Coordination on Green Investment

Implications of a Sustainability Transition in Europe

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Abstract

To reach its climate targets, the European Union has to implement a major sustainability transition in the coming decades. While the socio-technical change required for this transition is well discussed in the academic literature, the economics that go along with it are often reduced to a cost-benefit perspective of climate policy measures. By investigating climate change mitigation as a coordination problem, this thesis offers a novel perspective: It integrates the economic and the socio-technical dimension and thus allows to better understand the opportunities of a sustainability transition in Europe.

First, a game theoretic framework is developed to illustrate coordination on green or brown investment from an agent perspective. A model based on the coordination game "stag hunt" is used to discuss the influence of narratives and signals for green investment as a means to coordinate expectations towards green growth. Public and private green investment impulses – triggered by credible climate policy measures and targets – serve as an example for a green growth perspective for Europe in line with a sustainability transition. This perspective also embodies a critical view on classical analyses of climate policy measures.

Secondly, this analysis is enriched with empirical results derived from stakeholder involvement. In interviews and with a survey among European insurance companies, coordination mechanisms such as market and policy signals are identified and evaluated by their impact on investment strategies for green infrastructure. The latter, here defined as renewable energy, electricity distribution and transmission as well as energy efficiency improvements, is considered a central element of the transition to a low-carbon society.

Thirdly, this thesis identifies and analyzes major criticisms raised towards stakeholder involvement in sustainability science. On a conceptual level, different ways of conducting such qualitative research are classified. This conceptualization is then evaluated by scientists, thereby generating empirical evidence on ideals and practices of stakeholder involvement in sustainability science.

Through the combination of theoretical and empirical research on coordination problems, this thesis offers several contributions: On the one hand, it outlines an approach that allows to assess the economic opportunities of sustainability transitions. This is helpful for policy makers in Europe that are striving to implement climate policy measures addressing the targets of the Paris Agreement as well as to encourage a shift of investments towards green infrastructure. On the other hand, this thesis enhances the stabilization of the theoretical foundations in sustainability science. Therefore, it can aid researchers who involve stakeholders when studying sustainability transitions.

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Chapter 1

Introduction

Introduction

„All economic theory turns essentially, if implicitly on the problem of coordinating actors, and on the requirements for and consequences of different forms of coordination."
(Michael Storper and Robert Salais, 1997, World of Production, p. 27).

Europe is faced with the challenge of implementing a major sustainability transition (Van den Bergh, Kallis and Truffer, 2013; Grin, Rotmans and Schot, 2010; Frantzeskaki and Loorbach, 2010; Mercure *et al.*, 2016) in the coming decades to tackle the problems of climate change, social inequality and unsustainable growth. Policy-makers have embraced this threefold challenge on a global scale in the recently adapted sustainable development goals (SDGs), while scientists have dealt with sustainability transitions by creating new fields of research, such as sustainability science, socio-ecological systems (Fischer 2015) and transition research. Some recent works argue that the study of sustainability transitions has become a research field of its own (Markard, Raven and Truffer, 2012). The problems dealt with are considered to be complex since they address ecological, economic and social dimensions at the same time, extending the well-established perspective of a socio-technical transition (Geels and Schot, 2010). Markard (2012: 956) defines sustainability transitions as "long-term, multi-dimensional, and fundamental transformation processes through which established socio-technical systems shift to more sustainable modes of production and consumption." Thus, aside from assessing and developing only ecologically oriented technological solutions, a better understanding of comprehensive societal and economic factors in transitions is crucial in this field (Schneidewind and Augenstein, 2012) and serves as the motivation for this thesis. In this section, I will explain the context in which I developed my work, followed by a description of the research design of this dissertation (Section 1.1) and a short summary of its results (Section 1.2). Section 1.3 provides an outlook on further research.

Climate change mitigation as an investment opportunity

By focusing on climate change economics, I chose a highly relevant aspect of a sustainability transition that has so far not been assessed in an integrated manner. Much economic research on climate policy has been focusing on the costs of mitigation and adaptation measures. Macro-economic perspectives typically show a loss of gross domestic product (GDP) when global greenhouse gas (GHG) emissions are reduced to safe concentration levels of 450 ppmv. [1] For example, the Intergovernmental Panel on Climate Change (2015) suggests that the cost required ranges from 1% to 3.7% of GDP by 2030 (compared to baseline GDP).[2]

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[1] Parts per million by volume

[2] The Organization for Economic Cooperation and Development (OECD, 2008) estimates climate mitigation costs to be approximately 0.5% of GDP by 2030. Similar results are achieved by studies that investigate the necessary emission reductions on EU level, such as the Impact Assessment Report of the European Commission Staff (2014), and they come to similar conclusions: an emissions reduction of 40% costs – depending on the scenario – between 0.1% and 0.45% of GDP by 2030 (compared to the reference scenario).

In game theory, on an agent level, climate action is often described as a prisoner's dilemma in which rational actors can only reasonably defect (see e.g. Kruitwagen *et al.*, 2016; Nordhaus, 2015; Wood, 2010; Heugues, 2013). I will argue that this description, while appropriate in particular circumstances, is misleading in general. Rather than a prisoner's dilemma, the climate challenge presents a problem of coordination failure, as illustrated by the structure known as a stag hunt.[3]

The global agreement achieved at the COP21 in Paris in 2015 to keep the temperature rise well below 2°C and preferably below 1.5°C came with a different narrative, framing climate action as an opportunity, not only in terms of sustainability and wellbeing, but also in terms of investment and growth. This transition to sustainability can be seen in line with ideas of green growth.[4] The OECD defines green growth as being about "fostering economic growth and development while ensuring that the natural assets continue to provide the resources and environmental services on which our well-being relies. To do this it must catalyse investment and innovation which will underpin sustained growth and give rise to new economic opportunities" (OECD, 2011: 9). The Paris Agreement follows this definition[5], by combining climate action with the simultaneous effort to achieve the SDGs (Creutzig *et al.*, 2014) – an approach also taken up in the current G20 process (OECD, 2017).

Green investment needs in the European crisis

Paris brought not only the need for policy makers, business and industry, investors and citizens in Europe to rethink their scenarios and decisions concerning climate action. It also brought the need to shift large sums of capital from high-carbon to low-carbon sectors, businesses and projects (OECD *et al.*, 2015; Global Commission on the Economy and Climate, 2014; World Economic Forum, 2013).[6] Even though investment is flowing towards renewables[7] (McCrone *et al.*, 2017) and away from fossil sectors (Arabella Advisors, 2016; Baron and Fischer, 2015), and even though instruments like green bonds are increasingly being accepted by financial market

[3] First described by Rousseau (Rousseau, 1974), the stag hunt has been discussed in many different contexts. For an economic discussion, see Skyrms (2001).

[4] Well before the financial crisis, political leaders in the developing world started discussing the sustainability of their countries' economic growth (UNESCAP, 2012: 17). During a UNESCAP conference in 2005, 52 Asian and Pacific governments and other stakeholders (United Nations, 2017) signed a green growth declaration, stating that "increasing consumption and production resulting from unsustainable economic growth is placing increasing stress on the carrying capacity of Asia and the Pacific, as also elsewhere in the world" (UNESCAP, 2005: 19). As a consequence, the leaders recognized a "need to shift the development orientation from a 'Grow first, clean up later' approach to one of Green Growth, as a way of communicating environmentally sustainable growth to the broader community" (UNESCAP, 2005: 19). This process eventually led to the integration of green growth into policy measures such as stimulus packages. After the financial crisis in Europe, Asia and the US (UNESCAP, 2012:17), green growth remained a debated concept among governments, international organizations, companies and civil society. For a recent overview of the discussion concerning different types of green growth, see Rische et al. (2014).

[5] The New Climate Economy Report has for example put forward this narrative (Global Commission on the Economy and Climate, 2014).

[6] The European Union's High-Level Expert Group on Sustainable Finance aims to shift "the current capital allocation from an unsustainable pathway to a sustainable one" (EU High-Level Expert Group on Sustainable Finance, 2017: 42).

[7] In 2016, the amount of capital invested into renewables fell – mostly due to a decrease in costs – while installed capacity increased.

actors (The Climate Bonds Initiative Markets Team, 2017), Europe still lacks a substantial amount of green infrastructure[8] investment to get on track with its 2030 targets, partly due to low investment levels since the European economic and financial crisis.

Infrastructure is a central element in the complex sustainability transition for several reasons. First, it is long-lasting, consequently increasing the danger of a carbon lock-in. Secondly, when looking at transport, energy and building infrastructure, it is a major factor in global GHG emissions (Qureshi, 2016; Davis, Caldeira and Matthews, 2010). Thus, making existing infrastructure less carbon intensive and building new, low-carbon to zero-carbon infrastructure requires great financial efforts. Calculations of the global investment needed to shift to low-carbon infrastructure (until 2030) slightly differ, however, two well-cited studies earmark it at €85 trillion (World Economic Forum, 2013) and €94 trillion (Global Commission on the Economy and Climate, 2014). For the EU28, the European Investment Bank (EIB) estimates an annual infrastructure investment gap of around €345bn until 2030 (Berndt *et al.*, 2016). Estimates for the energy sector are at €100bn per annum, while the latest EU interim report on sustainable finance calculates a required additional investment for the climate and energy transition of €177bn annually until 2030 (EU High-Level Expert Group on Sustainable Finance, 2017).

However, since public funds are limited due to austerity policies and high debt levels in the wake of the financial and the sovereign debt crisis in the Eurozone (Revoltella *et al.*, 2016), the focus on investment sources for the transformation is increasingly shifting to the private sector. Policy makers try to incentivize private infrastructure investment (European Commission, 2016a; European Commission, 2015b) with instruments like the European Fund for Strategic Investments (EFSI) (European Commission, 2016b) or the Capital Markets Union (CMU) (European Commission, 2015a), emphasizing the need for low-carbon and renewable energy investments (European Commission, 2016c). Therefore, this thesis focuses on green infrastructure investment – considering specifically renewable energy infrastructure projects, power distribution and transmission infrastructure projects as well as energy efficiency improvements in line with the definitions of the United Nations Environment Programme Finance Initiative (UNEP FI, 2014).[9]

Equilibrium selection through coordination mechanisms

The question why there is an investment gap for green infrastructure and technologies is often addressed by bringing forward the argument of market failure. Zenghelis (2011) claims that due to spill-over effects from technological progress and due to ignorance of positive externalities, the private sector tends to underinvest in mitigation

[8] Green Infrastructure is here defined as renewables energies on the side of generation, grids on the side of transmission and distribution as well as energy efficiency in all of the building stock and industry.

[9] Serveral studies, e.g. from the World Economic Forum (2013), Inderst et al. (2012), OECD (2013), and Eyraud et al. (2011), define green investment in a different way. For a broad overview of the definitions of green investment and green finance, see Forstater and Zhang (2016).

technologies and, hence, needs to be incentivized. Mazzucato and Penna unite the concepts of market and coordination failure by highlighting that in situations "when agents are unable to coordinate their expectations and preferences throughout the business cycle, due to information asymmetries and high screening costs" (Mazzucato and Penna, 2015: 14), a Pareto-inferior equilibrium is obtained that leads to a lack of investment. This argument of coordination failure, defined as the "the failure to obtain a Pareto optimal equilibrium" (Straub, 1995: 340), is taken up in this thesis to discuss coordination on green investment in the context of the European sustainability transition.

The choice of game theory to analyze this coordination problem seems intuitive. In game theoretic experiments, uncertainty about the other players' actions often leads to coordination on Pareto-inferior equilibria – even if other strategies imply higher payoffs (see e.g. Van Huyck, Battalio and Beil, 1990; Cooper *et al.*, 1990). Expectations play a crucial role in explaining such coordination failure[10] (Beckert, 2009: 247; Hanaki *et al.*, 2013). In this thesis, I therefore investigate coordination mechanisms such as signals that can influence expectations concerning green investment. This fits well into current discussions in the EU on policies and instruments that are put in place to encourage institutional investment into sustainable infrastructure.

From green investment to green growth

Through coordination on green investment at the micro-level, as described above, stakeholders can establish new business models and forms of cooperation. This can trigger a re-coordination of expectations, supported by policy and market signals, and, thus, lead to a positive, collective, self-perpetuating dynamic that has the potential to shift the economy towards green growth.[11] If enough sectors are included and several mechanisms are in interplay, this coordination could lead to a new macro state of green growth. The EU just recently stated in the interim report of the High-Level Expert Group on Sustainable Finance that closing the green investment gap of around €11 trillion until 2030 will bring "significant benefits, including clean energy and reduced greenhouse gas emissions; it will also create new jobs in Europe, reduce energy poverty and improve air quality" (EU High-Level Expert Group on Sustainable Finance, 2017: 13).

An important step in this process is the integration of the mechanisms of green growth into economic analyses of climate policy (see Wolf, Schütze and Jaeger, 2016, for an excellent overview). Mechanisms identified in this thesis are expectations, technical progress and shocks in the form of an investment impulse. A green investment impulse could trigger technical progress and increase employment and demand in low-carbon sectors, hence coordinating the expectations of European

[10] In the entrepreneurship literature, investors are considered to react to norms, values, regulation and incentives at the company, sector or societal level (Bergek, 2013) while the organizational literature refers to growth and technological opportunities as coordination signals for firms (Storper and Salais, 1997).

[11] Creutzig et al. (2014) define a European energy transition and the renewable investment which comes along with it as a stimulus that could lead to more employment.

investors that have been seriously dampened by the crisis. A new report by the OECD supports this idea, saying that "combining economic reforms with ambitious climate policies in an integrated, synergistic manner can spur economic growth while also mobilising the investment needed to achieve longer-term climate objectives" (OECD, 2017: 7).[12] This thesis investigates such mechanisms in light of an ambitious climate policy.

Involving stakeholders to investigate coordination

Social science dealing with climate change and sustainable development is by nature interdisciplinary. Moreover, transdisciplinary (Bergmann and Schramm, 2008; Scholz *et al.*, 2006; Jahn, Bergmann and Keil, 2012; Mauser *et al.*, 2013) and participatory research methods (Becker, 2006; Glicken, 1999; Renn, Webler and Johnson, 1991) are commonly used to cope with the "societal embeddedness" (Granovetter, 1985: 487) and complexity (Klein *et al.*, 2012) of these issues that affect the whole of society and, thus, touch upon a multitude of different interests. Sustainability science (Kates *et al.*, 2001; Clark and Dickson, 2003) has taken a lead in integrating themes such as sustainable development and climate action with methodologies that come along with stakeholder involvement (SI). On the one hand, this dissertation follows the tracks of sustainability science by involving stakeholders in research in order to incorporate non-academic actors' views and knowledge (Welp *et al.*, 2006). During this process of stakeholder involvement, critical questions arose on knowledge production, understanding of science and the autonomy of science, leading to the observation that the theoretical foundations concerning practices (Ison, 2008; Scholz and Steiner, 2015b) and concepts (Scholz and Steiner, 2015a) of stakeholder involvement in sustainability science are yet to be stabilized.

