



Aalborg Universitet

AALBORG UNIVERSITY
DENMARK

Annotated Bibliography: Actor Behavior and Interactions in the Context of Sustainable Energy Transitions

Godoy, Jaqueline de; Gorroño-Albizu, Leire; Yang, Jinxj; Otreel-Cass, Kathrin

Publication date:
2020

[Link to publication from Aalborg University](#)

Citation for published version (APA):

Godoy, J. D., Gorroño-Albizu, L., Yang, J., & Otreel-Cass, K. (2020, Jul). Annotated Bibliography: Actor Behavior and Interactions in the Context of Sustainable Energy Transitions.

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- ? Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- ? You may not further distribute the material or use it for any profit-making activity or commercial gain
- ? You may freely distribute the URL identifying the publication in the public portal ?

Take down policy

If you believe that this document breaches copyright please contact us at vbn@aub.aau.dk providing details, and we will remove access to the work immediately and investigate your claim.

ANNOTATED BIBLIOGRAPHY:

Actor Behavior and Interactions in the Context of

Sustainable Energy Transitions

July 2020

Authors:

Jaqueline de Godoy, Aalborg University

Leire Gorroño-Albizu, Aalborg University

Jinxi Yang, Chalmers University of Technology

Feedback/Supervision:

Kathrin Otrek-Cass, Aalborg University/University of Gratz:

Authors Note:

This project has received funding from the European Union's Horizon 2020 research and innovation program under the Marie Skłodowska-Curie grant agreement No: 765515. The content reflects only the authors' view and the Research Executive Agency is not responsible for any use that may be made of the information it contains.

ABOUT THIS ANNOTATED BIBLIOGRAPHY

This annotated bibliography is produced as part of the ENSYSTRA project, which stands for “Energy Systems in Transitions”. ENSYSTRA is an Innovative Training Network action whose project consortium is comprised by universities and research centers, and by industrial partners in the Netherlands, the UK, Germany, Sweden, Denmark, and Norway. The objective of the project is to train the 15 PhD fellows in highly relevant issues for the energy transition in the North Sea Region and the EU as well as in interdisciplinary research.

As participants of the ENSYSTRA project, we have been asked to explore the possibilities for interdisciplinary collaboration. In work package 3 (“Actor Behavior & Interaction”), we realized this required us to develop a deeper understanding about each other’s research fields and projects. This annotated bibliography was started as the first step to build the necessary bridges. We would like to think that our efforts in introducing other ENSYSTRA participants to the main issues of our research projects could also be useful to others who are starting to get acquainted with the topics covered in the annotated bibliography. That is why we decided to publish it.



COVERAGE OF THIS ANNOTATED BIBLIOGRAPHY

The annotated bibliography collects key literature to understand the discussions about the following topics:

1. SOCIO-TECHNICAL ENERGY CULTURES AND DISCIPLINARY THINKING 1
2. PARTICIPATORY PROCESSES AND CITIZEN OWNERSHIP MODELS7
3. AGENT-BASED MODEL APPROACH OF INVESTMENT IN ELECTRICITY SECTOR..... 16



KEY FINDINGS

Socio-technical energy cultures and disciplinary thinking

- Methods conventionally used to understand energy cultures and identify disciplinary thinking can be ethnography, anthropology or network analysis (such as complex systems and Actor Network Theory).
- These methodologies are used to map and understand ontologies and epistemologies stances in which energy is managed and foresee the outcomes to society.

Participatory processes and ownership models

- Ownership has two dimensions: ownership of the process (i.e. the decision-making power) and ownership of the outcome (i.e. the distribution of benefits)
- Citizen ownership of energy is very diverse because different motivations and contextual factors have led to projects with diverse characteristics in terms of technology and scale, governance, legal structure, profit sharing, etc.
- Different citizen ownership models lead to different outcomes/benefits. Therefore, it is important to understand the differences between citizen ownership models for effective policy-making.
- The main distinctive characteristics of the citizen ownership models are related to geographical scope, type of profits and distribution of benefits.



- The barriers for participatory and democratic citizen ownership of energy are generally related to the small scale of the organizations.
- Suitable policies and regulations are seen as an important driver and the key to help the start and growth of community energy initiatives.

Agent-based model (ABM) approach of investment in the electricity sector

- ABM takes into account the bounded-rational behaviors of agents as a result of agents' limited foresight, imperfect information, etc., which is an advantage of agent-based model.
- ABM contributes to better understanding of the benefits and limitations of different model approaches, which can support real world planning and decision-making.
- Heterogeneity of agents such as different expected cost of capital and future carbon prices influences agents' investment choices.



