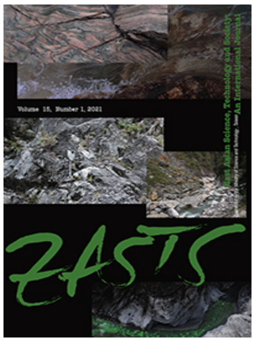

Routledge
Taylor & Francis Group

East Asian Science, Technology and Society: An International Journal

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/teas20

"All We Want, Is to Get Rid of the Straw": How Biofuel Policies Need to Be Multiple

Poonam Pandey, Govert Valkenburg, Annapurna Mamidipudi & Wiebe E. Bijker

To cite this article: Poonam Pandey, Govert Valkenburg, Annapurna Mamidipudi & Wiebe E. Bijker (2021) "All We Want, Is to Get Rid of the Straw": How Biofuel Policies Need to Be Multiple, East Asian Science, Technology and Society: An International Journal, 15:1, 4-23, DOI: 10.1080/18752160.2020.1868697

To link to this article: https://doi.org/10.1080/18752160.2020.1868697

Published online: 30 Mar 2021.

East Asian Science, Technology and Society: An International Journal (2021) 15:4–23
DOI 10.1080/18752160.2020.1868697

OPEN ACCESS

"All We Want, Is to Get Rid of the Straw": How Biofuel Policies Need to Be Multiple

Poonam Pandey, Govert Valkenburg, Annapurna Mamidipudi and Wiebe E. Bijker

Received: 2 June 2019 / Accepted: 18 July 2020

Abstract Second-generation (2G) biofuels are promoted worldwide as remedy to sustainable-energy challenges in the transport sector and as response to the criticism of first-generation biofuels. By utilizing agriculture and forest residues, 2G biofuels claim to support agricultural livelihoods and boost rural economies. Quantitative estimates exist of the availability of "waste" or "unused" or "surplus" biomass that could be fed into producing bioenergy. Most of current discourse on 2G bioethanol is about developing efficient technologies and supportive policies for biomass utilization and energy distribution, while availability and supply of that biomass are often taken for granted. This paper challenges these presumptions of biomass availability and technological feasibility. Following a social-constructivist analysis of technology and focusing on how political actors, scientists, industry, green-revolution and

P. Pandey
Department of Science and Technology-Centre for Policy Research, Indian Institute of Science, India
email: p.pandey23@gmail.com

G. Valkenburg
Department of Interdisciplinary Studies of Culture, NTNU, Norwegian University of Science and Technology, Norway
email: govert.valkenburg@ntnu.no

A. Mamidipudi
The Penelope Project, Deutsches Museum, Germany
email: annapurnam@gmail.com

W. E. Bijker
Department of Interdisciplinary Studies of Culture, NTNU, Norwegian University of Science and Technology, Norway
email: wiebe.bijker@ntnu.no

organic farmers envision biomass, this paper argues that the innovation for 2G is hybrid and complex, rather than merely logistical and economic. Biomass as feedstock is not an off-the-shelf commodity, but a dynamic and fluid entity, the availability of which is dependent on a number of cultural, social, technological and economic factors. Policies are needed that recognize the multiplicity of agricultural practices if a sustainable biofuel system is to be developed.

Keywords social construction of technologies · responsible research and innovation · biofuels · rice straw burning · sustainability policies

1 Introduction

The Social Construction of Technology (SCOT) literature argues that technologies are not made by the mere application of scientific facts, but rather through social processes that are constitutive of technological cultures (Bijker 1995, 2017). These observations have widened the horizons of understanding the interactions of technology and society by opening the black-box of technology (MacKenzie and Wajcman 1999). Especially this unpacking of complex socio-technical systems that are hidden under seemingly clear-cut technologies, seems to have spurred a growing popularity of STS in academia in the global south. The uptake of STS insights and approaches in policy domains, however, has so far been minimal. Questions about the relevance of STS for policy-making have also been asked for countries in the global west (Bijker 2017; Collins and Evans 2002; Jasanoff 1987). In this paper we want to contribute to the discussion about what STS can contribute to and can learn from science and technology policy-making in countries in the global south. We will do this by investigating the case of second generation (2G) bioethanol in India.

Our engagement with this field began when we were working on a project on the Responsible Innovation of Biogas, funded by the Dutch Research Council. In the project, we aimed to engage with relevant stakeholders that could enable a responsible innovation to convert rice straw into biogas. A huge amount of rice straw is currently being burned in the fields every year in India, causing severe health and environmental problems both nearby and more remotely. The conversion of rice straw into biogas seemed an effective and responsible solution for this problem. However, to our surprise, we saw very little interest in biogas among different stakeholders on the ground.

In the policy domain, we observed a preference for the production of 2G bioethanol from rice straw as a means to prevent rice straw burning. It was argued that the rice straw, now being burned as “waste,” could be converted into “wealth” with the right policy support and co-ordination between different stakeholders. This approach was supported by the National Policy on Biofuels (2009), which proposed a target of 20% blending of bioethanol into petrol by 2017. There was a general disappointment, by the end of 2017, that less than 2% of bioethanol blending had been achieved. Most of this bioethanol was produced from molasses from the sugar industry and not from agricultural waste; hence the interest in using rice straw as feedstock for 2G ethanol production. Based on recent estimates of availability of biomass and consideration of many other parameters, the new National Biofuel Policy (2018) lowered the target to 10% blending by 2022. However, policy-makers informed us that the majority of bioethanol is still expected to come from the sugar industry. Despite the predicted physical availability of biomass and the commitment by different stakeholders, its conversion to 2G bioethanol thus remains an unsolved challenge.[1]

In this paper, we explore how core insights from STS can be mobilized to understand, and possibly mitigate this policy conundrum. One layer of analysis will consist of the articulation of the polysemic nature of the problem, pointing to the multiple meanings of biomass and its availability, biofuel, and the phenomenon of burning agricultural residue. We take the SCOT approach as a starting point. A second layer of analysis consists of how these insights can be brought into the policy processes and what we can, as STS practitioners, both contribute to and learn from this reflexive engagement. The key argument here is the need for reflexivity as a condition for nurturing multiplicity in policy-making processes, as well as in our research. Section 2 discusses the literature on policy-relevant STS to situate the current discussion. Section 3 uses the SCOT approach to unpack biomass and thus demonstrate its interpretive flexibility. Section 4 discusses the relevance of STS for policy-making and how policy-making practices could inform STS.

2 Policy-Relevant STS: Rethinking Knowledge, Expertise and Public Participation

STS as the systematic study of science, technology, and society has often found itself at the boundary between critical inquiry and normative decision making (Bijker 2003; Jasanoff 1987). The tensions between a more inward looking theoretical and intellectual discipline, and a more engaging, practice oriented and "servicable" STS, repeatedly surface in academic discussions (Bijker 2003; Jasanoff 1987; Nowotny 2007; Webster 2007; Wynne 2007). Amidst these tensions, there are continuous efforts to contribute more meaningfully to the policy-making processes, especially by rethinking and re-articulating knowledge-making processes (Jasanoff 2004; Nowotny, Scott, and Gibbons 2001; Stirling 2008), re-imagining expertise (Bijker, Bal and Hendriks 2009; Collins and Evans 2007), and re-calibrating the role of diverse knowledge and expertise in policy decisions (Stilgoe and Guston 2017).