This thesis contributes to this stabilization in a twofold approach: First, with an analysis of conceptual foundations of SI in sustainability science, ranging from the co-design of research processes to the co-production of knowledge (Hirsch Hadorn *et al.*, 2006; Moser, 2016; Polk, 2015; Wiek, 2007) and questions about the science-policy interface. Secondly, this work was substantiated with evidence on current stakeholder practices among scholars and researchers engaged with sustainability or transition research.

Overall, this thesis highlights the fundamental role of coordination in achieving the climate targets and in shaping expectations and investment strategies. Furthermore, it shows how coordination of actor's expectations can lead to a sustainability transition with low-carbon infrastructure on the micro-level and green growth on the macro-level.

[12] Specifically, the report names the following drivers of growth: "investment in low-emission, climate-resilient infrastructure; an additional fiscal initiative to fund climate-consistent non-energy infrastructure; pro-growth reform policies to improve resource allocation; technology deployment; and green innovation." (OECD, 2017: 7)

1.1 Research design

All papers in this dissertation deal with the coordination and cooperation of different societal actors. Hence, the overarching attempt of this work was to clarify how such coordination can be established, combined with a critical reflection of the method of stakeholder involvement, which was used to obtain results in Chapter 5, 6 and 7. More specifically, the role of coordination for climate change mitigation and green investment was evaluated across the economic, the policy, the sociological and the methodological dimension. Table 1 provides a classification and overview of the chapters in this thesis and will be followed by a summary of the chapters and their main research questions.

Table 1 *Chapter Classification*

Chapter / Dimension						
Economic dimension	**Chap. 2**	**Chap. 3**	**Chap. 4**	**Chap. 5**	**Chap. 6**	**Chap. 7**
Investment	x	x	x	x		
Expectations	x	x	x	x		
Technical progress	x	x				
Green growth	x	x				
Level						
Macro	x	x				
Micro	x	x	x	x		
Policy dimension						
Climate & energy policy	x	x		x		
Financial market & investment policy				x		
Sustainability (SDGs)	x				x	x
Level						
International	x				x	x
EU		x		x		
Sociological dimension						
Stakeholder Involvement/ Co-design				x	x	x
Narratives	x	x	x			
Method						
Qualitative				x		x
Quantitative		x		x		
Theoretical	x		x		x	

1.1.1 Economic dimension

In standard macroeconomic theory, higher *investment* (I) is either achieved through a reduction in consumption (C) or an increase in public debt (G). The formula Y=C+I+G combined with I=I(R)[13] depicts this relationship: Investment depends positively on the interest rate R, i.e. investment tends to increase when interest rates are low. Using a Keynesian approach, expansive fiscal policy will increase national income on the *macro-level* in the short term through the multiplier effect, overcompensating a crowding-out of private investors. On the *micro-level*, firms will invest according to an expected price of credit, which can be influenced by government spending or investment subsidies. Chapter 3 discusses how a green *investment impulse* that serves as a shock to the economy (Bryant, 1994; Jaeger *et al.*, 2015; Bowen *et al.*, 2009) can change *expectations* and spur *technical progress* (Acemoglu *et al.*, 2012), and so can lead the European economy onto a green growth trajectory.

Keynes emphasized the power of expectations when it came to investment, output and employment (Hoover, 1997). While standard macro-economic theory generally accepts the postulate of rational expectations as introduced in the 1970s, recent approaches such as learning models have described a development of expectations over time. Addressing the criticism of the concept of rational expectations, the game theorists Evans and Honkapohja frame the latter as an equilibrium concept:

"We emphasize that rational expectations [RE] is in fact an equilibrium concept. The actual stochastic process followed by prices depends on the forecast rules used by agents, so that the optimal choice of the forecast rule by any agent is conditional on the choices of others. An RE equilibrium imposes the consistency condition that each agent's choice is a best response to the choices by others. In the simplest models we have representative agents and these choices are identical." (2001: 11)

Referring to the *micro-level*, experiments have shown that players tend to act irrationally (see e.g. Aumann, 1990; Cooper *et al.*, 1990; Van Huyck, Battalio and Beil, 1990), challenging Harsanyi and Selten's (1988) assumption that rational expectations let agents choose the payoff dominant and, thus, Pareto-superior equilibrium in a game with two Pareto-rankable equilibria. This idea is taken up in Chapter 4, which investigates coordination mechanisms for green investment on the investor level. Instead of using a game with one (Nash) equilibrium – like in a prisoner's dilemma –, I will argue that investment for mitigation and adaptation is better analysed as a stag hunt[14], allowing for two equilibria to choose from.[15] Therefore, I will discuss coordination mechanisms that either change the payoff function in the game directly, e.g. through subsidies for green investment, or target players' *expectations* exogenously, e.g. through credible narratives. Chapter 2 of this thesis describes such a narrative where large-scale green and low-carbon investments

[13] Y=GDP/output; C = consumption; I = investment; G = government purchases of goods and services

[14] Morgan offers an interesting discussion on whether narratives link economic models with the real world as a "cognitive bridge" (Morgan, 2012: 244) or, following Mink (1978), configure "the events of the world so that they can be understood" (Morgan, 2012: 245).

[15] Dynamic models can integrate learning of coordination, leading to some kind of "bounded" rationality (Sargent, 1993, Gintis, 2009).

for 1.5°C can lead to green growth while at the same time reaching climate and sustainability targets.

With regard to the economic dimension, my findings lead me to argue in favor of the following claims:

- Investors' negative expectations are holding back green growth, which would address climate change and sustainability goals at the same time (Chapters 2 and 4).
- This leads to coordination failure among investors and to the selection of a Pareto-inferior Nash-equilibrium (Chapter 4).
- A change in expectations or a re-coordination of expectations towards green growth can shift investment strategies and allow actors to coordinate on a Pareto-superior (Nash)-equilibrium (Chapters 3 and 4).

1.1.2 Policy dimension

Climate and energy policy strongly rely on economic actors in order to be implemented. Whether investors build wind farms or coal-fired power plants, therefore, also depends on signals from policy makers that shape expectations, e.g. through feed-in tariffs or financial market regulation. Chapter 2 covers international climate policy with regard to the United Nation Framework Convention on Climate Change (UNFCCC) as well as the SDGs (OECD, 2011). The SDGs are closely linked with the idea of green growth, which combines ecological, economic and social aspects. Chapter 3 deals with the effects of the implementation of European climate targets on the macro-level (European Commission, 2014) while Chapter 5 deals with the effects of current and future climate, energy and financial market policies in the EU on actor level. The implementation of all policies mentioned relies on actors from different areas of society. Sustainability science deals explicitly with this challenge of integration in a sustainability transition and is consequently the focus of Chapters 6 and 7. This leads to the following claims:

- Current climate policy is unlikely to reach its goals because it is too weak and lacks coherence with investment, financial market and economic policy in the EU (Chapter 2).
- Expectations can be influenced by signals from policy makers, markets and civil society (Chapters 3 and 5).

1.1.3 Sociological dimension

Stakeholder involvement is a powerful tool to investigate the coordination of agents. To find out which signals could influence green investment decisions, I have integrated actors from industry, civil society and business in the research design of Chapter 5. In a next step, European insurance companies, who are seen as investors with high potential for financing the transition to a low-carbon economy, were interviewed on market, policy and civil society signals, complementing the theoretical analysis with results from stakeholder dialogues. Since coordination as well as economic thought are strongly influenced by narratives (Morgan, 2012), they are discussed in more detail in Chapters 2, 3 and 4. Furthermore, dealing with co-design and co-production of knowledge obtained through stakeholder involvement was perceived as challenging. Thus, I decided to formulate a typology that further conceptualizes stakeholder involvement in sustainability science (Chapter 6). Chapter 7 collects evidence on current practices, ideals and needs when scientists involve stakeholders and contributes to the stabilization of practices in sustainability science. Concerning the methodologies, Chapters 2, 4 and 6 take a more theoretical approach, while Chapter 3 creates quantitative results and Chapter 5 relies on a mix of qualitative and quantitative data. I derived the following claims:

- Stakeholder involvement is helpful in understanding policy processes (Chapters 5, 6 and 7).
- Narratives that stakeholders inherit have a strong influence on economic activity and shape expectations for coordination (Chapters 2, 3 and 4).

In the following section, the chapters of this thesis with their respective research questions will be described, divided into three main areas: possibilities for green growth, coordination of investors' expectations on green investment and the role of stakeholders in sustainability science.

1.1.4 Research questions

Possibilities for green growth

A strengthening of the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty sets the context for **Chapter 2, published as Wolf *et al.* (2019)**, which describes the investment challenge for keeping global warming at 1.5°C as an opportunity to globally achieve a 'Great Transition' to green growth and to sustainable development as intended by the SDGs. Therein, we raise the research question: *How can the investment need for a 1.5°C scenario become an opportunity for green growth?*

To give a more comprehensive view of the effects of climate policy **Chapter 3, published as Schütze *et al.* (2017)**, introduces new mechanisms in a well-known computable general equilibrium model (GEM-E3). I address the research question: *Which mechanisms can be integrated into computable general equilibrium (CGE) models to better evaluate economic effects of climate policy that aims to foster investment?*

Coordination of investors' expectations on green investment

Game theory can be applied to investigate the relationship between expectations and trust among actors. **Chapter 4, published as Mielke and Steudle (2018)**, develops a game theoretic perspective on green investment, dealing with the research question: *Can a stag hunt-like model be used to gain insights on green investment and coordination failure?*

Chapter 5, **published as Mielke (2018)**, investigates signals of influence for private investment decisions by insurance companies in Europe, asking the following research questions: *What kind of signals from policy makers, market players or civil society actors influence insurers' investment decisions for green infrastructure today? And which signals could help them to coordinate on green investment?*

The role of stakeholders in sustainability science

Although by now, researchers often involve stakeholders, the scientific community still lacks comprehensive theoretical analysis of the practical processes behind their integration – for example on the different perceptions of scientists' roles and their objectives, the knowledge to be gathered, their understanding of science or the science-policy interface. **Chapter 6, published as Mielke *et al.* (2016),** aims to conceptualize stakeholder involvement in science by answering the following research question: *How can the different perceptions of stakeholder involvement in science be classified?*

Chapter 7, published as Mielke, Vermaßen and Ellenbeck (2017) provides evidence from sustainability research collected in an international survey to shed light on the following research questions: *What kind of scientists involve stakeholders and how? What kinds of ideals underlie scientists' SI practice? Do these ideals match the practice? How do researchers' ideals concerning stakeholder involvement relate to the types of SI identified in our previous research?*

The following section summarizes the results of the chapters.

1.2 Results

Through this thesis, the following contributions to current scientific discussions are made.

Chapter 2 describes a narrative where large-scale green and low-carbon investments for a 1.5°C target can lead to green growth while at the same time reaching climate and sustainability targets. The chapter outlines the investment needs of such a scenario and the mechanisms that can turn this challenge into a green growth opportunity.

With an enhanced version of a classical model used to assess the effects of climate policy in **Chapter 3**, I contribute to the integration of green growth trajectories into classical computable general equilibrium (CGE) models such as GEM-E3. Simulation results show that, given an ambitious GHG emission constraint and a price on carbon, positive economic effects are possible if 1) technological progress results to some extent endogenously from the model and 2) a policy intervention triggering an increase of investments is introduced into the model. The positive effects can then be further amplified if 3) the investment behaviour of firms is positively (negatively) influenced by higher (lower) sales expectations and these expectations become self-fulfilling. The result is important for policy making because the outcome suggests that investment-oriented climate policies can lead to a more desirable outcome in economic, social and environmental terms. It can also help find new policy solutions towards reaching the target of staying well below a 2°C temperature increase.

While new game theoretic approaches concerning out-of-equilibrium mechanisms (DeCanio and Fremstad, 2013) or coalitions (Hannam *et al.*, 2017) have moved away from the classical game theoretic view on climate action as a prisoner's dilemma on a country level, I discuss climate action on the investor level and translate the new narrative into a stag hunt in **Chapter 4**. In a simple model of a non-cooperative coordination game based on the stag hunt with two stable Nash equilibria, I examine the role of expectations and trust among investors when making decisions for brown or green investment. The coordination problems which arise in such games can lead to coordination failure, i.e. the selection of a Pareto-inferior equilibrium. As multiple experiments show, actors often fail to coordinate on a payoff dominant equilibrium in such games due to uncertainty (Van Huyck, Battalio and Beil, 1990; Hanaki *et al.*, 2013). Thus, I discuss how uncertainty could be reduced along two options: one that concerns a change in the payoff structure of the game and another one that concerns subjective probabilities. By drawing on experimental results and by using a model of brown and green investment, I show the limitations of these principles and discuss further mechanisms that could lead to coordination.

Chapter 5 analyses how signals could help to coordinate insurers' expectations concerning green investment. The largest European insurance companies, based on their total assets (Statista, 2016), as well as relevant investors' associations were asked to rank signals by their importance to their investment strategies, showing how the insurance sector perceives the influence of policy makers, market actors and civil society actors on their green infrastructure investment decisions. It can be concluded that policies concerning climate and energy as well as financial market and investment are important factors in the formation of expectations and the shift of investment strategies. Policy implications for climate risk disclosure, environmental, social and governance (ESG) criteria, carbon price reform and green bond design may be derived from this research. A substantial carbon price and the disclosure of climate risks can help to make carbon intensive investments less attractive. To incentivize a shift in investments towards green infrastructure, these instruments need to be accompanied by other measures. Aside from support schemes such as feed-in tariffs and guarantees by development banks, green bonds can be an important instrument – if designed in a competitive, transparent and standardized way. Most importantly, policy signals have to be coherent and credible to coordinate expectations. Civil society actors play a vital role in this coordination through their influence on the public debate on climate change as well as their engagement and divestment efforts with insurance companies.

Although researchers often involve stakeholders, the scientific community still lacks comprehensive theoretical analysis of the practical processes behind their integration. **Chapter 6** addresses this research gap by developing four ideal types of stakeholder involvement in science − the technocratic, the functionalist, the neoliberal-rational and the democratic type. In applying this typology, which is based on a literature review, interviews and practical experiences, I identify and discuss three major criticisms raised towards stakeholder involvement in science: the legitimacy of stakeholder claims, the question whether bargaining or deliberation are part of the stakeholder involvement process and the question of the autonomy of science. Thus, the typology helps scientists to better understand the major critical questions that stakeholder involvement raises and enables them to position themselves when conducting their research.

Chapter 7 evaluates current stakeholder involvement (SI) practices in science through a web-based survey among scholars and researchers engaged in sustainability or transition research. It substantiates previous conceptual work with evidence from practice by building on four ideal types of SI in science as developed in Chapter 6. The results give an interesting overview of the varied landscape of stakeholder involvement in sustainability science, ranging from the kind of topics scientists work on with stakeholders, to scientific trade-offs that arise in the field and to improvements scientists wish for. Furthermore, I describe a discrepancy between scientists' ideals and experiences when working with stakeholders. On the conceptual level, the data reflects that the democratic type of SI is predominant concerning questions on the understanding of science, the main goal, the stage of involvement in the research process and the science-policy interface. The fact that respondents expressed agreement with several types shows that they are guided by multiple and partly conflicting ideals when working with stakeholders. I therefore conclude that more conceptual exchange between practitioners as well as more qualitative research on the concepts behind practices is needed to better understand the stakeholder-scientist nexus.