ANNOTATED BIBLIOGRAPHY:

Actor Behavior and Interactions in the Context of Sustainable Energy Transitions

1. SOCIO-TECHNICAL ENERGY CULTURES AND DISCIPLINARY THINKING

This section of the annotated bibliography intends to show some insights on the socio-technical cultures and production of scientific knowledge in the context of energy research. The selected papers allow a comprehension on the existent currents of thought in social energy research. Through interaction with this section the reader will become aware of why questions on ontologies and ethics matter, the consequences of the underlying current of thoughts and beliefs on the knowledge production, as well as on the importance of interdisciplinary research and the methods used to advance the research in sustainable energy systems.

Latour, B. (2018). Down to Earth: Politics in the new climatic regime. John Wiley & Sons.

The 'Anthropocene narrative' includes prominent authors like Bruno Latour or Arne Næss who are concerned about the human impact on the Earth's geology and ecosystems including, but not limited to, anthropogenic climate change. Bruno Latour's book "Down to Earth: Politics in the New Climatic Regime" examines the world's geopolitical scenario. He develops a narrative based on the analysis of historical events like the US President Trump's



election, the migration crisis and Brexit, formulating them as facets of the same metamorphosis, and he also calls the climate crisis the new climatic regime. By hypothesizing on the drivers of recent historical events, e.g. the signature of the Paris Agreement, he concludes that we have become aware that the ideas of modernization and globalization, driven by some, are not compatible with the planet. Thus, some people decided to remain with the modernization plan, forgetting the idea of paying back to the land. Therefore, we have the growth of climate change denial adepts.

According to Latour, this is leading us into a state of deprivation of a shareable space and an inhabitable land, and that in order to overcome this, we need to search for a common world, measuring words and redefining meanings. Latour works with the abstract concepts of local, global, and the 'out of this world' and suggests a new concept to help us turn towards the "Terrestrial" as a proposal for rediscovering new ways of inhabiting the Earth. Latour reflects on the imbalance of power, where the citizens on the bottom are being represented by the ones in the top, but in a general and abstract form that creates two separated worlds. Latour's proposal may allude on how to replace capitalism and the consequent challenges of climate change.

Shove, E., & Walker, G. (2014). What is energy for? Social practice and energy demand. *Theory, Culture & Society*, 31(5), 41-58.

The article reviews disciplinary differences in which energy and societal systems are thoughtful reflections on the impacts on energy management. The author conceptually analyses the ambivalences on the meanings of energy in social theory, sometimes seen as a



driver and sometimes as an outcome of the society interactions. The former, takes for granted the energy demand of society, viewing energy as a resource base for development, where is necessary management and organization to utilize it (e.g. a structure of political, technological and economic systems). The latter is the author's theory, where energy supply and demand is part of the ongoing development of society, and the ongoing reproduction of bundles and complex social practices.

The paper reflects on the tendency of approaches used in engineering and material sciences, realizing that there is a tendency of taking the societal "need" for energy for granted, thus focusing on meeting demand more efficiently. The relevance of this article is because the way we frame energy have influences on how we see the problems and draw solutions e.g. in a transition for a sustainable energy system or reducing emissions of CO₂.

Sovacool, B. K., Heffron, R. J., McCauley, D., & Goldthau, A. (2016). Energy decisions reframed as justice and ethical concerns. *Nature Energy*, 1(5), 16024.

The paper investigates how concepts from justice and ethics can inform energy decision making. They proposed an energy justice framework centered on availability, affordability, due process, transparency, accountability, sustainability, equity, and responsibility. The paper puts climate change in the central discussion of justice and ethics, starts the discussion distinguishing between experience and imposed effects of climate change. To exemplify this distinction, they mentioned a study by Hunter et al that says that more prosperous countries impose 200 to 300 times more health damage on others, taking



into account historical emissions. They bring many examples of the complexity of the climate change crisis ahead. **They argue that moral society structure is ill-equipped to handle this, proposing that the perspective that concepts from ethics and justice provides a structure to deal with climate change dilemmas.**

By synthesizing elements of justice, they present a common framework to support energy decision-makers (which they included all actors that can make a decision about the use of energy conversion and use e.g. being policymakers, ordinary students, investors, consumers, jurists).