Opposing the linear model of diffusion of science and technology, much of the thinking in STS has approached knowledge claims as historically contingent and dependent on the socio-cultural context (Knorr Cetina 1995; Latour and Woolgar [1979] 1986). An important principle has been that of symmetry, which aspires to explain competing knowledge claims in the same terms, rather than explaining that some claims are eventually accepted because they are "true" (Bloor [1976] 1991). With regard to the politics of expertise, Nowotny and colleagues propose a re-imagination of the "policy room" and who might occupy it (Nowotny, Scott, and Gibbons 2001; Nowotny 2007). Collins and Evans (2002) characterize policy-oriented STS as a "third wave" of science studies, driven by a new and extended conception of expertise. Their concepts of "interactional" and "contributary" expertise are useful to describe and legitimize STS engagement with policy-making (Bijker 2017; Collins and Evans 2007). Webster (2007), through his work in different policy initiatives in the UK,

[1] Based on a study conducted by the Technology Information Forecasting Assessment Council (TIFAC) that calculated available biomass based on crops production and crops residue discarded.

identifies three intervention spaces where STS can do "(re-)constructive" work for policy-making. He advocates a deeper study of the epistemic culture of policy-making in order to understand the mechanisms through which formal and informal networks of trust inscribe meaning in knowledge and expertise. By acting as "interactional experts," Webster argues, STS scholars can use the tools of interpretive flexibility to re-define policy problems in ways that can bring different actors to platforms of common interest.

Wynne (2007) calls for a general move toward "institutional reflexivity." This means that rather than blaming the public for misunderstanding science, policy institutions are to reflect on their own historical role in creating public alienation (2007). Yet, when STS experts are invited to policy spaces, they often are expected to "fix" public discontents and "take care" of the social, ethical, and legal issues without disrupting the core agenda of the policy-making (Viseu 2015).

In order to be responsive to the changes in technological cultures and their vulnerabilities and uncertainties, Bijker (2017) proposes an expansion in the repertoire of STS and constructivist approaches. STS practitioners should not only describe the complex socio-technical reality as outside observers, but also embrace co-creating sociotechnical worlds by engaging with the institutions where such ordering and world-making happens (Bijker 2017; Downey and Zuiderent-Jerak 2017). Reflexivity in this context would mean being aware of one's own ontological and epistemological positions and prejudices. At the same time, reflexive engagement would imply humility to accept and renegotiate preconceived positions based on the learning from other epistemic positions and worldviews (Downey and Zuiderent-Jerak 2017). In the case of biofuel technologies and policies the above mentioned insights would mean the following.

First, as we will describe in detail in the next section, there is a lot to be gained by redirecting the focus of biofuel policies from a linear and top-down understanding of science-society interaction, where S&T creates, policy implements, and society adopts. A co-creating worldview calls for attention to all relevant arenas where these technologies are discussed, contested, constructed, and mobilized.

Second, studies in STS have shown that different arenas have different norms for relevance and validity of knowledge (Mamidipudi and Frahm 2020; Valkenburg et al. 2019). Thus, for biofuel policies to make sense to diverse stakeholders, it becomes crucial to understand how different groups mobilize available ideational and material resources to confront, challenge and negotiate with dominant knowledge claims inherent in such policies.

What we would like to add to this discussion, is the need for multiplicity in policy-making, and the role of STS scholars in facilitating this through our research heuristics. Sociotechnical ensembles around biofuel are by definition made up of heterogeneous stakeholders with diverse knowledge practices – not least between biofuel policy-makers and biofuel stakeholders "on the ground." Stakeholders cohere into sociotechnical ensembles around rice straw disposal, in our case two main ones, creating two discourses – one around the frame of Green Revolution and Biofuel, and the other around the frame of Organic Farming with no biofuel. Such discourses can be analyzed as storylines that form the basis for discourse coalitions (Hajer 1995), in the absence of closure around the desirability of turning rice straw into biofuel. Discursive approaches have been demonstrated as useful to study sociotechnical change involving unequal actors, allowing for an account of power relations as well as agency (Isoaho and Karhunmaa 2019). They can on the one hand explain how sociotechnical ensembles of biofuel may have diverse pathways, including non-change (Sovacool and Hess 2017), as well as become a means to create potential for change when building discourse coalitions that allow for new storylines (Hajer 1995). Given the diversity of interpretations between stakeholders, these discursive coalitions we identify, form multiple technological frames around biofuel. In particular, we argue that STS actors on the ground can support the developing of radical storylines to dismantle dominant interests (Smith and Kern 2009), thus co-creating change through uniting actors with different interests under a similar storyline (Kern 2012).

When encouraging more than one storyline, policy-makers can garner support for different pathways to evolve, that take into account participation of marginal groups. Critical here then is that rather than closure, interpretative flexibility is kept open. We propose this approach as a desirable nurturing of multiplicity that is inclusive of outcomes that may emerge from currently marginal positions.

Third, a reflexive engagement with diverse arenas of people, institutions, and practices would then enable us, STS practitioners, to revisit and re-interpret established theoretical concepts such as “closure” in SCOT. Finally, for STS practitioners to contribute in co-creating meaning and material, it is vital to not only *emphasize* reflexivity as an awareness of the multiplicity and situatedness of various knowledges, but also *practice* reflexivity as an awareness for STS-ers themselves of walking the delicate line between actionable knowledge claims and self-defeating constructivist-relativist conceptions of knowledge.

3 A Sociological Deconstruction of 2G Biofuels: The Interpretative Flexibility of Biomass and Its Availability as a Feedstock

The conversion of agricultural waste into 2G bioethanol offers a strategic research site to explore how a social-constructivist analysis can be carried toward a credible policy contribution. The core idea of such an analysis is that the working of a technology is underdetermined by science and engineering principles and thus the result of social processes too (Bijker 1995, 2015). The standpoints, perspectives, and frameworks of the various social groups that interact with the biomass to make it available as a feedstock for bioethanol production are all different. As a result, the technological conversion of waste biomass to 2G bioethanol assumes different meanings in each of their repertoires: it has *interpretative flexibility.*

The first step in a SCOT analysis, then, is to describe how various relevant social groups see a technology, in this case the production of 2G biofuel from biomass. We will focus our analysis on the availability of biomass as feedstock, and how this is itself an interpretative-flexible issue. The next step then, according to accepted SCOT heuristics, would have been to trace how this interpretative flexibility diminishes during the process of social construction of the technology, when one meaning of the technology becomes dominant. However, in this case of a contemporary development, such closure is not yet visible, and we will only be able to demonstrate the interpretative flexibility of biomass and thus explicate the various “conflicting” ideas of the technology. The social construction of a well-working biomass for 2G biofuels is still under way and we will reflect on how STS and policy-making can contribute to and learn from this on-going process of social construction.

In the following sub-sections, we describe how different relevant social groups all mobilize a different biomass for 2G bioethanol. In doing so we will briefly highlight how these groups emerged historically, the tensions and conflicts that shaped their worldviews, and the interests and perspectives that guide them. The concept of "relevant social group" is both an analyst's concept and an actor's concept: the researcher decides which delineation of relevant social groups works best to make sense of the data; but at the same time, actors do have their own idea of the groups that they belong to (Bijker 1995). In this case, we decided (as researchers) that we need to make a distinction between regular farmers and organic farmers; a more fine-grained distinction using geographical or caste indicators (possibly used by farmers themselves) we deem not necessary for our analysis. Our understanding of the historical emergence and constitution of the relevant social groups is primarily based on data collected during a four-year research period (2016–2019). A preliminary understanding of the relevant social groups was developed from literature and desk research, and by attending different policy and scientific events on biofuels. We used a snowballing method of sampling for interviews. Along with individual interviews from actors of different social groups, we also organized three conferences where members from these groups participated, interacted and exchanged their views. A full-day farmers' dialogue was conducted to engage with the diversity of views among farmers.