1.3 Outlook

With this thesis, I intend to foster a better understanding of the transition processes linked to climate policy in economics and sustainability science. By viewing climate action – ranging from investment into green technologies to enforcing climate polices – as a coordination problem, I contribute a different theoretical focus to the debate. This focus entails the importance of expectations and narratives as well as the need for stakeholder integration when studying sustainability problems. The author plans to continue this work in several ways, but always in collaboration with other researchers: The coordination model developed in Chapter 4 shall be integrated into a macro-economic framework, linking Chapters 2, 3 and 4. The discussions with institutional investors shall be continued to find out more about necessary instruments and products to enhance the energy transition in Europe with a special focus on the German 'Energiewende', thereby enriching the current debate on green finance. Since the author will continue to involve stakeholders in this line of research, conceptual contributions concerning the science-policy nexus are also planned.

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Part I

Possibilities for green growth

Chapter 2

Framing 1.5°C – Turning an investment challenge into a green growth opportunity[1]

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Framing 1.5°C – Turning an investment challenge into a green growth opportunity

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Abstract

In 2018, the Intergovernmental Panel on Climate Change (IPCC) produced a special report on the impacts of average global warming of 1.5°C above pre-industrial levels and related global greenhouse gas (GHG) emission pathways. It is set in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. This paper, which differs from the classical perspective on climate policy focusing on the net costs of mitigation efforts for society, takes up this context by proposing a win-win framing: The 1.5°C scenario should be seen as an opportunity for the world to achieve a Great Transition towards green growth. Since the latter combines ecological, economic and social aspects of development, it is closely linked to and shows synergies with the idea of sustainable development as described by the Sustainable Development Goals (SDGs). With this article, the authors outline the investment needs of such a scenario and the mechanisms that can turn this challenge into a green growth opportunity, e.g. technical progress and a re-coordination of expectations. Furthermore, the article discusses investment sources for the fundamentally needed energy and SDG transition. Since interest rates are low and investment remains below pre-crisis levels, there is room for a substantial increase in investment for the Great Transition without necessarily crowding-out other types of investment.

Keywords: green growth, sustainable development, investment, 1.5 degrees, 2030 timeframe

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1. Introduction

In 2015, at COP21 in Paris, it was agreed to "keep global temperature rise this century well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius". In parallel, the UN adopted the 2030 Agenda for Sustainable Development, with its 17 Sustainable Development Goals (SDGs) that address poverty eradication and climate change, among other issues. These SDGs open a perspective for green growth, which we interpret as combining ecological, economic and social aspects of development (e.g. OECD, 2011). However, the green growth concept has, in the past, been criticized for being synonymous with consumerism (Confino, 2012), or as failing to appropriately conceptualize social welfare (Jakob and Edenhofer, 2014). There have also been discussions on "degrowth" (e.g. Kallis, Kerschner and Martinez-Alier, 2012), "post-growth" (e.g. Hardt and O'Neill, 2017), as well as "a-growth" – an approach that disregards GDP (gross domestic product) growth as an overall measure of progress (Van den Bergh, 2017). However, along the lines of the argument by Hepburn and Bowen (2012), who state that continued economic growth is feasible and desirable if the understanding of growth significantly changes in its characteristics by transitioning from material output towards an "intellectual economy", we use the term "green growth" in the spirit of a win-win opportunity between environmental and human well-being in both economic and social terms. GDP growth seems to be a necessary, albeit far from sufficient, condition for increasing well-being (no poverty, zero hunger, quality education, etc. – as formulated by the SDGs), at least in the medium term. One could, therefore, interpret green growth as a means to an end, namely "green well-being". Nevertheless, since this is not a common term, we will use the concept of green growth here.

That said, since the IPCC special report (IPCC, 2018) aims to place humanity's response to the threat of climate change in the context of sustainable development and poverty eradication, a green growth focus seems highly appropriate, especially in developing countries. It entails the idea that limiting the global average temperature increase to 1.5°C can also help the world to achieve the SDGs. On this basis, this paper proposes a complement to the special report. It is organized as follows: Section 2 discusses investment needs for reaching the 1.5°C target and for achieving the SDGs. Section 3 argues that the huge magnitude of green investments needed would lead to a Great Transition towards green growth. The section explains basic economic mechanisms that lead to green growth and relates them to the world's ability to implement the SDGs. Section 4 discusses how such investments can be provided, and Section 5 concludes.

2. The investment challenge

Shifting the political climate target to well below a 2°C temperature increase, and especially to a 1.5°C increase, is mainly a question of the time horizon. Combining this change in time horizon with a discussion of the investment needs for decarbonizing the economy should play an important part in reframing the policy debate.

2.1 Comparing 1.5 with 2°C

Whether aiming at no more than 1.5 or 2°C above pre-industrial global temperature levels, the remaining "safe" emissions budget for GHGs should inform the primary emissions scenario to be followed by the world.[1] This might include the assumption that no temperature overshoot[2] will take place, since many of the physical, chemical, ecological, social, and psychological impacts of overshoot may not be reversible, even in the long run[3]. In both temperature scenarios, the economy, and in particular the energy sector, will need to become essentially GHG emissions free fairly soon.

A major difference between the time horizons for the 1.5 and the 2°C limits is nicely illustrated by Carbon Brief (2017): with a 50% (66%) chance of staying below 1.5°C warming and at the current rate of emissions, the remaining carbon budget would be used up in only 7.8 (4.1) years, versus 26.6 (19.1) years for a 50% (66%) chance of staying below 2°C.[4] A "back-of-the-envelope" type of calculation that assumes a linear decrease in emissions, for reasons of simplicity, implies that emissions have to fall to zero in twice the time that would remain at current emission levels. This corresponds to 15.6 (8.1) years, meaning 2032 (2025), for a 50% (66%) chance to meet the 1.5°C target. For purposes of analysis and policy development, the scenario of emissions falling to roughly zero by 2030 would, therefore, be a useful focal point. A recent perspective by Rockström et al. (2016) proposes a pathway in line with the Paris Agreement to keep warming "well below 2°C", namely one which follows a global "carbon law", halving gross anthropogenic CO_2 emissions every decade in all countries and sectors, leading to net-zero-emissions by 2050, and so on. This poses a similar focal point for the 2°C case that the 1.5°C scenario can then be contrasted with.

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[1] While carbon budget estimates come with their own uncertainties, they provide a simple and helpful focal point for actions to be taken.

[2] Overshoot means allowing the temperature increase to exceed a target, and then causing it to fall back down to the preferred goal within some reasonable time period (by removing CO_2 from the atmosphere).

[3] In addition, many negative CO_2 emissions technologies require higher amounts of net energy production and investment. Since they currently only exist at small scale, except for re-forestation, it would be difficult to develop, invest in, and install them in significant amounts by 2030. Finally, there may be negative environmental impacts such as localized earthquakes and water pollution. Therefore, the risks and benefits of overshoot scenarios can be evaluated if the designated temperature increase scenario fails.

[4] While IPCC and other reports use the word "probabilities", and we use the word "chances", these numbers merely refer to a distribution derived from the range of outcomes of the various physical climate models. We cannot know the actual probabilities of future climate scenarios occurring, unless we consider subjective probabilities, but this lies beyond the scope of this paper.

2.2 Advantages of a 2030 timeframe

An advantage of focusing on the shorter timeframe until 2030 is that it reduces uncertainty compared to the AR5 WGIII report, which mostly focused on the entire time period from 2005/2010 through 2100.[5] The 2030 timeframe is also on the active horizon of investors, especially those taking longer-term investment decisions. The introduction of a challenge such as decarbonization in this shorter timeframe can mobilize capabilities that might not have been available otherwise (Jaeger et al., 2011). "Cost-optimal" mitigation scenarios through 2100, which may lead to counterintuitive results – such as emissions in a 1.5°C scenario being higher than those in a 2°C scenario until about 2024 (see UNEP, 2016: xvi) –, are much less conducive to mitigation action. Therefore, as a research direction fitting the IPCC's special report, macro-economic analyses of mitigating climate change, with a typical timeframe of about 30 years (until 2050), should be complemented with or replaced by analyses focusing on the earlier period from 2020 until 2030. Furthermore, micro-economic analyses will be important when it comes to determining an appropriate mix of new technologies for each major region of the world, and for providing investment guidelines. This technology mix, as well as the financing mix, would depend, in part, on the relative costs of labor versus capital and the decrease in capital costs in each region, the existing policy regime, as well as on factors such as regional weather, climate trends and social and governance aspects. Also, as the timeframe of the SDGs is 2030, synergies may be reaped by coordinating investments needed for reducing emissions with those needed for achieving many of the SDGs. Potential synergies are outlined in Section 3.2 below.

2.3 Investment needs

The total investment needs for a 1.5°C target are not yet to be found in the literature. The comparison of timeframes above, however, implies that the total capital investment requirements for the transformation to a zero-emissions-economy must be fulfilled within about one decade – rather than in 3 decades for a 2°C scenario. This includes replacing the entire existing fossil fuel energy system, increasing energy efficiency substantially, reducing land-use emissions to roughly zero, and meeting new energy demand growth much more quickly. We explicitly highlight the importance of additional investment needs, e.g. in the electricity distribution and transmission systems, for mass transit and for new transportation technologies such as electric vehicles, which were often ignored in previous IPCC assessments and which go beyond "business-as-usual" levels. To get a rough idea of the magnitude of the required investments, the World Economic Forum (2013) calculated an annual investment need of US$5.7 trillion from 2015 to 2030 to keep global infrastructure in line with a 2°C target, amounting to US$85 trillion overall, whereas the New Climate Economy Report (Global Commission on the Economy and Climate, 2014) calculated a higher annual investment need of US$6.27 trillion (US$94 trillion overall) for the same period of time. However, many investments needed for carrying out a comprehensive energy transition, such as investments for additional mass transit and the electrification of all freight train lines, are omitted by the models relied on by such reports.

As a rough calculation, when averaging over the much shorter time frame until 2030, the rate of investment per year to meet a 1.5°C target would need to be about three times

[5] For a critical review of this type of analysis, see Rosen and Guenther (2016).

as high (in today’s dollars) as the respective rate to meet a 2°C target. Of course, this would depend on how the unit capital costs of the replacement technologies change over time, and on how fast energy demand grows (or shrinks). However, the higher temperature increase allowed in the 2°C scenario implies that in the 1.5°C scenario, investment needs for adaptation to climate change will be somewhat lower.

Given the much higher annual investment requirements of the 1.5°C scenario for the energy sector and related upstream and downstream sectors, other sectors of the global economy may have to, or will, shrink. This will lead to a structural shift in economic activities. However, the total investment pool of the world would not be limited to current global investment levels of about 25 percent of global GDP; rather the envisaged level would need to be several percentage points higher, including both public and private investments. Also, additional capital investments between 2020 and 2030 will be required in order to be able to accomplish all the non-climate change related SDGs. These would include, for example, funding for water and sewage systems, for educational and health institutions, as well as for organic agricultural systems. The additional and redirected investment needs for complying with the 1.5°C scenario, plus SDGs, would, probably, require more than US$10 trillion of annual capital investment. The ramp-up-period for implementation would have to occur within about 2-3 years from now on. How this could be achieved is discussed in the following section.

3. The investment opportunity: Green growth and SDGs

When it comes to analysing the economic impacts of a 1.5°C target, the focus should be on the impact of the additional capital investments needed for a decarbonization of the global economy, relative to business-as-usual. Also, the associated change in operating and fuel costs of various alternative technologies should be taken into account, as substantial shifts between sectors of the economy would occur.

To date, the effects of policies to mitigate climate change have largely been explored by combining an economic model, including some technological details for the supply side of the energy sector, with a climate system model (together called "integrated assessment model" (IAM)). A paramount assumption in most of these integrated assessment models is that labor and capital resources are employed at "optimal" levels in the reference scenario. Thus, in such models additional investments to further mitigate climate change would never be optimal over a time horizon of a few decades, and would come at a "net cost" to society during this period. "Net cost" typically means that GDP (or a measure of welfare) would be somewhat lower than otherwise. This occurs because mitigation investments are forcibly redirected from other areas of the economy where they would be "optimally" employed (this effect is known as crowding-out). A second result of the optimal use of production factors usually assumed within these models is that involuntary unemployment cannot be represented and hence not addressed.

Furthermore, most of these models consider technological progress as exogenously given. Therefore, higher investment levels do not lead to increased technological progress. Also, financial markets are usually considered an intermediary that allocates resources efficiently in climate economic models. Yet, additional financing needs (for larger capital investments[6]) must be accommodated by financial market actors as well as financial authorities and, hence, must be represented in the models. Thus, the effect of large additional investments in mitigation, as required for a 1.5°C target, cannot be investigated with this kind of model. A new report by the IPCC chairman, advising the AR6, acknowledges a "pushback" against IAMs due to a "perceived lack of transparency surrounding the assumptions and structure of the IAMs underpinning the assessment of global emission pathways" (IPCC Chairman, 2017: 34). The green growth literature, on the other hand, is rarely model-based (Wolf, Schütze and Jaeger, 2016).

3.1 Mechanisms that lead to green growth

The large additional investments of a 1.5°C scenario can have a positive impact on the economy and society via several mechanisms:

- The development of low-carbon and more energy efficient technologies is key for a transition to a low-carbon economy. A considerable increase in investments in low-carbon technologies will increase the production and productivity levels of these sectors. This will spur technical progress through product and process innovation, known as "learning by doing", and through "spillover" effects to upstream and downstream activities. More generally, technical progress will also

[6] It is useful to note that low-carbon technologies are, typically, more capital intensive (little or no variable costs during operation) than high-carbon technologies, which use fossil fuels while operating.

increase in other sectors where large investments are made, for example for reaching SDGs that are not environmentally focused.

- It can be expected that the large additional investment requirements for the period 2020-2030 in the 1.5°C scenario would cause a significant increase in the absolute number of jobs in all large economic regions of the world, relative to a 2°C scenario. To reach the SDGs relating to decent work and reduced inequalities, higher wages and salaries have to be ensured and, therefore, should be complemented by progressive labor market policies. In the EU, the financial crisis has caused investment levels and growth to fall, both of which have remained low in recent years (Baldi *et al.*, 2014). Decreasing inequality, as required by many SDGs, can also be achieved by additional investment and economic growth, and is likely to help meet the other non-climate SDGs, such as the elimination of hunger, improvements in education, etc.
- In turn, such actions would raise expectations relative to the current situation of low investment levels, high unemployment, and low economic growth in most economic regions (OECD, 2015). Expecting accelerating growth, companies will decide to invest to be able to meet the increasing demands for their products and services, which in turn – and partly as a self-fulfilling prophecy – will lead to growth due to the expansion of the capital goods sector.
- This said, a re-coordination and re-orientation of investments, both in magnitude and between sectors of the economy is needed to shift the world economy to a green growth path (Jaeger *et al.*, 2011; Jaeger et al., 2015). Seriously aiming at the 1.5°C target would be an important signal for investors that could trigger such a change (Mielke, 2018). The magnitude of the investments, and the timeframe outlined above, have the clear potential to provide a strong policy signal (Bowen *et al.*, 2009). In order to be credible, this signal for private investors also needs to be backed by public investment, which will then lead to further private investment following the logic of "animal spirits".