The paper evaluates five main energy problems that concern justice: 1. Involuntary resettlement as a violation of procedural justice (e.g. people are displacement for the construction of a hydroelectricity system); 2. Fossil fuel pollution as a human rights concern (power plants and automobiles release a variety of noxious pollutants into the air, threatening human and ecological health) 3. Energy poverty as a violation of distributive justice (people with no access to electricity have few educational opportunities); 4. Nuclear waste as an insult to future generations (nuclear reactors produce waste that will persist for longer than our species has existed); 5. Climate change as a controversial responsibility as a measure of corrective justice (activities of a group of persons injured to a much larger group).

Smith, J., & High, M. M. (2017). Exploring the anthropology of energy: ethnography, energy and ethics. *Energy research & social science*, 30, 1-6. doi: 10.1016/j.erss.2017.06.027

In this special issue article, it is discussed how **ethnographic and anthropological methods** can enrich the discussion around energy research, mostly focusing on the topic of



energy ethics. It is by looking at practices of scholars, people, and communities as a whole that insights on the underlying assumptions of what energy means to the people appears. The methods explained in this paper are valuable in the sense of grasping unexpected contexts, showing a great variety of views on the way people relate to energy and how the discussions are materialized.

In the first part of the paper, a discussion on **ethnographic methods** is held.

Ethnographic methods are an approach to research, characterized by its empiricism that can describe everyday life in different social worlds in-depth. Applying this method is a way of challenging our preconceived assumptions and deepens our understanding of energy speciations and practices. Furthermore, the paper discusses how **anthropologists** have studied energy, examples of which are on oil, nuclear, coalmines, and renewables. Anthropological studies can offer critical lenses on the course of the development of these types of energy and their implications to society, alluding to a reflection on how divergent thinking of values being taken-for-granted that informs the debate on science and policy. Besides that, the cultural development of society is being associated with energy production by early evolutionary theorists. The paper describes documentation of socio-cultural and environmental impacts being studied through anthropological lenses.



Wong, C. M. L. (2016). Assembling interdisciplinary energy research through an actor network theory (ANT) frame. *Energy Research & Social Science*, 12, 106-110. doi: 10.1016/j.erss.2015.12.024

Much progress has been done to integrate social dimension of energy, going beyond the technical research and penetrating into policy and decision-making. However, the progress has been slow, and the paper reflects on the implicit ontological separation between the material/nature world and social/culture world, this creates an unintentionally simplistic division of labor between the technical and social sciences in energy research.

The paper introduces Actor Network Theory (ANT), as a toolbox that researchers can use to disassemble conventional boundaries between the social and the material. In the first part of the paper, they review the concepts that the ANT brings. ANT started with the question on how science and technology were produced. This differs from the theories of other social sciences because removing the humans from the center of agency, offers a flat ontology. Thus, non-human entities are equal actors and entities have a network effect, depending on the interaction with other entities.



2. PARTICIPATORY PROCESSES AND CITIZEN OWNERSHIP MODELS

The literature in this section provides a basic insight into citizen ownership of energy. The chosen pieces of literature address: the generally accepted understanding of 'ownership', the diversity within citizen ownership, the benefits of different citizen ownership models and the drivers and barriers for citizen ownership of energy.

Walker, G. and Devine-Wright, P. (2008) 'Community renewable energy: What should it mean?', *Energy Policy*, 36(2), pp. 497–500. doi: 10.1016/j.enpol.2007.10.019.

In this article, the authors study the understanding that various stakeholders have in the UK about the concept '**community renewable energy**'. The analysis is based on a research project that was carried out between 2004 and 2006. Interviews were conducted with policy makers, managers of community energy programs, and local stakeholders, who also participated in surveys.

Two key dimensions of ownership were deduced: **ownership of the 'process'** (involvement and power in decision-making) and **ownership of the 'outcome'** (distribution of benefits). According to the authors, the process dimension ranges from 'open & participatory' to 'closed and institutional', and the outcome dimension from 'local and collective' to 'distant and individual'.

When being asked about their understanding of the concept 'community renewable energy', some participants in the study put the emphasis on open and participatory processes,



whereas others put it on local and collective outcomes instead. Some other participants also provided a much broader understanding of the concept, which also included more closed and institutional processes as well as more distant and individual outcomes.