3.1 Policy-makers: From Waste to Wealth

"Waste to Wealth" is the new slogan in Indian policy circles (Bagla 2016). The slogan is in line with the nationwide campaign "Swatch Bharat"[2] and international programs on clean energy and climate change. During the celebration of World Biofuel Day on 10 August 2019, the minister of Petroleum and Natural Gas presented his vision of "waste to wealth" in relation to conversion of agricultural residues to 2G bioethanol. The minister criticized previous policies on biofuels to not realize the potential of agricultural residues in the country and thus failing to meet the blending targets of ethanol into petrol. The new biofuel policy of 2018, he explained, is committed to creating an innovation ecosystem for 2G ethanol based on agri-residues. Meeting the revised blending targets is still a matter of concern, but with the building of bioethanol plants in the country and the supporting policies, things seem to be on the right path. The rough estimate of available biomass to be converted into biofuel, has more or less remained stable over the past few years.[3]

The focus on bioethanol as a clean renewable energy option goes back to 2002 when the planning commission of India produced a report on the subject (Planning Commission 2002). In the same year, the Ministry of Petroleum and Natural Gas (MoPNG), which is responsible for procurement and distribution of petrol-based

[2] Clean India Campaign of the central government.
[3] The first author has attended four consecutive World Biofuel Day celebrations starting from August 2016.

fossil fuels, launched the *Ethanol Blending Program* (EBP), projected to be in full operation by 2003 (Ray, Goldar, and Miglani 2012). Most of the bioethanol proposed in these policy narratives was first generation (1G): based on conversion of glucose, mostly residues from the sugar industry.

The focus on 2G bioethanol and the idea of agricultural residue as waste is spurred by the burning of huge amounts of rice straw in the northern states of India during harvesting season (Poonam et al. 2017a, 2017b). Based on the availability of this “waste,” promises are being made about the economic wealth that rice straw would bring when converted to 2G ethanol (Bagla 2016; Jacob, Mukherjee, and Jai 2017). Thus, in policy circles, the biggest hindrance in turning the vision of “waste to wealth” into reality is not the non-availability of biomass but the lack of supporting policies to enable an innovation ecosystem to produce and procure 2G bioethanol.

In the vision of “waste to wealth,” 2G bioethanol appears as a potential game changer and the stakes are very high. An estimated 115 billion Indian National Rupee (INR; some 150 M€uro) is needed for this effort (Jacob, Mukherjee, and Jai 2017). Three government-related oil marketing companies (OMCs: Indian Oil Corporation, Bharat Petroleum Corporation Limited, and Hindustan Petroleum Corporation limited) have promised to invest at least 1 billion INR in the building of twelve 2G ethanol plants all over the country. The MoPNG additionally tries to motivate these OMCs to create stubble collection centers in different parts of the country (2017).

To gather data on the availability of biomass, policy-makers have commissioned several studies (Binod et al. 2010; Gupta and Verma 2015; Singh and Gu 2010; Sukumaran et al. 2010). Most of these studies base their estimates on residue-to-crop ratios. Thus, based on the amounts of different crops produced in the country in a year, an estimation of the available amounts of agri-residues can be made. The reliability of this method has been questioned. Even if one could estimate how much agricultural residue is being produced in the country, its availability for conversion to biofuels is influenced by integration in the local rural economy (Ravindranath et al. 2005; Sukumaran et al. 2010).

This method, based on crop production estimates and crop-to-residue ratios, presents the agri-residue as stable and available, ready to be utilized by bioethanol plants, but it ignores and even obfuscates the historical ways in which formal and informal rural economies have been using these agricultural residues. The quantitative estimates of the available biomass, used in policy-making, thus remain “black-boxed.”

3.2 Scientists: Lignocellulose Breakdown and Lignin Valorization

In comparison to the biomass conception of policy-makers, which considers biomass availability for feedstock as a given and an opportunity, for chemistry scientists the problem unfolds quite differently. For them, the technology is not easily available “from the shelf” to turn the “waste” biomass into “wealth” bioethanol. For the scientific community, the physical availability of surplus agricultural residue does not automatically translate to availability of feedstock for the production of 2G bioethanol, though this is – for scientists – not a logistical problem. For them, the challenge of using agricultural and forest residues as a feedstock for biofuel conversion is the lignin in the residues and the lack of technological capability to either separate or valorize lignin in the production chain.

Many agricultural residues, and especially straw from rice plants grown in the north of India, contain lignin (the wood-like substance that provides rigidity to plant parts). In order to separate lignin from the cellulose and hemicellulose, the biomass requires pre-treatment. This pre-treatment is not chemically straightforward and increases the cost of biofuel production significantly. Lignin itself is high in energy content too, so it would be attractive as a feed-in substance for biofuel. However, the problem is that its complex chemical composition makes it impossible for bacteria to convert it to ethanol. Also, this envisioned value chain competes with the fact that, if separated efficiently, lignin could also be converted into many other valuable chemicals.

Lignocellulose-based conversion to ethanol presents a host of different scientific challenges in comparison to sugar-based (e.g. sugarcane molasses) or starch-based (corn) production (Bai, Anderson, and Moo-Young 2008; Sukumaran et al. 2010). Various steps in the conversion of lignocellulose-based biomass include pre-treatment, fermentation and hydrolysis.[4] All over the world, research is carried out into all these aspects of lignocellulosic conversion; and this is the case in India too.[5] Until now, however, no commercially viable production unit exists that converts lignin to ethanol. All units that currently use lignocellulose-based biomass, separate and burn lignin to produce energy.

Currently, the technologies that convert the C_5 and C_6 sugars of hemicellulose and cellulose in the pre-treated mix, are not very efficient either (Sukumaran et al. 2010). Research is carried out to develop more efficient technologies for these conversions. These technologies include the use of genetically modified organisms and synthetic biology (Levidow and Paul 2008; Mohr and Raman 2013). These approaches come with their own, specific sets of socio-economic, political and ethical challenges. These will need to be considered and addressed, before they can become viable elements in the 2G biofuel production.

Another challenge that scientists engage with is the development of so-called "feedstock-agnostic technologies": biofuel-producing technologies that run at an optimum level of production, irrespective of the type of biomass provided as feedstock.[6] As different types of biomass have different compositions and ratios of cellulose, hemicellulose and lignin, developing feedstock-agnostic conversion technologies is a daunting task.

The most prominent challenge, within the chemistry scientists' frame, remains the conversion of lignocellulosic materials into useful feedstock for ethanol. Thus, scientists primarily see a "convertible biomass," once they have solved this pre-treatment problem. As long as no efficient technologies exist for separation and use of lignin, the physical availability of lignocellulose-

[4] For a detailed understanding of the scientific process of lignocellulose based conversion to ethanol, see Binod et al. (2010), Sanchez and Cardona (2008).

[5] The Research Center at the Indian Oil Corporation has made substantial progress in pre-treatment of lignin. The Institute of Chemical Technology, funded by Department of Biotechnology (DBT-ICT), has set up a pilot plant based on lignocellulose-based biomass.