This last mechanism in particular and the sources of investment will be considered in more detail in Section 4. Recent work (Steudle et al., 2017 in preparation) suggests that, by including these mechanisms in conventional economic models, a more appropriate analysis of a transition towards green growth becomes possible.

Identifying green growth opportunities –arising from environment-related investments on the scale described above – can play an important role for the global response to climate change. Win-win opportunities between climate, on the one hand, and the economy and society, on the other, can make emission reductions a strategy of global self-interest.

This would strengthen the response to climate change compared to a situation in which this respective response is perceived as being a burden that needs to be shared (Jaeger et al., 2012).

3.2 Synergies with achieving the SDGs

Similarly, the following arguments can help strengthen the global response to climate change: If a level of capital investment is pursued worldwide that would enable a 1.5°C scenario to develop, the additional growth in employment and GDP, as well as changes in the composition of GDP, could facilitate the achievement of many other SDGs. For example, the rapid expansion of decentralized solar and wind electricity supply technologies in developing countries could provide hundreds of millions of people with access to electricity and, thus, help to achieve SDG #7 (affordable and clean energy). It would also prevent a carbon lock-in to older energy supply technologies, and enable developing countries to leapfrog developed countries in the energy sector. To limit the need to expand existing electricity grids, major investments could also be directed to the purchase of energy storage devices, such as batteries for shared community use. The expansion of the geographical range of electricity supplies would also help to implement SDG #7 (affordable and clean energy).

The increase of investment in industries consistent with sustainable development, should also go along with both the establishment of living wages for employees and extensive job training, in order to upgrade the skill levels of new employees in line with SDG #4 (quality education) and SDG #5 (gender equality). Digitalization provides a big opportunity to provide this type of training on a global scale. This could further help to realize SDGs #8 (decent work and economic growth), #9 (industry, innovation and infrastructure) and #11 (sustainable cities and communities).

Ceasing the use of fossil fuels for energy services in all industries and implementing efficiency measures would also help to make them more sustainable, as required by SDG #9. The achievement of 100 percent sustainable agriculture throughout the world would likewise support climate change mitigation (SDG #13) and improve life on land (SDG #15) as well as below water (SDG #14). These actions could greatly decrease poverty (SDG #1), help to eliminate hunger (SDG#2) and lead to good health and well-being (SDG #3). There exist many additional synergies between strengthening the global plan for mitigating climate change and achieving all non-climate SDGs by 2030. Of course, in order to enable the green growth scenario described above, the additional investment needs have to be successfully financed. The next section considers how this could be done.

4. Investment sources

The transition required to achieve the 1.5°C target can be called "Great Transition" or "Great Transformation". While the investment needs for the scenario identified above may seem huge, they are not historically unheard of in scale. For instance, massive additional investment yielded full employment in the United States during the beginning of World War II (1939-1942) (see Delina, 2016). This historical analogy demonstrates that in conditions of significant slack – as presently given – the world economy can be mobilized and changed very quickly if backed by a respective political will. In fact, policies can be very effective in increasing private investment. The introduction of the feed-in-tariff in Germany, which increased investment in renewable energy while decreasing capital costs much faster than expected, provides an example. Since currently interest rates are low and investment remains below pre-crisis levels, there is room for a substantial increase in investment for the Great Transition without necessarily crowding-out other types of investment. However, financial sector regulation that is better aligned with the 1.5°C pathway and the SDGs is essential. The mix between public and private investment will necessarily vary over time and by region. It will depend partly on the speed of the reduction of unit capital costs of no- and low-carbon technologies, and the policy mix (more market-based or more regulatory policy solutions; as well as the combinations of fiscal, financial and monetary policies) adopted.

4.1 Public investment

The change of the world economy that would be required to achieve a 1.5°C scenario is so significant that market mechanisms alone are not sufficient to realize a phase out of almost all GHG emissions by 2030. Since the capital costs are still relatively high, though falling rapidly, in order to effectively promote some low-carbon technologies (i.e. solar electric) public capital must be invested and used to incentivize large-scale private investment – in some if not all regions. Thus, governments will be required to provide the primary management and investment institutions to spark and implement the necessary transitions, both to achieve the 1.5°C scenario and the other SDGs. This need comes at a time when many governments in the European Union and elsewhere, reduced their public spending for infrastructure in the wake of austerity measures triggered by the sovereign debt crisis (Revoltella et al., 2016; Egler and Frazao, 2016). The US government under Trump may increase infrastructure spending, but has at the same time emphasized support for fossil-based industries such as coal, oil, gas, conventional cars, and others, which could result in a carbon lock-in of the US economy. In a 1.5°C scenario, austerity policies would have to exempt many energy system investments, at least the low-carbon ones required to achieve that scenario. To "crowd-in" private investors, governments would need to incentivize and regulate low-carbon infrastructure and technology investments beyond merely establishing high carbon taxes. Public expenditure can also be geared towards a green economy by redirecting existing public investment and greening public procurement processes (UNEP, 2011). Existing support schemes, like feed-in tariffs and other revenue guarantees, quotas, resource portfolio standards or tax cuts for project investment, could be massively scaled up. Apart from governments, the regional development banks could also play a leading role in this process due to their mandate and state backing. Public (development) banks need to be aligned with the 1.5°C scenario and the SDGs. They can, for instance, offer guarantees where needed and issue green bonds[7], whose proceeds are

[7] For a definition of green bonds see Climate Bonds Initiative (2017).

dedicated to low-carbon investments. They can also support private investment by offering technical assistance and capacity building, as well as by supporting flagship projects and good practices in the field of zero-carbon technologies and infrastructure. Governments can also help to leverage private capital through public-private partnerships or other investment vehicles. For example, the European Union's Fund for Strategic Investments (EFSI) aims at using 21 billion Euro of public money to leverage private investment in order to reach a total of 315 billion Euro for European small and medium-sized enterprises (SME), mid-caps, innovation and infrastructure. In terms of the 1.5°C target, such a support scheme would have to be limited to exclusively financing climate-friendly projects as well as scaled up massively[8]. Another possibility would be to scale-up instruments like the Green Climate Fund to collect and re-direct public capital towards mitigation and adaptation projects. At the same time, fossil fuel subsidies should be eliminated globally, as well as all other subsidies that could hinder the decarbonization process. This needs to be done cautiously, though, without neglecting the social dimension that the SDGs emphasize.

4.2 Private investment

Certainly, in the first few years of pursuing a 1.5°C scenario, some investments that would otherwise occur in a business-as-usual scenario would have to be redirected. First, this could happen via corporations in all industries diverting their own investments from their traditional products to renewable energies, enhanced resource efficiency technologies and to decentralized solar energy production at their building sites as well as in the communities in which they operate. Second, government or quasi-public mechanisms have to be established to redirect investment between major sectors of the economy. In combination with scaled-up public spending for the decarbonization of the economy, both would have a great impact on creating a credible green growth narrative, as laid out in Section 3.1 This narrative is necessary to re-orient investors' expectations towards a low-carbon economy with a credible and large demand for green products and infrastructure. Already today, private sources of funding play a big role in financing green investments, with US$243 billion in 2014, as compared to only US$148 billion of public investments (Buchner et al., 2015). In the last few years, in addition to an increasing volume of public green bonds being issued, private actors such as energy companies (EDF, Iberdrola), technology companies (Apple, Mitsubishi) and banks (BNP Paribas, Rabobank) have also issued green bonds. The total issuance of labeled green bonds has, thus, reached US$155.5 billion in 2017 (Climate Bonds Initiative, 2018). Institutional investors, who have a long-term focus and are currently looking for investment opportunities, could also be important players in financing the Great Transition. [9]

If uncertainty as to the credibility of climate policies and support mechanisms can be greatly reduced, private investors could coordinate around green investment, and, thus, further influence the expectations of actors in other sectors (Mielke and Steudle, 2018). To support the 1.5°C target, a critical mass of economic actors needs to coordinate around

[8] The European Commission has extended the EFSI until 2020 and scaled it up to 33,5 billion of public money to reach an investment total of 500 billion Euro.

[9] McKinsey estimates that institutional investors could fill up one third to half of the estimated infrastructure investment gap of about three trillion dollars a year under a 2°C scenario, if the right incentives and policies were put in place (Bielenberg et al., 2016). For a 1.5 degree scenario, the investment gap would be much larger and of shorter duration.

a new and different global growth path. One possibility to enhance credibility would be a short-term but large public investment impulse that would trigger technical progress, thus positively influencing investors' expectations, leading to fewer GHG emissions and – in some regions – higher growth rates at the same time (Jaeger et al., 2015). A credible green growth narrative could help to establish such a re-coordination of public and private investment to support a 1.5°C world.

A set of papers by Zenghelis and colleagues (see Zenghelis, 2011; 2012; Romani, Stern and Zenghelis, 2011) analyses the possibility of stimulating additional net private sector investment in detail. Given investment levels close to record lows in most OECD countries, the authors detect a "lack of confidence to invest rather than a lack of liquidity" (Romani, Stern and Zenghelis, 2011: 4) and they argue that credible long-term green growth policies provide opportunities for restoring confidence and leveraging additional, rather than only displacing, investment (Zenghelis, 2012). Similarly, a UNEP Green Economy Report calls for the private sectors' "understanding and sizing the true opportunity represented by green economy transitions across a number of key sectors" (UNEP, 2011: 1).

5. Conclusions

The IPCC Special Report must be complemented with a focus on the idea that a 1.5°C non-overshoot scenario can only be realized with a massive mobilization of financial and human resources. This requires a huge and immediate effort on the part of all governments, financial institutions, businesses, and civil society organizations. Analysis must stress that such a mobilization may even be required in order to achieve a 2°C non-overshoot scenario, including the SDGs, but at a lower annual level of investment with more time for ramping-up.[10] In order to achieve the 1.5°C target, large-scale investments, involving a significant fraction of global GDP per year, are required – and possible, as history has shown. They would also be beneficial for realizing more immediate economic and social goals through a coordination of investors' expectations and technological progress. Additionally, there are many economic and social synergies to be reaped between strict climate change mitigation policies and policies needed to implement the other SDGs. To this end, for a credible green growth narrative, climate policies have to be complemented with political incentives that substantially increase (public and private) investment levels. Countries and businesses will be more likely to work towards a 1.5°C scenario, if they expect economic benefits from doing so.

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[10] Note that "just" achieving the non-climate SDGs by 2030, as currently scheduled, would require its own mobilization of global financial and human resources.

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Chapter 3

The role of sustainable investment in climate policy[1]

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The role of sustainable investment in climate policy

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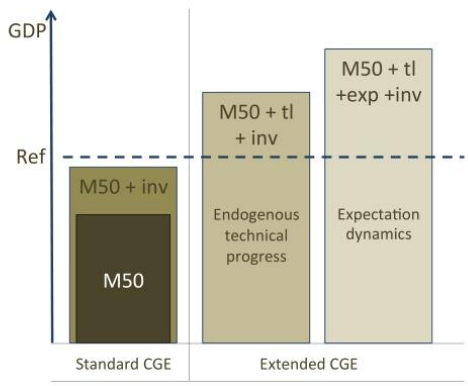
Abstract

Reaching the Sustainable Development Goals requires a fundamental socio-economic transformation accompanied by substantial investment in low-carbon infrastructure. Such a sustainability transition represents a non-marginal change, driven by behavioral factors and systemic interactions. However, typical economic models used to assess a sustainability transition focus on marginal changes around a local optimum, which – by construction – lead to negative effects. Thus, these models do not allow evaluating a sustainability transition that might have substantial positive effects. This paper examines which mechanisms need to be included in a standard computable general equilibrium model to overcome these limitations and to give a more comprehensive view of the effects of climate change mitigation. Simulation results show that, given an ambitious greenhouse gas emission constraint and a price of carbon, positive economic effects are possible if (1) technical progress results (partly) endogenously from the model and (2) a policy intervention triggering an increase of investment is introduced. Additionally, if (3) the investment behavior of firms is influenced by their sales expectations, the effects are amplified. The results provide suggestions for policy-makers, because the outcome indicates that investment-oriented climate policies can lead to more desirable outcomes in economic, social and environmental terms.

Keywords: climate policy, green growth, macroeconomic models, sustainable investment, technical progress, expectations, 1.5 ◦C

Graphical Abstract:



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1. Introduction

In climate policy debates, a widespread assumption is that effective climate policy comes at substantial initial costs, and that therefore it would be a burden and a risk for producers and consumers alike. This understanding is at least partially attributable to the models behind it, which usually exclude positive effects by construction (Wolf, Schütze and Jaeger, 2016). These models focus on marginal changes around an equilibrium that is Pareto optimal, except for climate damages in a more or less distant future. However, a sustainability transition typically implies a non-marginal transition from one economic equilibrium to another. Thus, a sustainability science approach differs from the standard economic approach, assuming, e.g., more complex interactions between the macro- and the micro-level (Antal and Van Den Bergh, 2016).

A concept that relates to the recent macroeconomic discourse, which refers to a transition between different economic equilibria, is the idea of green growth. Jänicke (2012), Wolf, Schütze and Jaeger (2016) and Pollin (2015) provide more in-depth discussions on green growth and the green economy. However, only few studies have investigated short-term economic benefits of climate policy (see e.g. Jaeger *et al.*, 2011; 2015) or interaction effects between environmental regulation and technical progress (Guo, Qu and Tseng, 2017). Related reports from international institutions such as the Organization for Economic Cooperation and Development (OECD), United Nations Environmental Program (UNEP), the Worldbank, the World Economic Forum and others (UNEP, 2011; World Economic Forum, 2013; Global Commission on the Economy and Climate, 2014; OECD, 2017) usually do not use the same models as used in macroeconomic climate policy analysis. Green growth is mainly described by narratives rather than by a trajectory that can be assessed with formal models. According to Antal and van den Bergh (2016), a synthesis of sustainability thinking and macroeconomics still needs to be accomplished.

Since most standard economic models exclude the possibility of green growth by construction, there are two possible solutions in terms of economic modelling: Creating new types of models that differ from the usual approach of computable general equilibrium (CGE) models, like, e.g., agent-based models, or changing certain mechanisms in CGE models in order to overcome some of their intrinsic limitations. Without in any way dismissing the former, this paper aims at the latter.