The conclusion of the study is that there is no common understanding of the concept 'community renewable energy'. The authors state that this may have positive as well as negative effects. On the positive side, there is more room for experimentation and innovation. On the negative side, when local people are not involved in, and do not benefit from, a local renewable energy project, conflicts and local opposition may arise.

Hicks, J. and Ison, N. (2018) 'An exploration of the boundaries of "community" in community renewable energy projects: Navigating between motivations and context', Energy Policy. Elsevier Ltd, 113, pp. 523–534. doi: 10.1016/j.enpol.2017.10.031.

In this article, the authors bring together the insight from 25 **community renewable energy** projects located in Australia, Europe, and North America in order to develop a theoretical framework and tools that advance the understanding on how community projects materialize and why they materialize the way they do. The authors take an action research approach for their study, where the data is collected through semi-structured interviews, participant observations, site visits, and project documents over a 12-year period.

The '**Community Renewable Energy Development Framework**' elaborated by the authors presents the interrelations between the '**contextual factors**', the '**motivations**', the '**key elements**' for decision in a project (i.e. 'community engagement', 'governance', 'technology & scale' and 'finance'), and the '**impacts & outcomes**'. According to the authors,



the *'context and motivations [...] form the foundation of a project and influence decisions made in other areas, leading to a range of outcomes'*. In the article, four contextual factors (i.e. physical, technology, institutional and community factors) and 22 motivations (grouped under social, political/policy, economic, technological, and environmental motivations) have been identified. The diversity of contextual factors and motivations explains the diversity in the characteristics of community renewable energy projects.

The authors also developed five spectrums that are based on project aspects, negotiated through the decision-making process, that lead to different outcomes. The five spectrums are *'choice of actors', 'decision-making power', 'scale of technology', 'distribution of financial benefit', and 'level of community engagement'*. According to the authors, the spectrums are a tool that helps differentiate between diverse forms of community renewable energy projects, which shall help academics, practitioners and policymakers in their work, and facilitate the assessment of suitability of policies against different targets.

Gorroño-Albizu, L., Sperling, K. and Djørup, S. (2019) 'The past, present and uncertain future of community energy in Denmark: Critically reviewing and conceptualising citizen ownership', *Energy Research & Social Science*. Elsevier, 57, p. 101231. doi: 10.1016/j.erss.2019.101231.

In this article, the authors analyze the ownership of wind turbines and district heating systems in Denmark from a long-term perspective. The objective is twofold: first, to provide updated quantitative values about ownership that can help advance the understanding about the interrelations between the institutional incentives, the energy system's transition and the



ownership of the energy system; second, to identify the key characteristics of the several citizen ownership models implemented in Denmark and develop citizen ownership categories in order to reduce the current confusion about the concept 'community energy', and in this way facilitate further research on the topic and policymaking. The methods comprise statistical analysis, literature review and contact to experts in order to identify, quantify, describe and categorise Danish citizen ownership models.

The authors estimate that 52% of all the existing installed wind capacity in Denmark in December 2016 had citizen ownership. According to their estimations, citizen ownership made a larger contribution to onshore wind capacity than large investor ownership also in periods with institutional incentives that did not favor citizen ownership over large investor ownership.

The same year, 96% of the district heating demand in Denmark was supplied by citizen-owned DH companies; they are either municipal companies or consumer-owned cooperatives. The main reason is the non-profit rule that applies to these monopolistic companies.

The authors identify several citizen ownership models, particularly for wind turbines, where the multiple changes in the institutional incentive system are one of the reasons that have motivated this diversity. It is concluded that **the main distinctive characteristics** of the citizen ownership models are related to **geographical scope** (local – distant), **type of profits** (unlimited private profits – limited private profits – common good), **and distribution of benefits** (inclusive – exclusive). Based on the quantitative results presented in this article and on scientific literature on the topic, the authors suggest that **different key characteristics could be desirable depending on the ultimate target of promoting citizen ownership**, e.g.



local acceptance, local development, affordable energy prices or mobilizing capital for investments.

Brummer, V. (2018) 'Community energy – benefits and barriers: A comparative literature review of Community Energy in the UK, Germany and the USA, the benefits it provides for society and the barriers it faces', *Renewable and Sustainable Energy Reviews*, 94, pp. 187–196. doi: 10.1016/j.rser.2018.06.013.

In this article, the author presents the results of a structured literature review of peer-reviewed scientific articles (which address the UK, Germany and the USA) in order to provide an overview of the understanding, benefits and barriers of '**community energy**'.