[6] Discussion with a senior scientist from the Department of Biotechnology-Institute of Chemical Technology (DBT-ICT), 8 March 2018, New Delhi.

containing waste, such as rice straw, holds little significance: the major part of this biomass cannot be utilized in the conversion process.

3.3 Biofuel Industry: Managing the Supply Chain

The industry is attracted by the policy vision of "waste to wealth" and assumes that scientists will solve the technical problems of dealing with the "convertible biomass" – the industry's main concern is yet a different one. A manufacturing plant's major challenge lies in setting up a sustainable supply chain and ensuring a smooth, year-round availability of feedstock. Many industrial participants in different meetings have underscored that the fate of this industry lies in the efficiency with which a supply chain can be set up and how an "evenly available biomass" can be created.[7]

The specific supply-chain issues are in part related to the situation on the farm, which will be discussed in the next section. A sustainable supply chain must also include efficient mechanisms to transport biomass from the farm to the industry, storage facilities to ensure year-round supply, and an integrated network of industry, local entrepreneurs and farmers to enable the above steps. These challenges are aggravated because the collection of rice straw and its transportation from the farm needs to happen within a 15–20 day window (see next section). All these requirements increase the costs of producing 2G biofuels.

Currently, the major operational cost of a biomass supply chain is remuneration to farmers for waste biomass transport, storage and mechanization. According to one industry representative, "coming to a consensus with farmers on the most appropriate remuneration for the waste biomass is currently the biggest challenge for the bioethanol plants." He commented that "if the biomass is really 'waste' for them, then it should be available at a negligible price" (Official, Bharat Petroleum Corporation Limited, 10 August 2019). An alternative approach to create a sustainable supply chain that takes the views of farmers more seriously, would focus on local needs and engage with farmers and their organizations. Such an approach would require the creation and support of local entrepreneurial capacity and a close cooperation between farmers' organizations, civil society, and industry.

Although these issues are discussed in the policy and industry domains, few attempts are made to actually engage farmers and civil society. There are some small companies such as Punjab Renewable Energy Private Limited (PERSPL) that have developed some experience in this field over the years, but without their being integrated into the larger biofuel frame, it is difficult for them to sustain.[8] For industry, the necessary "evenly available biomass" is still a far-away ideal.

3.4 Green-revolution Farmers: Rice Straw as Waste

The vast majority of farmers in the north of India use the green-revolution (GR) model of farming. This model, which became popular in the 1960s, is a high-

[7] Biofuel days 2016, 2017; EU-India conference on advanced biofuels, 7–8 March 2018.

[8] The issue of challenges to the survival of small enterprises working on biomass supply chain was raised by the CEO of PERSPL in a discussion on 7 March 2018, New Delhi.

input – high-output model that uses extensive irrigation, chemical fertilizers and pesticides, hybrid mass-produced seeds known as high-yielding varieties, and heavy mechanization (Larson et al. 2004). In the 1970s, this kind of farming, supported by central-government initiatives and programs resulted in a steep increase of production of food grains and a revolution in the way farming was conducted and thought about in India (Brooks 2005). The majority of farmers in the northern states of Punjab, Haryana and Uttar Pradesh, where the government schemes were implemented, have turned from traditional modes of agriculture to GR farming.

Most farmers who practice the GR model have a 15–20 day window between harvesting rice and sowing wheat. They are constrained by the time restrictions of the crop rotation cycle: an earlier harvesting of the rice or a later sowing of the wheat would both jeopardize the respective yields (Mukerjee 2016). Thus, the major challenge for farmers is to get rid of the straw in that 15–20 day period. In absence of better alternatives, most farmers burn the rice straw. This, as we have mentioned, leads to negative health and environmental impacts on farming communities and on nearby areas including the capital city of Delhi. So many problems are caused by straw burning, that the National Green Tribunal has passed a law to penalize farmers who burn the straw (Kazmin and Singh 2017; Poonam et al. 2017a, 2017b).

Over the years, many scientific and technological innovations were aimed at increasing productivity in less time and have been incorporated in the GR model. Some of these innovations have shortened the time between crop rotations, using the combine harvester machine that at once harvests the crop and separates the edible grains from the rest of the plant. Earlier, the excess rice straw was used as a fodder for animals. Over the years, the machine has replaced animals. In addition, the use of combine harvesters in combination with the practice of growing rice in standing water has led to the use of rice varieties with sturdier plant stems with higher silica and lignocellulose content (Raina and Sanger 2002). These sturdier stems, however, are inedible for animals. Among the many unforeseen challenges posed by GR farming, which only became apparent over time, one major problem is thus to get rid of the excess rice straw that has no use in the local farming practice.[9]

This puts additional pressure on the logistics that we already discussed in the previous section: not only is a logistical system needed to get the straw from the farmland to the biofuel conversion plants; this system also needs to operate at a high speed during a short time (Poonam et al. 2017b). It has to compete with the practice of burning, which vacates the field quickly and efficiently (at least in the short run, neglecting the long-term deterioration of the farmland). So, this "nuisance biomass" is rather burned than turned into 2G biofuel feedstock. Most GR farmers recognize the valuable nutrients that they lose by burning the rice straw. Hence, they also see the burning of straw as a protest against being excluded from the biofuel policy considerations by government and industry. The "nuisance" biomass of GR farmers, thus, also becomes a nuisance for other social groups.

[9] Discussion with farmers on 28 November 2016 during a farmers' dialogue event on "Responsible Innovation and Sustainable Agriculture: The Problem of Rice Straw Burning in Punjab," Village Bahawalpur, Patiala, Punjab.

3.5 Organic Farmers: Rice Straw as Food for the Soil

Organic and natural farming is gaining momentum in the northern states of India. This has happened in response to the negative impacts of the GR model (Bhalla and Chadha 1982; Rahman 2015; Shiva 2016; Singh 2000). One central feature of natural farming is attention to soil health as a way to increase profits with reduced use of resources and lower economic inputs (interview, farmer, 10 February 2017). This calls for enriching soil micro-flora and fauna, which is often damaged by the use of GR chemical fertilizers and pesticides (interview, CEO, KVM, 28 November 2016).

Rice straw serves as a great source of food for the soil ecosystem when mulched on the field after harvest. During our field visits to organic and natural farms in Punjab and interviews with farmers in Haryana and UP, farmers demonstrated that many different varieties of soil organisms (including the easily visible earthworms), which are beneficial for crops, are thriving on the decomposed straw (Farmers' Dialogue 28 November 2016). In addition, mulching and the presence of soil organisms help to retain the porousness and moisture of the soil. Farmers who practice organic and natural farming never burn their rice straw.[10] We were told during our field visits that they sometimes have to buy additional rice straw from nearby farmers in order to meet their planned "organic fertilizing." The organic farmers, then, are dealing with "nutrients biomass."

In comparison with GR farming, organic farming is typically questioned about its supposedly lower productivity and the required higher input of labor. While a detailed assessment of the benefits of organic farming is beyond the scope of this paper, its growing popularity in the northern states of India is relevant here. There are many civil society organizations, such as the Kheti Virasat Mission in Punjab, [11] which actively engage with farmer organizations to spread awareness about the benefits of natural and organic farming and to set up local markets that enable procurement and distribution of organic produce (interview, November 2016).