GEM-E3 (Capros *et al.*, 1999), the model used for this purpose is calibrated to the European economy and has been used for evaluating EU level climate policies numerous times. The current situation in Europe in the aftermath of the financial crisis is characterized by low levels of investment, growth and employment. This makes Europe an interesting case for the investigation of a new type of climate policy (Van der Ploeg and Withagen, 2013), focusing on economic benefits and the role of investment. Additionally, these insights can be helpful for the discussion on how to reach the recently agreed international 1.5°C climate target.

Our paper relates to the vast literature and reports on climate policy evaluation providing cost-benefit analyses. The IPCC (2014) suggests that the cost required to mitigate greenhouse gas (GHG) emissions to safe concentration levels (450 parts per million by volume (ppmv)) ranges from 1 to 3.7% of GDP by 2030 (compared to the baseline GDP). The OECD (2008) estimates climate mitigation costs to be approximately 0.5% of GDP by 2030. According to these calculations, timely and globally concerted action would reduce the costs of GHG abatement (Kriegler *et al.*, 2013). Studies that investigate the reduction of EU level GHG emissions, such as the European Commission Impact Assessment Report (European Commission Staff, 2014) come to similar conclusions. Depending on the policy scenario, the costs of a 40% emission reduction scenario is estimated to lie between 0.1% and 0.45% of GDP by 2030 (compared to the reference scenario).

According to the Impact Assessment Report, the implementation of a carbon price in all sectors and the reuse of the revenues to reduce labour costs would reduce the economic costs of GHG abatement. The reported costs are usually measured by comparing a reference scenario without constraints with a counterfactual scenario that includes a GHG emission target as an additional constraint to the optimization. In this way, the outcome can only be as good as, or worse than, the reference scenario. Rosen (2016) and Rosen and Guenther (2016) provide a more detailed review of the analytical approaches and assumptions used in the Fifth Climate Assessment (AR5) of the IPCC (2014) and their shortcomings.

Some models of climate policy (see e.g. Stern, 2007) include the future benefits from avoiding climate damages and air pollution, where the proper discount rate of avoided future costs is a decisive parameter and is therefore often debated. Potential short-term economic benefits, such as increased technical progress, international competitiveness, a positive investment climate or other feedback effects are usually not examined. However, when investigating fast decarbonization possibilities, which becomes ever more important with a 1.5°C climate target, the impact of large amounts of investment on innovation and spillover effects should not be neglected. A key question is whether GHG mitigation can bring about economic benefits, even when costs of climate change (damages) in the future are not taken into account. Wolf, Schütze and Jaeger (2016) provide a comprehensive overview of different modelling approaches that address positive economic effects and the mechanisms they depend on.

This paper will investigate three mechanisms which are considered important for positive effects of climate mitigation:

1. Several studies argue that the transition to a low-carbon economy requires large additional investment, e.g., UNEP and IEA estimate the required additional investment at global scale to be US$0.5 trillion annually by 2020 and US$1 trillion annually by 2030, in order to reach the target of staying below 2°C global warming (International Energy Agency, 2014). This number would increase for a 1.5°C target. However, academic literature on the effects of green investment programs is scarce. To address this research gap, we introduce an investment program and investigate its effects.

2. Technical progress is often regarded as a key mechanism for reducing abatement costs. Wing (2006) notes that computational models used to evaluate the costs and benefits of climate policy often treat technical progress as exogenous and invariant to climate policy, and therefore disregard the feedback effects involved. There is a variety of approaches for the endogenization of technical progress, from the original hypothesis on induced technical change (ITC) by Hicks (1932) to directed technical change for climate change mitigation by Acemoglu *et al.* (2012). Most commonly used approaches are the stock of knowledge approach (see e.g. Popp, 2004) and the learning-by-doing approach (see e.g. Grübler and Messner, 1998; Grubb, Chapuis and Duong, 1995). We introduce a simple learning-by-doing mechanism based on production levels.

3. As pointed out by Wing (2006), the endogenization of technical progress via learning-by-doing gives rise to multiple equilibria. With more than one possible equilibrium, the question of equilibrium selection arises, which causes problems in a general equilibrium framework. This problem can be described as a coordination problem (see e.g. Bryant, 1983; Cooper and John, 1988). To address this, we introduce a mechanism of adaptive expectations, in which investment decisions of firms are influenced by sales expectations in the specific sector.

Although there are numerous studies on the effects of endogenous technical progress by various scholars (see Wing, 2006, for an overview), it usually has not been studied in combination with other model changes or policies, such as adaptive expectations or an investment program. We want to test whether an investment program combined with changes in the model mechanisms can trigger a shift from economic costs to benefits within the given model framework.

This paper is organized as follows: In Section 2, we first describe the standard CGE model and the default features of the modelling framework. Second, we describe the model mechanisms considered crucial in determining the overall economic impact of GHG mitigation, and especially key mechanisms for sustainable investment. Third, we provide a description of different scenarios, which are characterized by different combinations of policies and model changes. Section 3 compares the results of these scenarios and Section 4 summarizes the findings.

2. Materials and methods

The objective of this work is to discuss crucial mechanisms for a more comprehensive economic evaluation of climate policies that foster investment.

2.1 Landscape

There are different modelling approaches, such as macro-econometric, computable general equilibrium or systems-dynamics, which are used to assess the economic impacts of alternative climate policies.

Computable general equilibrium (CGE) models are the most commonly used tools for the assessment of climate policy, since they simultaneously capture the interrelation of all markets and agents while allowing for the integration of alternative policy scenarios. All scenarios in these models represent an optimal allocation of resources under different types of constraints. By construction, the reference scenario represents a long-run equilibrium where the economy grows at a steady rate. Hence, all other scenarios lead to sub-optimal solutions within the given analytical framework. CGE models, however, may fall short on realism as they do not capture market imperfections. However, several extensions to the classical Arrow-Debreu-type (Arrow and Debreu, 1954) of general equilibrium models have been made, to make them more realistic. Such extensions are involuntary unemployment in the labour market (Boeters and Savard, 2011), oligopolistic competition and monopolies (Balistreri and Rutherford, 2013) and endogenous productivity (Tarr, 2013).

This paper addresses additional mechanisms that are expected to play an important role for climate policy.

2.2 The GEM-E3 model

This section provides an overview of the core structure and key mechanisms of the model used.

2.2.1 Model description

For the purpose of this paper, a well-established computable general equilibrium (CGE) model, GEM-E3, is used. This description is based on the detailed model description of GEM-E3, which can be found in the GEM-E3 reference manual (Capros *et al.*, 1999) and the GEM-E3 model documentation (Capros *et al.*, 2013). The model has been applied for policy analyses and impact assessments of climate policy, such as the Impact Assessment Report of the European Commission (European Commission Staff, 2014).

The GEM-E3 model is a macroeconomic recursive-dynamic CGE model with multiple regions and sectors. It consists of a CGE core and an environmental module. Different versions of the model can differ regarding their characteristics, such as varied closure rules and institutional regimes. The environmental module includes emission permits, energy efficiency standards and several policy options for allocating emission permits and for using the generated revenues. Labour, (total factor) productivity and expectations on sectoral growth rates are the main determinants of economic growth. The main characteristics of the model are:

Firms: Firms operate under perfect competition and use a nested production function, including capital, labour, energy and materials. Firms are characterized by myopic expectations.

Households: Representative households (one for each country and region) maximize a utility function to determine their demand for goods and services. The household can buy durable (equipment) goods, non-durable (consumable) goods, and services. The use of durable goods requires some amounts of non-durable goods.

Markets: Firms optimize their profits and households optimize their utility, determining supply and demand for goods and services. Equilibrium prices are derived in the market, by ensuring that supply equals demand. Consumption and investment are allocated using transition matrices.

Technology: Technical progress is exogenously represented in the production function. In each time step, the producer can change its production inputs depending on changes in prices of labour, capital and all intermediate goods and services. The electricity sector is more detailed, differentiating between different technologies producing electricity.

Externalities: Greenhouse gas emissions are included as an environmental externality by introducing an additional constraint on the system. The emission constraint produces a shadow price for the emissions. Firms can invest in pollution abatement capital, which reduces emissions per unit of output, and hence its costs. This version of the model does not include damages to the environment and the economy in the future.

Output: Projections are made in 5-year intervals and include macroeconomic output (investment, capital, consumption, employment, balance of payments, input-output-tables, and others) as well as output related to energy and the environment (energy use and supply, greenhouse gas emissions, pollution permits, pollution abatement capital).

Appendix A provides a short technical description of GEM-E3-M50, the version of the model used for this paper, as also presented in Jaeger *et al.* (2015).

2.2.2 Investment and related mechanisms

The hypothesis to be tested in this paper, is that investment is a key mechanism for producing positive economic effects of climate policy. In order to test this hypothesis, it is necessary to determine the variables that are inputs to and outputs of investment from the investment function in GEM-E3 (as shown in Formula (6) below):

1. *Inputs to investment:* The investment demand is endogenously specified using Tobins'Q (Tobin, 1969), by comparing the market price of capital with its replacement cost. In the current implementation, investment depends on: the optimal demand for capital (given by the production function and elasticities), the depreciation rate (technologically determined), the interest rate (arising from financial market dynamics which are outside the scope of the model), the unit cost of investment, expectations on sectoral growth (exogenously defined), as well as a calibrated scale parameter. We derived two main possibilities of influencing the investment decision:
   - To change the unit cost of investment via an investment subsidy
   - To endogenize expectation dynamics, such that investors learn from their past experience.

2. *Outputs of investment:*
   - Technical progress is exogenous in the model at hand. In the real-world, however, investment has an influence on technical progress – therefore this mechanism will be addressed.
   - Investment influences the size of the capital stock and through that production and employment. Its effect is the substitution of labour with capital and between different types of capital – leading to higher unemployment and crowding-out of investment as a first-round effect (which is then offset through higher production levels as a second-round effect). This is an issue we will investigate in the simulation results.

The key mechanisms which will be investigated further in Section 2.3 are: the effects of an investment subsidy, expectation dynamics and technical progress.

2.2.3 GHG emissions constraint

A standard way of introducing climate targets is in the form of a policy that puts a cap on total emissions allowed, hence an additional constraint is added to the optimization problem. In this case, we have chosen a more ambitious climate target than the one agreed in the European Union (40% by 2030 compared to 1990), namely 50% (the respective scenario is called M50 only, as described in Section 2.4). Simulations for the Impact Assessment Report (European Commission Staff, 2014) have shown that applying a 40% GHG emission reduction target leads to small negative effects on GDP between 0.1% and 0.45% by 2030 (compared to the reference scenario).To give a structured overview of the model changes and expected outcomes, we formulate a number of propositions. Proposition 1 is used in combination with the model extensions but is based on an existing mechanism in the model.

Proposition 1. *The introduction of an emission cap in the form of an additional constraint to the optimization problem, will lead to a worse economic outcome.*

2.3 Relevant mechanisms and related model extensions

This section describes the model changes implemented to account for the mechanisms described in Section 2.2.2. The propositions are used to structure the model changes and the expected results based on the mechanisms of general equilibrium models in general and the GEM-E3 model in particular.

2.3.1 Investment program

A key goal of this paper is to evaluate the effects of a considerable increase in low-carbon investment (public or private) in addition to the introduction of a GHG emission cap. Greening the economy is the target of a number of green recovery proposals (e.g. Bowen *et al.*, 2009; Edenhofer and Stern, 2009; Zenghelis, 2012; Beyerle and Fricke, 2014), notably the Green New Deal proposed by the European Green Party (see e.g. Schepelmann *et al.*, 2009) and the New Climate Economy Report (Global Commission on the Economy and Climate, 2014). They highlight the large scale and long-term benefits, such as "building the foundations of sound, sustainable and strong growth in the future" (Bowen *et al.*, 2009: 2). Two channels through which public expenditures can be geared towards a green economy are proposed by UNEP's Green Economy Report: redirecting public investment and greening public procurement (UNEP, 2011). Further, increasing the leverage effect of public investment on private investment is being discussed at different levels, national, EU and international. UNEP's Green Economy Report suggests government actions that set conditions for private investment: to phase out fossil fuel subsidies, to reform existing incentives and provide new incentives, and to strengthen market-based mechanisms (UNEP, 2011: 14).

The World Economic Forum (2013) concludes that 80% of investment will have to come from private sources. Zenghelis (see 2011; 2012; Romani, Stern and Zenghelis, 2011) analyses the possibility of stimulating additional net private sector investment in detail. Finding historically low investment levels in most OECD countries, the authors see a "lack of confidence to invest rather than a lack of liquidity" (Romani, Stern and Zenghelis, 2011: 4) and argue that credible long-term green growth policies provide opportunities for restoring confidence and leveraging additional investment (Zenghelis, 2012: 3). Similarly, the Green Economy Report calls for the private sectors' "understanding and sizing the true opportunity represented by green economy transitions across a number of key sectors" (UNEP, 2011: 14).

A key assumption of CGE models, however, is full employment of resources. Under this assumption, any new investment project will reduce investment elsewhere. This crowding-out effect is a key distinction between optimizing and non-optimizing models. If increasing investment levels improves the economic situation, this can either point to the fact that there is another possible equilibrium point, which actors

cannot foresee or cannot coordinate on. Or it points to the fact that there are market imperfections in place that lead to a non-optimal outcome in the current situation.
To represent this mechanism in the model, a green investment program was introduced. For the purpose of this paper, the investment program was modelled as a change in policy. The value-added tax (VAT) is increased and the resulting additional revenues are used to subsidize investment. It is important to note that, what we want to investigate is the effect of the investment program and not how the additional investment is funded. The way it is implemented is comparable to other reallocation policies, such as the introduction of a price on carbon or a cap on the maximum amount of carbon emissions. Therefore, it can be expected that it leads to a crowding-out effect. The required additional VAT is calculated such that the government revenues are increased by 10% compared to the reference case plus the GHG emission constraint (the scenario M50 only). Hence, the new VAT revenues are determined by:

$$\text{VATrevenues}^{Cf} = \text{VATrevenues}^{M50\ only} \times 1.1 \tag{1}$$

where "Ref " denotes the reference scenario, "M50 only" the 50% GHG emission reduction scenario and "Cf " denotes the counterfactual scenarios, meaning the "M50 only" scenario with additional model changes.

The subsidy per unit of investment, P_{Sub}^{INV}, is calculated such that the new investment is equal to the M50 only investment plus the additional value-added tax (VAT) revenues:

$$INV^{Cf} = INV^{M50\ only} + \text{VATadditionalRevenues}^{Cf} \quad \text{and} \tag{2}$$

$$P_{INV}^{Cf} = P_{INV}^{M50\ only}\left(1 + (P_{Sub}^{INV})^{Cf}\right), \tag{3}$$

with P_{Sub}^{INV} being a negative value.