The analysis of the understanding of the concept concludes that the diverse interpretation of the term 'community' and the recurrent adaptation of the understanding of the concept 'community energy' in order to make it fit the scope of the specific research are the main causes for the existing plurality in the understanding of what community energy is or is not. 'Community' has been understood as both geographically confined ('communities of locality') and geographically dispersed ('communities of interest'). Similarly, the term has been used to refer to 'actors', 'scale', 'place', 'network', 'process', and 'identity'. In spite of the differences among the diverse understandings of 'community energy', the author concludes that **the concept implies sustainable energy technology solutions and participatory and democratic processes, where centralistic structures and participation without power are excluded.**



The identified benefits include benefits for the implementation of the energy transition (e.g. contribution to renewable energy targets, enhanced local acceptance of renewable energy, more sustainable energy consumption and technological and organizational innovation) as well as for the society (e.g. economic benefits for the communities and individuals, creation of jobs, development of skills, strengthening of sense of community, self-realization, increased participation in social debates and activities, etc.).

The barriers are concluded to be generally related to the small scale of the organizations. Suitable policies and regulations are seen as an important driver and the key to help the start and growth of community energy initiatives.

Berka, A. L. and Creamer, E. (2018) 'Taking stock of the local impacts of community owned renewable energy: A review and research agenda', *Renewable and Sustainable Energy Reviews*, 82, pp. 3400–3419. doi: 10.1016/j.rser.2017.10.050.

The authors conduct a structured literature review on the local impacts of **local citizen ownership** of renewable energy in order to describe the impacts, analyze the context in which they arise and evaluate the empirical evidence that supports the correlation between local citizen ownership of renewable energy and a given local impact.

The identified and analyzed impacts are: 'socio-economic regeneration', 'empowerment', 'knowledge & skill development', 'social capital', 'affordable energy access', 'energy literacy & environmentally benign lifestyles' and 'increased support for renewable energy'. The impacts are grouped under **direct project impacts** and **long-term indirect project**



impacts. Moreover, the associated project types and the preconditions for each impact are pointed out.

The evaluation of the empirical evidence that supports the correlation concludes that most literature dealing with local impacts of local citizen ownership of renewable energy is based on case studies and qualitative interviews. 'Increased support for renewable energy' is found to be the impact that is better grounded, 'socio-economic regeneration' and 'empowerment' to lack robust evidence and 'access to affordable energy' to be the least addressed. Furthermore, a lack of survey-based and statistical evidence is observed across all impacts.

Finally, **the level and timing of inclusive engagement and the type of project are concluded to have strong influence in the achievement of a given local impact.** Based on the findings, the authors define research priorities and provide methodological recommendations.

Kooij, H. J. et al. (2018) 'Between grassroots and treetops: Community power and institutional dependence in the renewable energy sector in Denmark, Sweden and the Netherlands', Energy Research and Social Science, 37, pp. 52–64. doi: 10.1016/j.erss.2017.09.019.

In this article, the authors analyze and compare the flourishing and development of grassroots initiatives in Denmark, Sweden, and the Netherlands. The objective of the article is to advance the understanding about the '**conditions of possibility**' that support the



appearance of grassroots initiatives and how grassroots initiatives may influence those conditions.

Grassroots initiatives are defined in the article as 'open and bottom-up activities' that involve local and regional stakeholders and that 'seek to provoke changes that go beyond or against the orchestrated paths of transition'.

The data is collected through literature review and semi-structured interviews and the analysis is structured around the three categories of conditions of possibility defined by the authors; these are '**material-economic conditions**', '**actor-institutional conditions**' and '**discursive conditions**'. The first includes available energy resources and infrastructure, demand profiles, market structures, ownership, etc. The second includes the evolutionary relationship between grassroots initiatives, other actors in the energy sector and the institutions (i.e. 'rules of the game'). The third includes the differences in existing discourses as well as the dominant discourse on the transition to renewable energy and the legitimacy of different actors to participate in it. For each of the categories, constraining and enabling factors for grassroots initiatives are identified based on the comparison of the analysis conducted for the three countries.

In line with former findings in Belgium, Germany, and the UK, the authors point out that the environment for grassroots initiatives is becoming more 'hostile' and that, at the same time, grassroots initiatives are finding new strategies to adapt to that environment. The analysis concludes that the power relations are strongly influenced by the economic market discourse, which dominates in the three countries studied in this article. Therefore, the authors recommend that grassroots initiatives use the **discourse of e.g. 'affordability, reliability and**



safety' and warn that **grassroots initiatives need to adopt 'commercial or businesslike attitudes'** (which might endanger some of the advantages of community initiatives, e.g. local support) in order to be able to play under the current rules of the game.



