for the electricity system than for CAVs, partly because CAVs for personal use are still in a testing phase. We also found that there is more potential for harmonization across political jurisdictions (e.g. the European and North American regulations) for privacy than for safety and equity (Lee and Hess 2021a). The relatively greater opportunity for harmonization for privacy results from the general policy guidance on digital privacy rights in both the United States and Germany (Bundesbeauftragter für den Datenschutz und die Informationsfreiheit 2020; Dahn 2014; European Commission 2016). Although there are industry-specific privacy rules, such as for health information and electricity customer data, the underlying principles about data collection and sharing tend to be similar across the industries and technological systems.

With respect to electricity, rules to protect electricity customers' privacy date back to the analog era, when data-sharing guidelines were developed (Lee and Hess 2021a). With the digital era, concerns with privacy have increased because of the granularity of the data that can be collected, especially for residential customers. In contrast, until recently automobiles were not connected to the Internet. As the capacity for data-gathering of trip patterns and driver behavior has increased, so have concerns with privacy. With respect to CAVs, some of the German manufacturers also were offering opt-out programs and privacy modes in their vehicle design (Barry 2020). Advocacy organizations have also begun to seek better privacy protections from governments for CAVs in both Germany and the U.S. (Allgemeiner Deutscher Automobil-Club e.V. 2020; Hess 2020).

Summary: insights from the multiple comparative perspective

Table 2 synthesizes some of the findings that emerged from the collaborative work in teaching, workshops, and research. The table uses the comparative, sociotechnical design perspective across technological systems, values, and countries to identify differences in the salience of values across technological systems, the similarity and portability of problems and solutions across the systems and value areas, and the harmonization potential across the political jurisdictions.

With respect to salience of the three value types across the technological systems, we found that the concern with values varied across the technological systems: safety concerns are higher for CAVs than DDM, and equity concerns are currently defined for DDM but poorly defined for CAVs (hence the use of ridesourcing to anticipate potential concerns for CAVs). Privacy concerns are well defined for both domains, but privacy guidance and rules are currently more advanced for DDM due to legacy analog rules and emerging digital privacy rules in countries where advanced metering infrastructure is implemented.

With respect to similarity and portability across technological systems, we also found that the degree of similarity of the problems and solutions, and consequently the portability of solutions, varied across the values. Safety and equity concerns are quite different for CAVs and DDM, and portability of policy solutions across the technological systems is likely to be limited. For privacy, the portability is higher because general

Table 2. Summary of Comparisons

Value Domain	Salience of Values across Technological Systems	Similarity and Portability of Solutions across Technological Systems	Differences across National Boundaries and Harmonization Potential
Safety	CAVs: highly salient, continues longstanding consumer safety concern and vehicle safety policies DDM: some equipment concerns	CAVs and DDM: low portability because of different types of safety concerns	CAVs: several areas of potential identified for CAV safety rules and guidance DDM: high potential because equipment failure would likely cross countries
Equity	CAVs: problems are only anticipated at this point; ride-sharing can be used to improve anticipation DDM: problems already experienced for low-income customers	CAVs and DDM: low portability because of different types of equity concerns (some potential for income-related portability)	CAVs: limited in several areas due to cultural and transportation system differences, but other areas of potential are identified DDM: relatively high potential for income disparities
Privacy	CAVS: not yet salient because of current testing phase DM: longstanding rules from analog era and increasing attention to digital electricity privacy	CAVs and DDM: higher portability because digital privacy rules and concerns span different technological systems	CAVs and DDM: high potential because of similarity of GDPR and FIPPs

frameworks involving digital privacy will likely apply to both technological systems. Moreover, some of the programs and policies that we identified in the harmonization study of electricity privacy could also apply to companies that house databases of CAV records.

With respect to harmonization across political jurisdictions, for CAVs, we found that there is harmonization potential for safety even though there are different regulatory cultures for safety, and we identified areas of harmonization that drew on model practices across countries. With respect to equity, we identified some categories of equity that may be amenable to harmonization for CAVs. For DDM, the concerns with technical equipment failure (safety) and with effects of time-of-day pricing on low-income customers could be the basis for harmonization. For privacy, there are similarities between the GDPR regime in the European Union and the FIPPs-based approach in the U.S. (Lee and Hess 2021a).