Proposition 2. *In a standard CGE model, such as GEM-E3, an investment program leads to an outcome that is worse than the scenario it is based on (M50 only), because it reallocates resources away from the optimal allocation.*

Proposition 3. *If the reference scenario is the optimal scenario by assumption, an investment program will always lead to crowding-out of consumption by investment (and of investment in one sector by investment in another) in the short-run.*

2.3.2 Learning by doing

CGE models, apart from few exceptions which will be described below, represent technical progress exogenously. However, the technical progress of clean technologies is key for a transition to a low-carbon economy. A considerable increase in low-carbon investment will increase the production level of these sectors. This will increase technical progress for these products through product and process innovation. An exogenous rate of technical progress does not take this feedback effect into account when higher levels of investment are applied.

Wing (2006) differentiates four ways of introducing technical progress endogenously, two of which are used less often: (1) price-induced input augmentation and (2) backstop-technologies; and two of which are more popular: (3) the stock of knowledge approach and (4) the learning-by-doing approach. Price-induced input augmentation is not used very often, due to difficulties in specifying a function that describes the relation between relative input prices and the augmentation of different inputs. Backstop-technologies are regarded as a semi-endogenous approach, which allows for radical technical change by introducing a new production technique. The new technique will be employed in response to an increase in prices, which in turn is dependent on other variables, mostly exogenous.

The stock of knowledge approach results from the new economic growth literature, where knowledge is represented as a kind of capital, the stock of knowledge (H), which grows with R&D investment, depreciates over time and follows an innovation process (transformation function) – which includes the efficiency of innovation, diminishing returns to R&D and spillover effects. However, the problem is the lack of disaggregated data on R&D and the calibration of initial knowledge stocks. The central argument is that climate policy does not increase R&D in general but that there is a trade-off between innovation (accumulation of knowledge) in different sectors. Popp (2004) and related papers implement a stock of knowledge approach into the DICE model. Furthermore, Acemoglu and colleagues (2012) use a stock of knowledge approach as well and find that a combination of carbon taxes and (temporary) research subsidies is sufficient to redirect technological development towards clean technologies through investment.

In the learning-by-doing (LBD) approach, the key parameter is the learning rate which depends on experience in a given sector. See Arrow (1962) for a discussion on which economic variables are a good proxy for experience. Bottom-up models favor the LBD approach and mostly use cumulative capacity or cumulative production levels as a proxy for experience. Grubb *et al.* (1995) use cumulative abatement as a proxy.

There is a rich literature on learning and experience curves, which started with a study by Wright (1936) who introduced the concept of "learning curves", measuring learning-by-doing as labour cost reduction in relation to cumulative output. He found a constant percentage of unit labour cost reduction per doubling of cumulative output in airframe manufacturing. Later on, the concept was extended to "experience curves", by including different learning effects through R&D, production scale, cost of capital, etc. and by investigating total product costs instead of labour costs. Nagy *et al.* (2010) compare three different "laws" of technical progress (time, production levels and cumulative production) for a large set of technologies and find that all three show very similar development paths for a large set of technologies. However, it is not straightforward to transfer these micro-level learning curves to the macroeconomic level.

The goal here is not to build on the vast amount of literature on technical progress by providing deeper insights into the forces that drive it. Instead, we start from the point that technical progress is present and is linked to the "experience" in a sector. Hence, exogenous learning parameters which do not change in response to policy induced changes in sectoral compositions, miss an important part of the feedback effects triggered by climate policy.

In the model used, technical progress or total factor productivity $TFP_{i,j,t}$ is determined by calibrating the model to exogenously given GDP growth rates. This is done because the purpose of the model is not to predict growth, but to assume that under business as usual the official growth rate predictions (e.g., by DG ECFIN (2012) in the EU) will be realized in the reference case.

In our approach we have semi-endogenised TFP in order to reflect learning by doing effects from higher production levels. The equation below describes the computation of TFP. It remains a calibrated parameter but an additional factor is added that depends on the production level:

$$TFP_{i,j,t}^{Cf} = TFP_{i,j,t}^{Ref} \cdot \frac{Q_{i,t-1}^{Cf}}{Q_{i,t-1}^{Ref}} \tag{4}$$

where "i" denotes the sector, "j" denotes the region and "t" denotes the time. $Q_{i,t-1}$ is the sum of the sectoral outputs over all regions j, i.e. $Q_{i,t-1} = \sum_j \ Q_{i,j,t-1}$ because spill-over effects between different regions are important for technological progress. The correction factor $Q_{i,t-1}^{Cf}/Q_{i,t-1}^{Ref}$ shows that technical progress in a given sector increases when the production in that sector increases. This means that TFP stays the same in the reference case (as production does not change). However, different levels of production in the counterfactual scenarios lead to different levels of TFP.

The review by Wing (2006) showed that a common way to prevent implausible market share dynamics in LBD approaches is to include upper bounds. In this paper we introduced an upper bound on the correction factor. Furthermore, for simplicity we assume that shrinking sectors do not "unlearn" immediately in response to reductions in demand. Hence, to prevent unreasonable dynamics, the correction factor is limited to a range from 1 to 3., i.e.,

$$TFP_{i,j,t}^{Ref} \leq TFP_{i,j,t}^{Cf} \leq 3 \cdot TFP_{i,j,t}^{Ref}. \tag{5}$$

Proposition 4*. The partial endogenization of learning-by-doing leads to an improvement of GDP as compared to M50 only, due to its effect on productivity.*

Proposition 5. *The combination of learning-by-doing with an investment program leads to an improvement of GDP, because the investment program triggers a stronger learning-by-doing effect.*

2.3.3 Expectations

The before mentioned literature suggests that technical progress creates positive externalities in the form of spillover effects, which can lead to underinvestment in these technologies. There are two main reasons for this: (1) the social benefit of innovation is higher than the private benefit of the individual investors (2) the benefit is often beyond the investment horizon of the individual.

Often, investors do not take into account their individual contribution to overall technical progress (because this depends on the behavior of others). Instead, they take it as given and collectively invest below the social optimum. Zenghelis (2011) describes climate change as a market failure emerging from uncoordinated actions of individuals that leads to a collectively inferior outcome. Such a mechanism of expectation dynamics has already been investigated in Jaeger *et al.* (2011; 2015). If several producers invest more into their productive capital, they will experience higher overall technical progress. If this experience is taken into account in investment decisions in the next period, this can lead to positive expectation dynamics.

Investment connects two time steps in a model. Expectations about future prices, policies and demand are crucial in determining the return on investment (which is subject to uncertainty) and therefore, the investment decision. The latter then drives the optimal allocation of capital leading to the optimal outcome. In the model used, time is modelled in a recursive dynamic way and agents have myopic expectations. Investment is described by the following function:

$$INVV_{i,t} = A1_{i,t} \cdot K_{i,t} \cdot \left(\left(\frac{PK_{i,t}}{PINV_{i,t} \cdot (r_t + d_{i,t})} \right)^{A} + STGR_{i,t} + d_{i,t} \right). \qquad (6)$$

where A1 is a calibrated scale parameter; K is the optimal demand for capital; PK is the cost of capital; PINV is the cost of investment; d is the rate of depreciation; r is the national interest rate; STGR is an exogenous parameter expressing expectations about sectoral growth. STGR represents the expectations on the future rate of capital return, to ensure that the investment plans are actually realized. Since STGR is an exogenous parameter calibrated to the reference scenario, it does not change with production levels (sales expectations of firms).

However, to include a response to increased rates of investment, this parameter should change endogenously, depending on the economic performance of that sector. For the purpose of better representing expectation dynamics, the following adjustment of STGR was implemented to represent adaptive expectations:

$$STGR_{i,j,t}^{Cf} = STGR_{i,j,t}^{Ref} \cdot \left(\frac{Q_{i,j,t-1}^{Cf}}{Q_{i,j,t-1}^{Ref}} \right)^{2}. \qquad (7)$$

Similar to the correction factor described in Section 2.3.2, this represents the fact that sales expectations in a given sector depend on past experience: the larger the change in production level in that sector in a specific country, the higher the sales expectations for the next period and vice versa. The difference to Section 2.3.2 is that output values are differentiated by country and sector, $Q_{i,j,t-1}$, because for expectation dynamics we do not assume large spillover-effects between countries (larger sales in one country do not necessarily lead to higher sales expectations in another country). Furthermore, we assume expectations to be more responsive to increases in production than technical progress, which is why we assume a quadratic relationship. In sectors with small output levels, the correction factor can lead to large adjustment of the STGR parameter. To take this into account, the correction factor is limited to a range from 0.5 to 3, allowing for negative effects on expectations as well, i.e.,

$$0.5 \cdot STGR_{i,j,t}^{Ref} \leq STGR_{i,j,t}^{Cf} \leq 3 \cdot STGR_{i,j,t}^{Ref}. \tag{8}$$

Proposition 6. *The partial endogenization of expectations does not lead to an improvement of GDP as compared to M50 only, as it amplifies the negative effects of the emission target through its effect on production levels.*

Proposition 7. *The combination of all three mechanisms (adaptive expectations, learning-by-doing and an investment program) is expected to result in higher levels of GDP as compared to all other scenarios, because the three effects work in the same direction.*

The next section describes the scenarios used for the analysis.

2.4 Scenario description

For the purpose of testing the propositions, different scenarios are defined. The geographical focus is Europe, since the low levels of investment make it an interesting case for these specific model changes.

2.4.1. Reference scenario (Ref)

The first step is to define a reference scenario, which represents the optimal growth path in the absence of any imperfections or frictions and assumes a business-as-usual world in terms of policies.

The data used for GEM-E3-M50 for the European Union consists of national accounts data and input-output tables from Eurostat. One underlying assumption of the reference scenario is that the output growth rate is in line with macro-economic projections, in this case 2012 Ageing Report prepared by DG ECFIN (2012). According to this report, the EU28 will have a growth rate of 1.5% over the period 2015–2050 and a decrease in the working age population. The methodology for the calibration of the exogenous parameters is described in more detail in the GEM-E3 model documentation (Capros *et al.*, 2013). Although the calibration of the reference scenario is not based on the latest data and projections, we do not consider this as problematic. This paper aims at identifying general mechanisms and focuses on the comparison of a reference scenario with counterfactual scenarios.

The different counterfactual scenarios are compared and evaluated against the reference scenario. A counterfactual scenario uses different assumptions (including changes in exogenous variables or policies). If these changes do not affect the reference scenario, the model does not need to be re-calibrated. The aim of the model changes introduced for the purpose of this paper is to keep the calibration of the reference case unchanged, to ensure comparability of results.

2.4.2 Climate policy scenario (M50 only)

All assumptions are identical to the reference scenario for this scenario. Additionally, it includes a constraint on total greenhouse gas emissions. To show the impact of an "extreme" scenario, we chose a more ambitious emission reduction target than the currently agreed target of 40% (compared to 1990). For this scenario, we apply an emissions reduction target of 50% compared to 1990 (approx. 46% reduction from 2005). No changes in climate policies are assumed for non-EU countries. To exclude other reallocation effects, it is assumed that the carbon tax revenues are not reused in the economy for a specific purpose (although this is generally possible within GEM-E3) but they are used instead to improve the public budget.

2.4.3 Variants with model changes

To perform an evaluation of the effects of the mechanisms introduced into the model, several scenarios with different combinations of model changes have been analysed. The scenarios are specified in Table 1.

Abbreviation	Scenario	Description
Ref	Reference	Optimal path, assuming a business-as-usual policy framework
M50 only	M50	50% reduction of GHG emissions compared to 1990
M50 inv	M50 with investment program	Part of the investment required to decarbonize the EU economy is financed by increasing consumption taxes
M50 tl	M50 with technical progress	Learning by doing effects are introduced in the sectors producing both clean energy technologies and other equipment goods
M50 exp	M50 with adaptive expectations	The investment decision of firms is adjusted so as incorporate expectation dynamics, next to myopic expectations
M50 tl + inv		M50 with technical progress and investment program
M50 tl + exp		M50 with technical progress and adaptive expectations
M50 tl + exp + inv		M50 with technical progress, adaptive expectations and investment program

Table 1 Scenario description

3. Results

3.1 Macroeconomic aggregates

This section shows the main findings of the simulations. Table 2 shows the results of all scenarios compared to the reference scenario in 2030. For GDP, employment, and energy consumption and energy intensity, the results for 2030 are also depicted in Figure 1. Appendix B shows the main outcomes of the reference scenario. The combined scenario (M50 tl + inv + exp) performs best in all four dimensions.

	M50 only	M50 tl	M50 exp	M50 inv	tl + exp + inv
GDP	−0.56%	−0.22%	−1.04%	−0.24%	+9.73%
Employment	−0.76%	−0.46%	−1.41%	−1.21%	+1.18%
Energy Use	−4.91%	−3.83%	−5.57%	−4.87%	−2.73%

Table 2 Macroeconomic results, all scenarios compared to reference in 2030

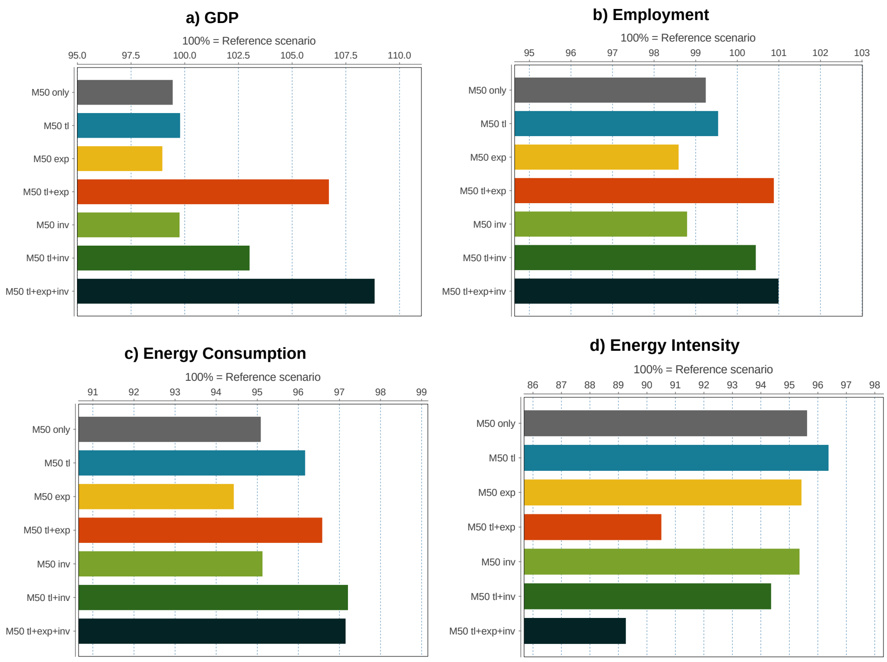

Fig. 1 Results for GDP and employment, energy consumption and energy intensity in 2030, comparing all counterfactual scenarios with the reference scenario.

We can see that the M50 only scenario (with an ambitious climate target, but no model changes applied), shows a decrease in GDP compared to the reference scenario (−0.56% GDP in 2030 compared to reference) due to a 50% GHG emission reduction target. This corresponds with the results of the European Commission Impact Assessment Report on the 2030 climate and energy framework (2014), showing GDP effects between −0.1% and −0.45% in 2030 when comparing a 40% emission reduction scenario with the reference scenario. *This outcome supports Proposition 1*.