3. AGENT-BASED MODEL APPROACH OF INVESTMENT IN ELECTRICITY SECTOR

The literatures listed below mainly focus on using an agent-based model (ABM) approach to simulate the transition to low carbon technologies in the electricity system. These literatures illustrate the concepts of ABM in its application in electricity system modelling. The literatures also present important features of ABM, which differ from other types of model. The features studied in the literatures include the agent's heterogeneity, pathway dependency, adaptability, etc. Some of the literatures below also present comparison results with optimization models, and highlight advantages and shortcomings of ABMs.

Jonson, E. *et al.* (2018) 'Exploring the competition between variable renewable electricity and a carbon-neutral baseload technology', *Energy Systems*. Springer Berlin Heidelberg, 11(1), pp. 21–44. doi: 10.1007/s12667-018-0308-6.

In this study, the authors have set up an agent-based model (ABM) and simulated investment in power plants. The agents in this study are power companies, and they invest in new power plants to increase their profits. Each year, the agent makes prediction of profitability of different investment options, such as coal, gas, wind, solar, and nuclear power plants and invests in the most profitable ones. This study also compares the results from this ABM with results from an optimization model. There are two main findings resulting from this study: firstly, with an increase carbon tax in the system, the installed capacity of variable renewable energy increases over time, while the installed capacity of coal power plants



decreases. Secondly, comparing with the results from the optimization model, the agents underinvest in wind power plants during the first 25 years, but then they overinvest afterwards. This is because the agents in the model have limited foresight and information about future carbon price.

Kraan, O., Kramer, G. J. and Nikolic, I. (2018) 'Investment in the future electricity system - An agent-based modelling approach', *Energy*. Elsevier Ltd, 151, pp. 569–580. doi: 10.1016/j.energy.2018.03.092.

This study uses an ABM approach for simulating possible energy transition pathways. They simulated the decision making in investing in new power plants by agents with heterogeneous anticipations of the future. The agents use hurdle rates ranging from 4%/yr to 20%/yr. The results show that varying the carbon price scenarios, heterogeneous agent's behavior results in a large bandwidth of possible transition pathways. Their study has also shown that average profits of agents are increasing with carbon prices.

Barazza, E. and Strachan, N. (2020) 'The impact of heterogeneous market players with bounded-rationality on the electricity sector low-carbon transition', *Energy Policy*. Elsevier Ltd, 138, p. 111274. doi: 10.1016/j.enpol.2020.111274.

This study investigates the impact of heterogeneous agents on electricity sector transition was conducted by Barazza and Strachan (2020). By using an agent-based model called BRAIN-Energy, they explored the impacts of agents' heterogeneity on the investment decisions of electricity generation technologies. The heterogeneity in their model is characterized by



agents' aims, technology preferences, capital costs of investment, foresight length, expectation of future costs, and electricity demands etc. They modelled the transitions of the UK, Germany, and Italy electricity sectors. They found that actors' heterogeneous characteristics pose barrier to effective decarbonization and affect the speed of the transition, and that the limited foresight of agents and path-dependency lead to inefficient investment cycles.

Vögele, S. and Rübhelke, D. (2013) 'Decisions on investments in photovoltaics and carbon capture and storage: A comparison between two different greenhouse gas control strategies', *Energy*. Elsevier Ltd, 62, pp. 385–392. doi: 10.1016/j.energy.2013.09.030.

This study assesses the investment cost (of PV and CCS) and investment decision features in Germany and analyzes the impacts on the electricity production and price.

Via analyzing four scenarios, this study investigates how investment in the PV and CCS affects the producer's surplus. This study shows that on one hand, the investment in PV and CCS lowers the electricity price, which decreases the revenue of the producer, but on the other hand, lower price increases the consumers' consumption and increases electricity exportation to neighboring countries, which positively affects the producer's surplus. This study also investigates how the additional supplier's surplus compensates the higher investment cost of PV (due to necessary backup plants) and CCS. The results show that only CCSprod-scenario (production of the CCS power plants corresponds to the electricity production of the additional 20 GW PV assumed to be installed in the PV-scenario) has an overall positive impact (supplier surplus minus cost).