Discussion

The projects outlined above provide some suggestions of different ways in which we experimented with a comparative, sociotechnical design perspective, that is, a perspective that is 1) sociotechnical in the sense of including interactions of social scientists and computer scientists, 2) design-oriented in the sense of identifying problems of both policy and system design, and 3) comparative from multiple angles (across technological systems, societal values, and political jurisdictions). The aspiration is that by having interactions of social scientists and computer scientists in this broader comparative, design context, software and hardware design can be improved, and the recommendations developed for improved policy design, guidance, and standards can also be improved. We do not pretend to offer a full solution to the complicated challenges of sociotechnical collaboration. However, based on the collaboration, we develop some hypotheses about the differences in opportunities for collaboration (section 5.1), and we discuss limitations and potential for future research (section 5.2).

Differential opportunities for collaboration

We suggest that it may be easier to develop a comparative, sociotechnical design perspective in the classroom and policy outreach settings than in research. Because the reward system for research tends to focus on the disciplines, multidisciplinary research is often undervalued. For example, for a social scientist positioned in a traditional discipline such as sociology, one's colleagues view the research as 'applied' and not as contributing to the discipline.

However, in the classroom setting, the value of cross-disciplinary training for students is widely shared by social scientists and computer scientists and engineers. Faculty can present their own research and teach from their areas of expertise, and the integrated perspective can be achieved cumulatively across a semester by breaking down topics into different technological systems, countries, and societal values and implications. In our seminar, we used a matrix structure that involved an intersection of a societal value, a technological system, and the policy and software design dimensions (e.g. safety dimensions of CAVs, with both policy and software design perspectives).

We also found a relatively welcome environment in the policy workshops, where there is general agreement that policy should not be in a perpetual situation of catch-up to rapid digitization and innovation of technological systems. Policymakers, industry representatives, engineers, and scientists all called for more research on comparative policy, which the social scientists developed, and for the integration of policy design with system design. Arguably, the relatively welcome environment was related to the information-sharing and advisory dimension of the workshops; in other words, the workshops were not connected to specific policy proposals at play. For example, at the time of the CAV workshop in the U.S., there was an intense controversy over a CAV bill that had stalled in the U.S. Senate, where consumer safety organizations had mobilized a large coalition to achieve improved safety rules (Hess 2020). The workshop stayed away from the more specific policy controversies, and instead the participants focused more on the broader issue of harmonization potential and challenges.

For research in software systems design that integrates a sociotechnical perspective, the situation was more challenging. One reason is that existing funded projects do not necessarily lend themselves to the integrated sociotechnical design approach, which requires collaboration in the planning stage. Nevertheless, as noted above, some of the research was able to achieve a sociotechnical design perspective with cross-national training of students, and one of the collaborative projects involved integrated, team-based research with both social scientists and computer scientists.

With respect to the policy research, one approach that we adopted was to break down the comparative task by focusing on one societal value issue (e.g. safety, equity, or privacy) and one technological system, with comparisons across countries or other political jurisdictions. Another approach was survey research that held the country and technological system constant but compared across a wide range of values. Although no single study involved multiple comparisons across values, countries, and technological systems, the cumulative sum of the projects developed multiple perspectives on the complex problem of how to design technology-aware policy that can also have some potential for harmonization across countries while recognizing cultural and legal differences. Even with the limited comparison between two relatively similar countries (both advanced, Western economies and polities), significant differences emerged.

Limitations and future research

It would be helpful to expand the comparative approach beyond the scope developed in the project to date. With respect to technological systems, adding additional systems and associated industrial sectors (e.g. digital transitions in the medical field, finance, water supply, buildings, etc.) would likely lead to more developed hypotheses and insights on salience, portability, and harmonization. With respect to societal values, the research projects described here focused on only three areas, and future research could examine additional value domains, such as the ones also examined in the classroom portion of the project (e.g. security, sustainability, and democracy). With respect to political jurisdictions, this collaboration focused on Germany and the U.S., with some additional cross-national comparisons. By including non-Western and less wealthy countries as well as paying more attention to scalar differences in political jurisdiction, future research would likely afford additional insights into values and opportunities for innovation in both policy and technology design.