For organic farmers, rice straw, thus, is not a waste, but an important input for their agricultural practice. Even though they produce rice straw, they are not interested to offer it as feedstock for bioethanol plants. This is hardly recognized in policy circles. The recent annual national budget (2018–2019) announced support of organic farming. If these mandates are brought into practice, and if more and more farmers subscribe to organic agriculture, the calculated availability of rice straw as feedstock would decrease. If procurement of rice straw from organic farmers is to be part of the equation, there has to be a strategic focus on alternative ways of improving soil fertility, for example through organic manure. A Punjab biogas industry using rice straw as feedstock has indeed been successful in engaging with farmers and addressing their needs to improve soil health.[12] This biogas plant provides farmers

---

[10] The one-day farmers' dialogue on "Responsible Innovation and Sustainable Agriculture: The Problem of Rice Straw Burning in Punjab," Village Bahawalpur, Patiala, Punjab; meeting with another group of farmers organized by Krishi Vigyan Kendra, Nurmahal, Jalandhar Punjab on 27 July 2016 and multiple field visits to organic farmers in July 2016.

[11] http://www.khetivirasatmission.org/organic-farmers-market.html accessed on 9 March 2018.

[12] http://www.sampurn.in/about-savpl/ accessed on 9 March 2018. Such civil society organizations are important when considering reform of agricultural practice, but since in this case they are aligned to the RSG of organic farmers, we will treat them together.

with organic manure in exchange for rice straw. Enterprises like these have a considerable advantage in enrolling local communities and hold a competitive edge in acquiring biomass for 2G ethanol production.

To sustain organic farming, policy mechanisms would need to be developed to include such small and medium entrepreneurs into the 2G biofuel value chain. It would then turn the "nutrients biomass" into a "waste-to-wealth biomass" and perhaps even an "evenly available biomass." Alternatively, rather than persuading the organic farmers to enroll in the industrial production system for bioethanol, the availability of biomass for 2G bioethanol could be more appropriately estimated by recognizing and respecting their intention to enrich the soil by traditional methods of biomass utilization.

4 Analysis: How Can SCOT Contribute to Biofuel Policy-making?

In contrast to dominant assumptions in the biofuel policies, we have described how the different locations of relevant social groups in the socio-economic-political landscape and their different frames of agriculture and energy production result in making different biomasses. These different biomasses have very different assets and problems – biomass as "waste-to-wealth," "convertible," "evenly available," "nuisance," and "nutrients." We thus have, in the parlance of SCOT, demonstrated the interpretative flexibility of the technological substance biomass. This interpretative flexibility is not caused by any chemical or physical differences between the five biomasses – they are chemically, physically, and biologically identical. The huge differences – enough to prevent a smooth implementation of any 2G biofuel policy – are caused by the social, cultural, ideological, economic, and political differences between the relevant social groups, and the specific ways in which they are situated in relation to agriculture and energy production. As a result of these differences, the calculated availability of biomass to meet the policy targets of producing 2G biofuels make little sense. Based on our engagement with diverse discourses that shape different worldviews, in this penultimate section, we will discuss what this might mean for the future development of 2G biofuel, and how STS practitioners can contribute to policy-making while bringing back reflexive insights from the field to rethink their own concepts.

4.1 Discourse Coalitions and the Multiplicity of Frames

For an effective biofuel policy there needs to be coordination between policy goals and efforts on the ground to achieve these. This coordination is only possible when a policy document can produce shared meanings and worldviews for all relevant actors. One way through which shared meaning is created, a notion central to the SCOT approach, is that of *closure*: reduction of interpretive flexibility, such that one meaning becomes dominant and the character of a technology becomes more fixed.[13] Also, closure typically entails that the controversial history of a technology

[13] The concept of "closure" was coined by Harry Collins in his controversy studies of scientific knowledge. In SCOT, often the concept of "stabilization," rather than closure, is used to stress the time-drawn character of decreasing interpretative flexibility. Here we will continue to use "closure" since it does highlight the controversial nature that interpretative flexibility can also be a sign of.

(and in this case also: technology concepts as enshrined in policy) fades out of view, rendering the final outcome seemingly the only possible outcome of history (Bijker 1995). In real life, the process of closure is a lot messier and requires multiple efforts. These include inhibitory and persuasive tactics by powerful social groups. For example, in our case, the legal ban on burning straw puts farmers in a position where, despite their discontents, selling straw at a lower price may seem like less of a "nuisance." The buy-back guarantee for bioethanol from government at an attractive price works as a persuasive tactic to attract entrepreneurs to establish bioethanol plants. Similarly, in order to enroll farmers, the entrepreneurs have tried to attract them by providing organic manure in return for straw. In our analysis above, it is clear that closure has not yet been achieved: multiple understandings of biomass still exist next to one another. However, there seems to be a possibility of convergence and creation of shared meanings through discourse coalitions (Hajer 1995). The first discourse coalition is taking shape around the policymakers' waste to wealth, the scientists' convertible biomass, the industry's evenly available biomass, and the nuisance biomass of green revolution farmers – together turning waste rice straw into continuously available and convertible biomass that can be utilized to produce 2G ethanol profitably for all. This discourse coalition may result in a technological frame which we call the GR-biofuel frame. The second discourse coalition is formed around the nutrient biomass of organic farmers, making production sustainable for both farmer and consumer, and leading to the sustainable use of environmental resources. We call this the Organic Farmer (OF) frame. While this second discourse coalition is mainly led by the organic farmers, the other stakeholders do play a role in this coalition too. The state promotes organic farming in some of its policies, industry supports sustainable production and research of circular economies, the GR farmer is quick to grasp technological solutions that organic farmers propose, and many agricultural university scientists support in-situ straw management which effectively supports the organic farmers' worldview.

By recasting our analysis in terms of discourse coalitions, the object of STS analysis has shifted from the conversion technology and the biomass to the technological frames themselves – and to the discourse coalitions that bring different stakeholders together in creating shared meanings and worldview. In this situation, interpretative flexibility is staying open rather than disappearing into a singular closure; and reflexivity as practice becomes necessary for all relevant social groups, as they negotiate their various, often contradictory, positions within two discourse coalitions.

4.2 Mobilizing Discourse Coalitions for Inclusive Policy-making

So, how can the biofuel policies mobilize these discourse coalitions and establish the coordination between goals and actions? Based on the discussion and insights from different social groups above, it could be argued that the biofuel policy should make active efforts to support the discourse coalition around the GR-biofuel frame and the OF frame. Thus, by a "careful" negotiation between creating shared meanings and worldviews (GR-biofuel frame) and making space for diversity and differences (OF frame), biofuel policies can be more inclusive and effective.

In the first frame, the four biomasses do highlight different aspects and identify different problems as “the” problem. Nevertheless, they are not mutually exclusive: ideally, if the lignocellulose issue is tackled, and the supply chains are in place, and the straw is collected from the farmers who want to get rid of it anyway, then the policy-makers, scientists, biofuel industry, and green-revolution farmers would probably be able to come to an implementation that all can be satisfied with, at least to some degree. That leaves, still firmly in place, the fact that also within the GR-biofuel frame, production of 2G biofuels does offer many more challenges than merely technological and logistical ones. This is specifically the case when there is strong disagreement between the different social groups about the worth of agricultural waste.