M50 combined with the investment program (M50 inv) shows slightly improved GDP results if compared to the M50 only scenario. *This outcome does not support*

Proposition 2 if measured in terms of GDP. However, the proposition can be supported if measured in terms of "welfare", a measure of how well consumer preferences are satisfied. Due to the crowding-out effect, an increase in investment causes a decrease in consumption, which reduces the welfare of the consumer in the short-run.

However, GDP results remain below the reference case, which means that the negative effect of the emission target is only partially offset by the investment program. This means that an ambitious climate target in combination with an investment program leads to lower economic costs than a climate target alone (in terms of loss of GDP as compared to the reference scenario) but does not lead to economic benefits compared to the reference case (but compared to M50 only). The investment program leads to a crowding-out effect, hence an increase in investment, and at the same time a decrease in consumption. *This outcome supports Proposition 3*.

M50 combined with only technical progress (M50 tl) shows slightly improved GDP results if compared to the M50 only scenario. *This outcome supports Proposition 4*. However, GDP results remain below the reference case. This means that the negative effect of the emission target is partially offset, but no positive economic effect can be found.

M50 combined with adaptive expectations (M50 exp) leads to lower GDP growth compared to both the M50 only scenario and the reference scenario. *This outcome supports Proposition 6*. This means that investors' expectations amplify production levels in a negative way. The combinations of model changes on the other hand show positive economic effects, despite the GHG emissions constraint.

The combination of technical progress and an investment program (M50 tl + inv) results in GDP improvements compared to the reference scenario and the M50 only scenario in 2030. *This outcome supports Proposition 5*. The combination of technical progress and adaptive expectation (M50 tl + exp) results in GDP improvements compared to the reference scenario and the M50 only scenario in 2030 as well. This means that positive expectation dynamics can have a similar effect as the investment program. The combination of investment program, technical progress and adaptive expectations (M50 tl + inv + exp) show even higher GDP results. *This outcome supports Proposition 7*.

Regarding employment, the outcome of the M50 only scenario is worse than the reference scenario. The same is the case for combinations of M50 and one model change (tl, inv or exp), which shows that these mechanisms alone do not lead to positive effects. Employment levels for M50 exp and M50 inv are even below M50 only. This general conclusion is in line with the European Commission Impact Assessment Report on the 2030 climate and energy framework (2014). However, in the combined scenarios (M50 tl + inv, M50 tl + exp and M50 tl + exp + inv) the employment effect is positive as compared to both the M50 only and the reference scenario in 2030.

Total emissions are the same for all scenarios, due to the constraint on GHG emissions. Figure 1 shows the energy intensity and energy use in 2030 for all scenarios, which show improvements as compared to the reference case.

The development over time (see Figure 2) from 2015 to 2030, shows that the investment program causes a reduction of GDP at first. This can be explained by the the first round effect where investment is crowding-out consumption and the fact that positive effects from the additional investment are only realized in the next time step, hence after 5 years.

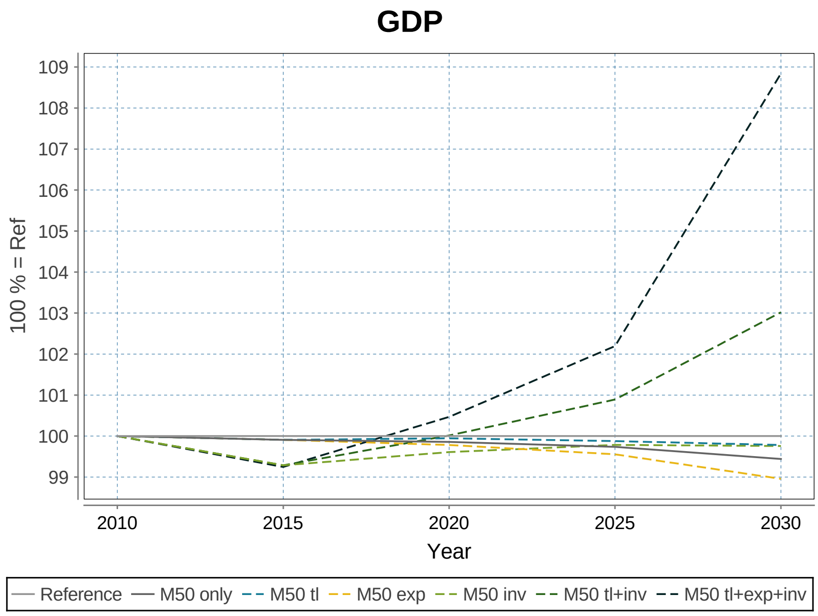

Fig. 2 Results for GDP over time

3.2 Sectoral impacts

The sectoral disaggregation is what distinguishes CGE models from optimal growth models, which are also used for assessments of economic impacts of climate policy. Results at sectoral level can give us insights into crowding-out of investment between sectors. The sectoral dimension is also important for finding out which sectors will contribute most to the transformation in terms of emission reduction (relevant for climate policy) as well as in terms of economic development (important for economic, labour and education policy).

The changes in production levels and emissions of the different sectors are presented in Figure 3. The energy sector shows the largest emission reductions (approximately 50% compared to the reference scenario, for every alternative scenario), hence this is the sector that needs to contribute most to the abatement process. The energy-intensive industry will also reduce emission levels considerably. The transport sector is expected to contribute the least to emission reductions. Equipment goods producers will increase emissions, but much less than the increase of the production level. The overall reduction of GHG emissions is 50% in all scenarios, due to the binding constraint on these emissions.

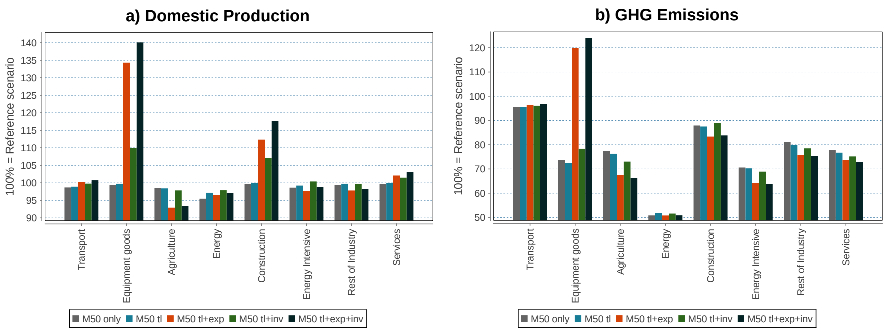

Fig. 3 Results by sector for production levels and GHG emissions compared to the reference scenario in 2030.

In economic terms, sectors contributing to energy efficiency improvements, such as construction, equipment goods and services will show higher domestic production due to larger investment in these sectors. Also at sectoral level, we can see a crowding-out effect of the investment program from some sectors to others. *This outcome again supports Proposition 3.*

4. Discussion

Reaching the Sustainable Development Goals, including climate action and affordable clean energy, requires a fundamental socio-economic transformation accompanied by substantial investment in low-carbon infrastructure. However, there has been little macroeconomic analysis that evaluates the effects of a substantial increase of investment in low-carbon technologies. The usual analyses of climate policy show negative economic effects of emission targets, because they are treated as an additional constraint to the optimization process, e.g., in CGE models and additional feedback effects are not taken into account. However, when evaluating the effects of a large increase of investment for the decarbonization of the economy, assuming no effect on technical progress and investors' expectations does not give a comprehensive picture. Rather, a sustainability transition should be analyzed as a non-marginal change of the economic state, driven by behavioral factors and systemic interactions.

This paper identifies key mechanisms that need to be included in a standard computable general equilibrium model to overcome these limitations. These mechanisms are an investment program, technical progress and adaptive expectations. The results of this work highlight the central role of large additional investment and provide a more comprehensive analysis of the effects of climate policy.

The outcomes of the scenarios with single model changes are in line with what can be expected from the literature on macroeconomic climate policy assessment (see e.g. Popp, 2004; Grübler and Messner, 1998; Grubb, Chapuis and Duong, 1995) and from the model properties: Technical progress partially offsets the negative economic effect of introducing an ambitious emission constraint. The introduction of adaptive expectations alone, amplifies the negative effect, because it depresses sales expectations of firms. An investment program leads to crowding-out of consumption with investment and therefore to less efficient resource allocation.

The results of the combined scenarios (M50 tl + inv and M50 tl + exp, M50 tl + exp + inv), however, add new insights to the literature on the role of technical progress in climate economic models: Technical progress is necessary for positive economic effects of climate policy, but not sufficient. Combining technical progress with an investment program or adaptive expectations leads to positive economic effects. These findings build on Wing (2006), who argued that the endogenization of technical progress gives rise to multiple equilibria. Indeed, the partial endogenization of technical progress introduces the possibility for a different economic growth path. The investment program as well as adaptive expectations introduce the possibility of switching between different economic growth paths.

The results provide suggestions for policy makers aiming for ambitious climate goals. If ambitious climate policy (towards 1.5 ◦C) should bring about more desirable economic outcomes, it should not be implemented in isolation. Instead, green growth policies should be the core of a wider economic program aimed at increasing investment levels and enhancing technical innovation. Green public procurement and green public investment (as proposed in UNEP (2011)) will be an important element, as well as implementing credible long-term green growth policies that restore confidence and leverage additional private investment (Zenghelis, 2012).

We can draw conclusions on the mechanisms that lead to a change in the direction of the economic effects of climate policy. However, drawing conclusions on the magnitude of the effect requires additional empirical validation and sensitivity analysis. Furthermore, generalizing these results to other countries requires more in depth analysis at the (EU) member state level as well as an extension of the analysis to other countries. Additionally, research on the role of the financial market is required in order to address the question of how to finance such an investment program, how potential funding constraints might reduce the positive effect or whether credit-financed investment can reduce the crowding-out effect.

Appendix A: Short technical description of the GEM-E3 M50 model

This section provides a short technical overview of the GEM-E3-M50 model, as presented in Jaeger *et al.* (2015). It provides the general structure of the model in order to better understand the model changes described in the paper. This description is based on the detailed model description of GEM-E3, which can be found in the GEM-E3 reference manual (Capros *et al.*, 1999) and the GEM-E3 model documentation (Capros *et al.*, 2013).

Appendix A.1 Firms

Firms maximize their profits subject to technology constraints:

$$Max\, P \times Q - Cost \tag{A1}$$

$$s.t.\, Q = CES(K, L, E, M) \tag{A2}$$

A Constant Elasticity of Substitution (CES) is used as production function. Firms production is modelled via nested production functions so as to explicitly reflect different substitution elasticities among different inputs:

$$Q_i = TFP_i \times \bar{Q}_i \cdot \left(theta_i \times \left(\frac{KLEi}{\bar{KLE}_i}\right)^r + (1 - theta_i) \times \left(\frac{MAi}{\bar{MA}_i}\right)^r \right)^{\frac{1}{r}} \tag{A3}$$

$$KLE_i = \bar{KLE}_i \times \left(theta1_i \times \left(\frac{KLi}{\bar{KL}_i}\right)^{r1} + (1 - theta1_i) \times \left(\frac{ENi}{\bar{EN}_i}\right)^{r1} \right)^{\frac{1}{r1}} \tag{A4}$$

$$KL_i = \bar{KL}_i \times \left(theta2_i \times \left(\frac{Ki}{\bar{K}_i}\right)^{r2} + (1 - theta2_i) \times \left(\frac{Li}{\bar{L}_i}\right)^{r2} \right)^{\frac{1}{r2}} \tag{A5}$$

$$MA_i = \left(\sum_{j=1}^{n} theta3 \times \left(\frac{IOj,i}{\bar{IO}_{j,i}}\right)^{r3} \right)^{\frac{1}{r3}} \tag{A6}$$

where Q: total output, TFP: Total Factor Productivity, KLE: Capital–Labour–Energy bundle, MA: Material bundle, theta: distributional parameters between KLE and MA, r,r2 and r3: elasticity of substitution parameters, KL: Capital–Labour bundle, EN: Energy bundle, theta2: distributional parameter between KL and EN, IO: intermediate inputs, theta3: distributional parameter among intermediate inputs.

Appendix A.2 Households

Households maximize their utility, subject to an income constraint:

$$MaxU = LES(C, LJV) \tag{A7}$$

$$s.t.M = w \cdot L + r \cdot K + foreignTransfers \tag{A8}$$

where U: Utility represented by a Linear Expenditure System function, C: Consumption, LJV: Leisure. Households follow a twostep decision process. At first they allocate their resources among consumption/labour supply and savings and then they allocate aggregate consumption over different consumption purposes.

$$C = ch \cdot \frac{bh}{P} \cdot (M - P \cdot ch - Savings) \tag{A9}$$

where ch: subsistence minima, bh: consumption share parameter.

Appendix A.3 Government consumption

Government consumption (GC) is set exogenously (gcexo), GC=gcexo.

Appendix A.4 Investment

The model is recursive dynamic over time, meaning that multiple (static) equilibria are linked over time with a stock-flow-relationship of capital and investment. Agents have myopic expectations with respect to prices, meaning that the set of decision parameters is constant over time. Endogenously specified investment is determined using Tobins'Q (i.e., by comparing the market price of capital with its replacement cost). The motion equation of the capital stock is:

$$K_t = (1 - d) \times K_{t-1} + INVV_t \tag{A10}$$

Firms in the current year decide on their optimal capital stock by comparing the rate of return on capital to its replacement cost.

$$INVV_{i,t} = A1_{i,t} \times K_{i,t} \times \left(\left(\frac{PK_{i,t}}{PINV_{i,t} \times (r_t + d_{i,t})} \right)^{A} + STGR_{i,t} + d_{i,t} \right). \tag{A11}$$

where A1 is a calibrated scale parameter; K is the optimal demand for capital; PINV is the unit cost of investment; d is the depreciation rate; r is the national interest rate and STGR is the (exogenous) expectation on sectoral growth.

Appendix A.5 Labour supply

The model does not assume full employment of labour. It incorporates the following labour supply curve that inversely relates wages [w] with unemployment rate [unrt]:

$$w_{j,t}(unrt_{j,t}) = a_{j,t} + \frac{b_{j,t}}{Unrt_{j,t}^{\eta_{j,t}^{Ref}}}. \tag{A12}$$

Appendix A.6 GHG emissions

Energy related CO_2 emissions are calculated by applying the appropriate emission factors to fossil fuel burning.

$$EMCO_{2ff,i} = e_f CO_{2ff} \times AER_{ff,i} \times EN_{ff,i} \tag{A13}$$

Process related GHG emissions are linked with the volume of production.

$$EMGHG_i = e_f CO_{2ff} \times Q_i \tag{A14}$$

The imposition of a GHG emission reduction target generates a dual value that increases the user cost of the emitting activity.

$$GHGTARGET \geq EMCO_2 + EMGHG \perp CTAX \tag{A15}$$

Appendix B: Reference scenario

Table A1 shows annual growth rates and Table A2 the labour market outcomes from 2015 to 2030 for the reference scenario.