Future research could also examine trade-offs and convergences. For example, in the electricity system, privacy concerns have tended to limit real-time pricing frequency in some countries. However, policies that place limits on the sampling frequency will preclude the benefits of transactive energy. Our combined approach to policy and system design suggests that there are other ways to achieve privacy goals without sacrificing the benefits of transactive energy.

Conclusion

There is great potential in an open-ended, experimental perspective that includes policy design, technology design, and their interactions in collaborations involving social scientists, engineers, and scientists. A comparative, sociotechnical design approach to RI for emerging technological systems is intended to develop questions and to identify problems and potential solutions rather than to prescribe rules. The strategy identifies a broad set of societal values in an empirically based, open-ended way that does not start with a pre-determined set of philosophically derived values or ethical principles. Rather, it begins with real-world, on-the-ground challenges that are emerging with the digital transitions that are occurring with existing technological systems. Actors from diverse quarters—scientists and engineers, policy makers, industry leaders, social scientists, and public interest organization leaders—have recognized and articulated the challenges.

Consistent with other work in RI and STS described above, the approach borrows from the design professions to develop an open-ended, exploratory approach that can be applied to problems of policy, user interfaces, software, and hardware. By articulating the goal of policy-aware technology design and technology-aware policy design, the approach also includes relatively siloed research projects (e.g. a social science analysis of comparative policy regulations and a student's computer science modeling project that solves a problem in the digitalization of technological systems). However, the approach also encourages experiments with more integrated projects in teaching, policy outreach, and research that involve collaborations between social scientists and computer scientists and engineers.

We build on this tradition of sociotechnical collaboration and design thinking by developing a multiple comparative perspective that examines problems and solutions in both the policy and technology areas from the perspectives of different technological systems, societal values, and political jurisdictions. The approach uses the differences as points of potential insight for examining challenges and potential solutions. It then develops a second-order analysis of the comparative salience of different value domains, the similarities and portability of solutions across technological systems, and the harmonization potential of solutions across political jurisdictions. To keep the comparisons manageable, the analysis presented here is restricted to two aspects of the digitization of electricity and transportation systems, three types of societal concern or value, and two countries. Even with this restricted scope, the analysis is quite complex, and it has a steep learning curve. But it also offers new insights that may not be evident in projects with a narrower scope of perspectives.

We found that the multiple perspectives on comparison led to a much more robust approach to teaching than standard 'societal implications' perspectives, and it also led to creative and informative discussions in the workshops. However, the pathway from these more basic forms of engagement to collaborative, multidisciplinary research is more challenging. We were able to achieve sociotechnical integration in some of the student research projects and in one collaborative project (described in 4.3). However, in general, the differences in values and research priorities across disciplines makes the collaborations between social scientists and computer scientists/engineers challenging, and the international collaborations within a discipline were easier to achieve.

For research teams that wish to pursue this approach, several suggestions emerge from this collaboration and analysis. First, the approach requires research teams of social scientists and technical scientists (e.g. computer scientists and engineers) that include different geographical or jurisdictional perspectives (such as across countries), collective expertise in at least two technological systems, and the capacity to examine more than one societal value issue (e.g. safety, equity, or privacy). In other words, attention to these three aspects of the project needs to go into the original planning for the team. Second, researchers need to be aware of the differential opportunities for collaboration and realize that not all projects will be aligned with the vision of a comparative, sociotechnical design perspective. Opportunities are likely to be greatest in the areas of teaching and policy outreach, but they can also occur when social scientists work together with computer scientists and engineers in design projects, especially when the design projects include students and an educational component. In other words, the approach outlined here argues against assuming that every project will be a full-blown application of the vision of comparative, sociotechnical design. Rather, elements of the vision will come together at different points in the collaborations, and they may also inform ongoing projects in new and unpredictable ways.

No one can predict the complicated societal implications of innovation, including large-scale cyber-physical systems that were the focus of this project. However, an approach that builds on the experimental and exploratory approach of the design professions can help to facilitate multidisciplinary communication, education, and collaboration. By bringing in social scientists (who in turn can engage or represent users, civil society organizations, and policymakers) and by having conversations across different political cultures (such as the more neoliberal approach of the U.S. and the more precautionary approach of Germany), it is also possible to explore a middle ground that enables innovation without unintentionally increasing our (human and animal) suffering.

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