Besides focusing on efforts toward integration of the above-mentioned different bio-masses, in order to be effective, the biofuel policy needs to pay attention to the second frame too – of the fifth group, organic farmers. Currently, the GR-biofuel frame emerging from the first four groups seems largely incompatible with organic farming and in-situ management of straw. The only point of connection we currently see is the version of biofuel production that promotes organic manure supply to the farmers. This solution itself does not seem to have a large support within the GR-biofuel frame. And, for organic farmers, because of the lack of any consideration for the health of the soil, the GR-biofuel frame presents a disruption rather than an opportunity. Thus, we expect that the OF frame will *not* converge or merge into the GR-biofuel frame. Its ways of dealing with rice straw, which is more concerned with the mutual co-existence and inter-relationship between soil micro-fauna, livestock, and human beings, differs in too many significant ways from the GR-biofuel frame.

For the biofuel policies to be effective, in this case, it is important that they are inclusive and valorize both these frames rather than one at the expense of other. We observed that the frames of the various relevant social groups do not receive equal attention when policies are formulated. The social, economic, and political differences between the relevant social groups are such that they do not have equal access to the centers of policy-making and are not heard equally well. There are, in other words, important power differences between these groups. The views and knowledge of the Ministry of Natural Gas and Petroleum, major industries, and scientists typically have more power than the views of, for example, farmers, civil society organizations, or small entrepreneurs. In addition, the problem is not only that farmers’ knowledge is poorly included into policy and technology development. It is also that their knowledge is considered through the lens of experts and policy-makers, which already forms a straitjacket by which important cognitive capital is lost (Mamidipudi and Frahm 2020; Valkenburg et al. 2019). A lack of attention to these other knowledges and practices will prevent any policy from working. The failure of the previous biofuel (2009) policy in meeting the blending targets is probably the most direct proof that local meanings, practices, and diverse worldviews, even if currently perceived as marginal, can accrue power and need to be taken into account during policy deliberations.

Indeed, the power differences that account for the prioritization of (in this case) the GR-biofuel frame, are not naturally given or cast in stone. Rather, they can change, both by contingent developments in the relations between groups, and by strategic interventions. Hence, policies could be formulated to mitigate them. An example of an intervention to give more voice to a relatively powerless perspective was our organizing the farmers' meeting and the subsequent invitation to the organic farmers to participate in the workshops with scientists, policy-makers, and industrialists. For policy to include largely unheard voices, specific expertise is needed. It is insufficient for such expertise to be multidisciplinary. Rather, it needs to be transdisciplinary, i.e. able to enroll and incorporate knowledges that are not regularly considered formal expertise, but stem from other origins such as crafts, traditions and practices. NGOs might be important providers of such knowledge, though trust in them as producers of reliable data is low (Han et al. 2015; Pandey and Sharma 2017).[14] Thus, mobilizing discourse coalitions for inclusive policy-making requires that policy creates conditions for nurturing multiplicity of discourses, rather than works toward singular outcomes. Particularly, by not closing out marginal views, policy-makers can create space for possibilities that may not currently be plausible, but are deemed desirable for the future.

4.3 Thinking Through Multiple Closures

The insights gained from the field about the emerging discourse coalition in support of two frames suggest that the biofuel policies should actively keep the interpretive flexibility alive. They also enable us, STS practitioners, to critically reflect on our own disciplinary positions and concepts. As a result, we argued for multiple closures in SCOT. Although, our suggestions may seem peculiar within the SCOT perspective, this is not necessarily the case: the SCOT heuristic does not *normatively* make a plea toward consensus or singular closure; rather SCOT offers a framework to *empirically* study these processes of technology development which are found to often – but not necessarily always – end up in singular closure. We suggest that in this case of biomass policy, it is advisable to deliberately work toward maintaining multiple frames (in this case two), rather than to work toward singular closure. While it remains to be seen whether this can work in practice, there is no fundamental reason why two or more discourse coalitions could not result in stabilizing two frames. For SCOT itself, this suggests further research on how such multiplicity can be convincingly conceptualized.

In this context, we need to recognize that what counts as closure depends on the level of analysis chosen. A well-known example of parallel technology evolution is offered by computer operating systems: Microsoft Windows, Apple's iOS and the Linux/Unix ecosystems each perform more or less the same functions and it depends on the level of analysis whether they count together as closure of "the operating system," or separately as multiple independent closures of different operating systems. Also, if the notions of stability and closure are in the SCOT framework primarily explained by social causes and not by natural and technical ones, then a multiplicity of closures would probably require the ability to think of multiple power structures existing in parallel, which probably brings additional

[14] For a detailed discussion on engaging with heterogeneity of knowledge see Valkenburg (2020).

challenges of demarcation (of practices, paradigms, social systems, etc.). And finally, it would require the conceptualization of *what exactly* it is that is multiple. Could something that, in the end, is largely technologically the same (in this case: bioethanol technology) function in the two different frames? And if so, do the frames then represent merely different ways of viewing the world or fundamentally different ontologies?

5 Conclusion

In this paper we employed the SCOT perspective to explain why there is a stark gap in aims and targets proposed in biofuel policies in India and the actual practice and achievement of these targets. The SCOT framework enabled us to understand that other than the frame developed and promoted in the biofuel policies, many diverse frames with different understandings of biomass, agriculture, and bioenergy exist. These frames and worldviews are constituted and supported by diverse social groups which are crucial stakeholders in biofuel policy. The diversity of worldviews keeps the interpretive flexibility, of biomass and technology, open. This results in a lack of closure, only partially shared meanings and worldviews and thus gaps in promises and practices. The challenge in front of biofuel policies is: how to create shared meanings and common interests in the face of diversity and interpretive flexibility (Valkenburg 2020). We argue that biofuel policies should actively support emerging discourse coalitions that might eventually converge and stabilize frames. This convergence does not necessarily mean moving toward singular closure. Rather, the discourse coalitions enable convergence of meanings and interests that keep the diverse frames alive. With the evidence from the case discussed here, we propose to actively pursue multiple closures so that marginal interests do not get excluded from the policy process. In our case, the discourses are converging around two frames – GR-biofuels and Organic Farming. Discourse-coalition forming is an active and dynamic process that varies over time. Some of the discourse coalitions have converged while others have diverged. However, in order to prevent skewing of support toward powerful interests, there needs to be a strong focus on inclusion, social justice, and environmental sustainability.

Inclusion of more heterogeneous forms of knowledge and plurality of perspectives in policy-making is crucial for public support, especially when these publics are stakeholders in the said policy. This comes again with a double challenge. Conceptually, it raises the issue of how policy should proceed if knowledge is available for policy remains multiple. And strategically, it is by no means granted that STS practitioners will be listened to when their main message is one of making things more complicated. At the same time, things are not at all hopeless. In our specific case, we see that agricultural university scientists, who previously were only focused on technology promotion, have now reframed their strategy to support in-situ straw management and this aligns very well with the OF frame of managing biomass. While it is hard to generalize this observation, at least it shows that the messiness of the empirical world also provides hooks to work in a specific direction.

The focus here should not be on how to make STS output more singular, but on how to make policy arenas more receptive to heterogeneous input and support them with the concepts needed to facilitate multiplicity. Regarding the ability of STS to speak to policy, the main challenge is how to be relevant while at the same time being open-ended and impartial toward specific frames.[15] In line with general notions on *responsible research and innovation*, holding that innovation processes should amongst other things be responsive (e.g. Stilgoe, Owen, and Macnaghten 2013), STS could aspire to articulate policy options that enable such responsive innovations, rather than advising toward specific techno-scientific solutions.

In any case, it will remain challenging for STS to be policy-relevant if it also aspires to cherish multiplicity. For all the reasons given in this article, we do believe this to be an endeavor worth embarking on.

References

Amy, Kazmin, and Jyotsana Singh. 2017. "Smoke -choked Delhi Pushes Farmers to Stop Burning Straw." *Financial Times*, October 19.

Bagla, Pallava. 2016. "Wealth from Waste: A Novel Indian Biotech Solution." *The Economic Times*. May 1.

Bai, F. W., W. A. Anderson, and M. Moo-Young. 2008. "Ethanol Fermentation Technologies from Sugar and Starch Feedstocks." *Biotechnology Advances* 26 (1): 89–105. doi:10.1016/j.biotechadv.2007.09.002.

Bhalla, G. S., and G. K. Chadha. 1982. "Green Revolution and the Small Peasant: A Study of Income Distribution in Punjab Agriculture: II." *Economic and Political Weekly* 17 (21): 870–877.

Bijker, Wiebe E. 1995. *Of Bicycles, Bakelites, and Bulbs: Toward a Theory of Sociotechnical Change*. Cambridge, MA: MIT Press.

Bijker, Wiebe E. 2003. "The Need for Public Intellectuals: A Space for STS." *Science, Technology & Human Values* 28 (4): 443–450. doi:10.1177/0162243903256273.

Bijker, Wiebe E. 2015. "Social Construction of Technology." In Vol. 24 of *International Encyclopedia of the Social & Behavioral Sciences*, 2nd ed. edited by James D. Wright, 135–140. Oxford: Elsevier.

Bijker, Wiebe E. 2017. "Constructing Worlds: Reflections on Science, Technology and Democracy (And a Plea for Bold Modesty)." *Engaging Science, Technology, and Society* 3: 315–331. doi:10.17351/ests2017.170.

Bijker, Wiebe E., Roland Bal, and Ruud Hendriks. 2009. *The Paradox of Scientific Authority: The Role of Scientific Advice in Democracies*. Cambridge, MA: MIT Press.

Binod, Parameswaran, Raveendran Sindhu, Reeta Rani Singhania, Surender Vikram, Lalitha Devi, Satya Nagalakshmi, Noble Kurien, Rajeev K. Sukumaran, and Ashok Pandey. 2010. "Bioethanol Production from Rice Straw: An Overview." *Bioresource Technology* 101 (13): 4767–4774. doi:10.1016/j.biortech.2009.10.079.

Bloor, D. [1976] 1991. *Knowledge and Social Imagery*. 2nd ed. Chicago: University of Chicago Press.

Brooks, Sally. 2005. "Biotechnology and the Politics of Truth: From the Green Revolution to an Evergreen Revolution." *Sociologia Ruralis* 45 (4): 360–379. doi:10.1111/j.1467-9523.2005.00310.x.

Collins, H. M. 1991. "'Captives and Victims: Comment on Scott, Richards, and Martin'." *Science, Technology & Human Values* 16 (2): 249–251. doi:10.1177/016224399101600207.

Collins, H. M., and R. Evans. 2002. "The Third Wave of Science Studies: Studies of Expertise and Experience." *Social Studies of Science* 32 (2): 235–296. doi:10.1177/0306312702032002003.

Collins, H. M., and R. Evans. 2007. *Rethinking Expertise*. Chicago, IL: University of Chicago Press.

Downey, Gary Lee, and Teun Zuiderent-Jerak. 2017. "Making and Doing: Engagement and Reflexive Learning in STS." In *The Handbook of Science and Technology Studies*. 4th ed., edited by Ulrike Felt, Rayvon Fouché, Clark A. Miller and Laurel Smith-Doerr, 223–251. Cambridge, MA: MIT Press.

Gupta, Anubhuti, and Jay Prakash Verma. 2015. "Sustainable Bio-ethanol Production from Agro-residues: A Review." *Renewable and Sustainable Energy Reviews* 41: 550–567. doi:10.1016/j.rser.2014.08.032.

[15] We recognize that STS research is often, and almost inevitably, perceived as supporting the relatively marginal and less powerful. For this inevitability, see Scott, Richards, and Martin (1990). For the need and possibility to, nevertheless, aspire impartiality and symmetry, see Collins (1991).

Hajer, Maarten A. 1995. *The Politics of Environmental Discourse: Ecological Modernization and the Policy Process*. Oxford: Oxford University Press.

Han, X., C. Engeman, R. P. Appelbaum, and B. H. Harthorn. 2015. *Democratizing Technologies: Assessing the Roles of NGOs in Shaping Technological Futures*. Santa Barbara, CA: NSF Center for Nanotechnology in Society, University of California. http://www.cns.ucsb.edu/sites/www.cns.ucsb.edu/files/demtech/Democratizing%20Technologies%20Conference%20Report.pdf

Isoaho, K., and K. Karhunmaa. 2019. "A Critical Review of Discursive Approaches in Energy Transitions." *Energy Policy* 128: 930–942. doi:10.1016/j.enpol.2019.01.043.

Jacob, S., S. Mukherjee, and S. Jai. 2017. "PetroMin Pushes OMCs to Buy Paddy Stubble." *Business Standard*, November 25.

Jasanoff, Sheila S. 1987. "Contested Boundaries in Policy-relevant Science." *Social Studies of Science* 17 (2): 195–230. doi:10.1177/030631287017002001.

Jasanoff, Sheila. 2004. *States of Knowledge: The Co-production of Science and Social Order*. London: Routledge.

Kern, F. 2012. "The Discursive Politics of Governing Transitions Towards Sustainability: The UK Carbon Trust." *International Journal of Sustainable Development* 15: 90–106. doi:10.1504/IJSD.2012.044036.

Knorr-Cetina, Karin. 1995. "Laboratory Studies: The Cultural Approach." In *Handbook of Science and Technology Studies*, edited by Sheila Jasanoff, Gerald E. Markle, James C. Petersen and Trevor Pinch, 140–166. Thousand Oaks: Sage.

Larson, Donald W., Eugene Jones, R. S. Pannu, and R. S. Sheokand. 2004. "Instability in Indian Agriculture—A Challenge to the Green Revolution Technology." *Food Policy* 29 (3): 257–273. doi:10.1016/j.foodpol.2004.05.001.

Latour, Bruno, and Steve Woolgar. [1979] 1986. *Laboratory Life: The Construction of Scientific Facts*. Princeton, N.J.: Princeton University Press.

Levidow, L., and H. Paul. 2008. *Land-use, Bioenergy and Agro-biotechnology.* Berlin: WBGU.

MacKenzie, Donald, and Judy Wajcman. 1999. *The Social Shaping of Technology.* Milton Keynes: Open University Press.

Mamidipudi, Annapurna, and Nina Frahm. 2020. "Turning Straw to Gold: Mobilizing Symmetry in Responsible Research and Innovation." *Science, Technology and Society.* doi:10.1177/0971721820902964.

Mohr, Alison, and Sujatha Raman. 2013. "Lessons from First Generation Biofuels and Implications for the Sustainability Appraisal of Second Generation Biofuels." *Energy Policy* 63: 114–122. doi:10.1016/j.enpol.2013.08.033.

Mukerjee, Polash., 2016. "Crop Burning: Punjab and Haryana's Killer Fields." *Down to Earth*. October 25.

Nowotny, Helga. 2007. "How Many Policy Rooms are There? Evidence-based and Other Kinds of Science Policies." *Science, Technology & Human Values* 32 (4): 479–490. doi:10.1177/0162243907301005.

Nowotny, Helga, Peter Scott, and Michael Gibbons. 2001. *Re-thinking Science: Knowledge and the Public in an Age of Uncertainty.* Cambridge: Polity Press.

Pandey, Poonam, and Aviram Sharma. 2017. "NGOs, Controversies, and 'Opening Up' of Regulatory Governance of Science in India." *Bulletin of Science, Technology & Society* 37 (4): 199–211. doi:10.1177/0270467619861561.

Planning Commission (PC). 2002. *Report of the Committee on Development of Biofuels*. New Delhi: Government of India.

Poonam, Pandey, Govert Valkenburg, Annapurna Mamidipudi, and Wiebe Bijker 2017a. "Stubble Burning and Pollution: It Is the Question of Dignity and Identity of Farmers." *Hindustan Times*. October 27.

Poonam, Pandey, Valkenburg Govert., Mamidipudi Annapurna, and Bijker Wiebe. 2017b. *The Key to Resolving Straw Burning: Farmers' Expertise*. Maastricht: Maastricht University.

Rahman, Saidur. 2015. "Green Revolution in India: Environmental Degradation and Impact on Livestock." *Asian Journal of Water, Environment and Pollution* 12 (1): 75–80.

Raina, Rajeswari Sarala, and Sunita Sangar. 2002. "Water Quality, Agricultural Policy and Science." *Knowledge, Technology & Policy* 14 (4): 109–125. doi:10.1007/s12130-002-1018-9.

Ravindranath, N. H., H. I. Somashekar, M. S. Nagaraja, P. Sudha, G. Sangeetha, S. C. Bhattacharya, and P. Abdul Salam. 2005. "Assessment of Sustainable Non-plantation Biomass Resources Potential for Energy in India." *Biomass & Bioenergy* 29 (3): 178–190. doi:10.1016/j.biombioe.2005.03.005.

Ray, Saon, Amrita Goldar, and Smita Miglani. 2012. "The Ethanol Blending Policy in India." *Economic and Political Weekly* 47 (1): 23–25.

Sanchez, Oscar J., and Carlos A. Cardona. 2008. "Trends in Biotechnological Production of Fuel Ethanol from Different Feedstocks." *Bioresource Technology* 99 (13): 5270–5295. doi:10.1016/j.biortech.2007.11.013.

Scott, Pam, Evelleen Richards, and Brian Martin. 1990. "'Captives of Controversy: The Myth of the Neutral Social Researcher in Contemporary Scientific Controversies'." *Science, Technology & Human Values* 15 (4): 474–494. doi:10.1177/016224399001500406.

Shiva, Vandana. 2016. *The Violence of the Green Revolution: Third World Agriculture, Ecology, and Politics*. Lexington, KY: University Press of Kentucky.

Singh, Jasvinder, and Gu Sai. 2010. "Biomass Conversion to Energy in India—A Critique." *Renewable and Sustainable Energy Reviews* 14 (5): 1367–1378. doi:10.1016/j.rser.2010.01.013.

Singh, R. B. 2000. "Environmental Consequences of Agricultural Development: A Case Study from the Green Revolution State of Haryana, India." *Agriculture, Ecosystems & Environment* 82 (1–3): 97–103. doi:10.1016/S0167-8809(00)00219-X.

Smith, A., and F. Kern. 2009. "The Transitions Storyline in Dutch Environmental Policy." *Environmental Politics* 18: 78–98. doi:10.1080/09644010802624835.

Sovacool, B.K., and D.J. Hess. 2017. "Ordering Theories: Typologies and Conceptual Frame-works for Sociotechnical Change." *Social Studies of Science* 47: 703–750. doi:10.1177/0306312717709363.

Stilgoe, Jack, Richard Owen, and Phil Macnaghten. 2013. "Developing a Framework for Responsible Innovation." *Research Policy* 42 (9): 1568–1580. doi:10.1016/j.respol.2013.05.008.

Stilgoe, Jack, and David H. Guston. 2017. "Responsible Research and Innovation." In *The Handbook of Science and Technology Studies*. 4th ed., edited by Ulrike Felt, Rayvon Fouché, Clark A. Miller and Laurel Smith-Doerr, 854–880. Cambridge, MA: MIT Press.

Stirling, Andy. 2008. "'Opening Up' and 'Closing Down' Power, Participation, and Pluralism in the Social Appraisal of Technology." *Science, Technology & Human Values* 33 (2): 262–294. doi:10.1177/0162243907311265.

Sukumaran, Rajeev K., Vikram Joshua Surender, Raveendran Sindhu, Parameshwaran Binod, Kanakambaran Usha Janu, Kuttavan Valappil Sajna, Kuni Parambil Rajasree, and Ashok Pandey. 2010. "Lignocellulosic Ethanol in India: Prospects, Challenges and Feedstock Availability." *Bioresource Technology* 101 (13): 4826–4833. doi:10.1016/j.biortech.2009.11.049.

Valkenburg, Govert. 2020. "Consensus or Contestations: Reflections on Governance of Innovation in a Context of Heterogenous Knowledge." *Science, Technology and Society*. doi:10.1177/0971721820903005.

Valkenburg, Govert, Annapurna Mamidipudi, Poonam Pandey, and Wiebe E. Bijker. 2019. "Responsible Innovation as Empowering Ways of Knowing." *Journal of Responsible Innovation*. doi:10.1080/23299460.2019.1647087.

Viseu, Ana. 2015. "Caring for Nanotechnology? Being an Integrated Social Scientist." *Social Studies of Science* 45 (5): 642–664. doi:10.1177/0306312715598666.

Webster, Andrew. 2007. "Crossing Boundaries Social Science in the Policy Room." *Science, Technology & Human Values* 32 (4): 458–478. doi:10.1177/0162243907301004.

Wynne, Brian. 2007. "Dazzled by the Mirage of Influence? STS-SSK in Multivalent Registers of Relevance." *Science, Technology & Human Values* 32 (4): 491–503. doi:10.1177/0162243907301086.

Disclosure Statement

No potential conflict of interest was reported by the authors.

Poonam Pandey is a policy research fellow at DST-Centre for Policy Research, Indian Institute of Science, Bangalore. She works on the policy-related concerns surrounding emerging technologies such as the governance of innovation, future trajectory of research and Responsible Research and Innovation (RRI). She uses an interdisciplinary approach that relies on STS, innovation studies and development studies.

Govert Valkenburg is a senior researcher at the Department of Interdisciplinary Studies of Culture, Norwegian University of Science and Technology. His PhD from the University of Twente was at the interface between philosophy of technology and science and technology studies. His research interests have included medical research practices, privacy and security technologies, and practices of innovation around sustainable energy and energy transitions. Across these fields, an overarching theme has been the democratization of knowledge and the notion of epistemic justice.

Annapurna Mamidipudi is a postdoctoral researcher in the ERC-funded PENELOPE project at the Deutsches Museum in Munich. Her research includes the study of how craftspeople innovate their material practices and make knowledge claims to build recognition in contemporary society. To this end she creates collaborative spaces for scholars and craftspeople such as the large conference that brought together more than 500 weavers and international historians of technology in Chirala, India, in 2018.

Wiebe E. Bijker is adjunct professor at the Department of Interdisciplinary Studies of Culture, Norwegian University of Science and Technology (NTNU) and emeritus professor at Maastricht University. His research is focused on the relations between science, technology and society, and especially on the social construction of technology. Two important themes are the democratization of technological culture and the role of science and technology for societal development. Bijker is founding co-editor of the monograph series "Inside Technology" of MIT Press and Past-President of the Society for Social Studies of Science.