Table A1 Macroeconomic annual growth rates of the reference scenario

EU-28	2015–2020	2020–2025	2025–2030
Gross Domestic Product	1.5%	1.6%	1.5%
Investment	1.4%	1.6%	1.5%
Public Consumption	1.6%	1.6%	1.5%
Private Consumption	1.6%	1.7%	1.6%
Exports	2.0%	2.0%	2.1%
Imports	2.3%	2.3%	2.3%
Labour productivity	1.2%	1.6%	1.7%

Table A2 Labour market outcomes of the reference scenario

EU-28	2015	2020	2025	2030
Employment (in m. persons)	224	227	227	225
Population (in m. persons)	434	436	432	425
Labour Force (in m. persons)	101	102	101	99
Unemployment rate	11%	10%	9%	9%

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Part II

Coordination of investors' expectations on green investment

Chapter 4

Green investment and coordination failure: An investors' perspective[1]

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Green investment and coordination failure: An investors' perspective

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Abstract

To achieve the goal of keeping global warming well below 2 °C, private investors have to shift capital from brown to green infrastructures and technologies and provide additional green investment. In this paper, we present a game-theoretic perspective on the challenge of triggering such investments. The question of climate change mitigation is often related to the prisoner's dilemma, a game with one Nash equilibrium. However, the authors perceive investment for mitigation and adaptation as a coordination problem of selecting among multiple equilibria. To illustrate this, we model a non-cooperative coordination game, related to the stag hunt, with a brown equilibrium with lower payoffs that can be achieved single-handedly and a green equilibrium with higher payoffs that requires coordination. As multiple experiments show, in such games actors often fail to coordinate on a payoff dominant equilibrium due to uncertainty. Thus, we discuss how uncertainty could be reduced along two options: one that concerns a change in the payoff structure of the game and another that concerns subjective probabilities.

Keywords: stag hunt, coordination failure, green investment, strategic uncertainty, risk dominance

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1. Introduction

The commitment to keep temperature rise well below 2°C, and desirably below 1.5°C, creates major investment needs in the coming decades (OECD *et al.*, 2015; Global Commission on the Economy and Climate, 2014; World Economic Forum, 2013). Climate change mitigation and adaptation thus require a shift of capital from brown to green infrastructures and technologies (Qureshi, 2016). Currently, the investment gap to adjust the European energy sector in line with the climate targets amounts to €100bn annually until 2030 (Berndt *et al.*, 2016). The question why there is underinvestment in green infrastructure and technologies is often addressed by bringing forward the argument of market failure. Zenghelis (2011) claims that, due to ignorance towards positive externalities, the private sector tends to underinvest in mitigation technologies, and hence needs to be incentivized. Mazzucato and Penna unite the concepts of market and coordination failure by highlighting that in situations "when agents are unable to coordinate their expectations and preferences throughout the business cycle, due to information asymmetries and high screening costs" (Mazzucato and Penna, 2015: 14), a Pareto-inferior equilibrium is obtained, leading to a lack of investment.

This paper discusses the question of underinvestment in technologies and projects for climate change mitigation with a game-theoretic approach. It builds on abundant game-theoretic literature on climate diplomacy on the country level, starting with games concerning international environmental agreements and environmental problems (see e.g. Barrett, 1994; Mäler, 1989). The problem of climate change is often discussed in the context of the one-shot prisoner's dilemma[1],dealing with free-riding when agents make decisions on how to use common pool resources or (global) public goods (see e.g. Diekert, 2012; Heugues, 2013; Ostrom, 1990). While this has been the most prominent approach in the climate change debate, games that allow for cooperation of actors have become increasingly important. Examples are dynamic, repeated games[2], dealing with self-enforcing strategies (Dutta and Radner, 2004; Heitzig, Lessmann and Zou, 2011), inequality and communication (Tavoni *et al.*, 2011) or coalitions and clubs (Carraro and Siniscalco, 1993; Finus, 2008; Hannam *et al.*, 2017; Nordhaus, 2015; Wood, 2010), as well as one-shot coordination games such as the stag hunt (DeCanio and Fremstad, 2013; Madani, 2013).

This paper enhances the above mentioned literature with a new perspective: In contrast to climate negotiations where the important players are national governments, we discuss capital allocation towards green and brown infrastructures and technologies as a coordination problem among investors[3]. This leads to a substantially different perspective due to time horizons: Since serious damages by cause of global warming are expected to manifest in the long-term future (Pachauri *et al.*, 2014),

[1] In variations, Hardin's (1968) tragedy of the commons and Olson's (1965) collective action problem relate to the same conflict that underlies the prisoner's dilemma.
[2] The repeated prisoner's dilemma allows for cooperation. In this paper, we only analyze one-shot games.
[3] For a game-theoretic perspective on cooperation between shareholders and companies concerning climate change risks, see Kruitwagen et al. (2016).

climate negotiations among countries are often described with a prisoner's dilemma. In contrast, the time horizon of investors is usually shorter. Consequently, investments in mitigation measures are reasonable only if players expect positive returns[4] in the short to mid-term. The latter is more likely in maturing markets that display a larger number of investors as well as more technological progress and hence a lower investment risk. Thus, instead of using a prisoner's dilemma, a game with only one Nash equilibrium, we perceive investment for mitigation and adaptation as a coordination problem of selecting among multiple equilibria. To illustrate this, we propose a simple framework of a non-cooperative coordination game related to the stag hunt with a "green" and a "brown" Nash equilibrium.

To explain coordination on certain equilibria, including coordination failure[5], the game-theoretic literature provides a broad variety of equilibrium selection principles and coordination mechanisms. For static games, deductive equilibrium selection principles,[6] defined by Haruvy and Stahl as being "based on reasoning and coordination on focal points", can be applied. In this case, players are assumed to have "beliefs consistent with some equilibrium" (Haruvy and Stahl, 2004: 320). By drawing on experiments and by using a simple model of brown and green investment, we show the limitations of two well-known examples, payoff dominance (Harsanyi and Selten, 1988; Schelling, 1960) and risk dominance (Harsanyi and Selten, 1988; Harsanyi, 1995), and discuss further mechanisms that could lead to coordination.

This paper is organized as follows: Section 2 explains the stag hunt as a basis for discussing win-win-strategies, leading to the analysis of equilibrium selection principles in coordination games in Section 3. Furthermore, experiments that have dealt with risk dominance and payoff dominance are described briefly. Section 4 develops a coordination game of investors in an economy with green and brown investment strategies. In this stag hunt, the risk dominant and the payoff dominant equilibrium don't coincide. This allows one to discuss the effects of uncertainty on agents' equilibrium selection. In Section 5, we analyze coordination mechanisms that can influence expectations, leading to an overview of possible signals signals (Storper and Salais, 1997; Zenghelis, 2011; Skyrms, 2016) for coordination on green investment. Section 6 concludes with macro-economic considerations.

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[4] This refers to the expected value of return, including the probability that an investment will default.

[5] Coordination failure is here defined as the selection of a Pareto-inferior equilibrium.

[6] In this paper, we only analyze one-shot games. Thus, we focus on deductive selection principles and cannot consider inductive selection principles. The latter e.g. emphasize learning (see e.g. Van Huyck et al., 1997; Golman and Page, 2009; Kandori et al., 1993; Binmore and Samuelson, 1999; Knez and Camerer, 2000; Fudenberg and Levine, 1998) and evolutionary dynamics (see e.g. Pacheco et al., 2009; Young, 1993; Crawford, 1991) to predict an equilibrium in iterated games.

2. The stag hunt

When the French philosopher Jean-Jaques Rousseau laid the foun- dations for the two player game called stag hunt, he illustrated a social dilemma that contrasts collective and individual rationality (Rousseau, 1974: 175):

> "That is how men may have gradually acquired a crude idea of mutual commitments and the advantage of fulfilling them, but only insofar as their present and obvious interest required it, because they knew nothing of foresight, and far from concerning themselves with the distant future, they did not even think of the next day. If a group of them set out to take a deer, they were fully aware that they would all have to remain faithfully at their posts in order to succeed; but if a hare happened to pass near one of them, there can be no doubt that he pursued it without a qualm, and that once he had caught his prey, he cared little whether or not he had made his companions miss theirs."

Hence, in the game-theoretic derivation of this paragraph, two strict Nash equilibria exist: Coordination on hunting the stag leads to the efficient equilibrium, delivering higher payoffs[7] for all players, whereas uncertainty about the other players' actions leads to a Pareto-inferior outcome and, thus, an inefficient equilibrium where both players hunt a hare. Fig. 1 illustrates a classical stag hunt game with a payoff of 3 for both players hunting the stag and a payoff of 2 each when both individually hunt a hare.

		Hunter #2	
		Hunt stag together	Hunt hare alone
Hunter #1	Hunt stag together	3 3	0 2
	Hunt hare alone	2 0	2 2

Figure 1 A 2x2 stag hunt game.

While in a prisoner's dilemma, the mutually beneficial solution does not emerge because of an individual incentive not to cooperate, in a stag hunt, achieving the mutually beneficial solution depends on trust, making it a conflict between mutual benefit and personal risk (see Skyrms, 2004).

The stag hunt has been studied in different variations and forms. It is, for instance, used to describe collective action problems (Medina, 2007; Pacheco *et al.*, 2009; Harrison and Hirshleifer, 1989) or social structures (Skyrms, 2004). Evolutionary game theorists have extended it to n-players and iterated it (Skyrms, 2007; Binmore and Samuelson, 1999; Moreira *et al.*, 2012; Young, 1993). Others applied it to macro-economic settings (Bryant, 1994; Cooper and John, 1988).

Concerning climate change, the stag hunt has been used to illustrate decisions in climate negotiations among countries. DeCanio and Fremstad (2013) analyze the whole spectrum of 2×2 order one-shot games in the light of climate negotiations,

[7] The question of the relationship of payoffs and utility and the derived implications for risk needs further research that is beyond the scope of this paper.

focusing on Nash equilibria and Maxi-min strategies as equilibrium concepts. They come to the conclusion that whether such negotiations can be characterized as a coordination game or a prisoner's dilemma (PD) depends on how strongly players take into account the possible risks of climate change. If considered an existential threat, countries are likely to coordinate on the payoff-dominant abate-abate equilibrium which – if reached – is self-enforcing; whereas if their main goal is, e.g., to gain geopolitical advantages, "the PD characterizes the situation and the outlook for coordination is dim" (DeCanio and Fremstad, 2013: 182). Madani (2013) extends the range of solution concepts used by these authors to show a broader range of equilibria, especially including the possibility of a Pareto-optimal outcome in an interactive prisoner's dilemma.

While we relate to these important contributions, we take a different approach. Instead of analyzing climate change on country level, our focus is on investors. As an illustrative example for green investment decisions in the context of climate change, we set up a coordination game resembling a stag hunt. Since the stag hunt exhibits two pure-strategy Nash equilibria, game theorists seek the help of selection criteria in order to obtain a stable solution.[8] Section 3 will provide a closer look at equilibrium selection principles in coordination games as well as an overview of influential experiments which tested these selection principles.

[8] There is an established literature on deductive equilibrium selection principles, like payoff dominance, as well as an emerging literature on inductive ones, such as social learning in iterated games.

3. Equilibrium selection in coordination games

Whenever more than one strict pure-strategy Nash equilibrium exists in a game, refinements cannot predict a unique solution. Thus, the problem of equilibrium selection arises (Harsanyi and Selten, 1988). Under such conditions, players face a coordination problem, which can lead to coordination failure, i.e. "the failure to obtain a Pareto-optimal equilibrium" (Straub, 1995: 340).[9] Two equilibrium selection principles developed by Harsanyi and Selten (1988) – payoff dominance and risk dominance, will be described in more detail here.

3.1 Payoff dominance and risk dominance

In their 'General Theory of Equilibrium Selection', Harsanyi and Selten (1988) developed the criteria of payoff and risk dominance for non-cooperative 2×2 games with two pure-strategy equilibria in order to find answers to the coordination problem described above. Payoff dominance is there described as follows:

When there are two equilibria *r* and *s* of the game, *r* payoff dominates *s* if the payoffs of all players at *r* are larger than the payoffs of all players at *s*.[10] Thus, in the example of Fig. 1, the stag equilibrium payoff dominates the hare equilibrium because both players receive a higher payoff if they collectively hunt the stag instead of individually pursuing the hare. If there is a Nash equilibrium that payoff dominates all the other equilibria, this Nash equilibrium is considered the payoff dominant one. Since there are only two Nash equilibria in the example of Fig. 1, the equilibrium where both players choose to hunt the stag is payoff dominant.

The risk dominant equilibrium is based on pairwise comparison of equilibria and can be determined via their Nash products. The Nash product reflects each player's opportunity cost of unilateral deviation from the equilibrium. For the example given in Fig. 1, the Nash product of the stag equilibrium is 2, and the one of the hare equilibrium 4. Since the latter is larger, the hare equilibrium is the risk dominant one, while the stag equilibrium is payoff dominant. In their derivation of the Nash product, Harsanyi and Selten (1988) consider the thresholds for the subjective probabilities a player has to assign to the behaviour of the others in order to decide which strategy to choose. In the example of Fig. 1 this means: If hunter 1 assumes hunter 2 to hunt the stag with a probability of more than $p_S^{(1)}$=2/3, he will choose to hunt the stag as well, while he has to assume the other to hunt the hare with a probability larger than $p_H^{(1)}$=1/3 in order to go hare hunting himself. Thus, in the example of Fig. 1, hunter 1 has to have strong reasons to assume player 2 will go stag hunting; in case he translates his uncertainty to assuming player 2's probabilities for stag or hare hunting to be

[9] In the case of a stag hunt, this would correspond to both hunters choosing the Pareto-inferior equilibrium in which they each individually chase a hare.

[10] Mathematically formulated following Harsanyi and Selten that is: When *r* and *s* are equilibrium points of the fixed standard form *n*-players game $G = (\Phi, H)$, with the pure-strategy combination set $\Phi = \times_{i \in \{1,\dots,n\}} \Phi_i$ and a payoff function $H: \Phi \to \mathbb{R}^n$, *r* payoff dominates *s* if $H_i(r) > H_i(s)$ for every $i \in \{1, \dots, n\}$, i.e if the payoffs at *r* are larger than the payoff at *s* for all players.

fifty/fifty, he optimises his expected payoff by going hare hunting, because $p_H^{(1)} < 0.5$ (and thus $p_S^{(1)} > 0.5$). In this sense, a smaller risk factor stands for a lower risk.

In the following, we will call these probabilities risk factors of the player for the respective equilibrium. To determine risk dominance, it is equivalent to compare the products of these probability thresholds (i.e. $p_H^{(1)}p_H^{(2)}$ and $p_S^{(1)}p_S^{(2)}$ in our case) or the Nash products (see Harsanyi and Selten, 1988). The one with the larger Nash product has the smaller risk factor and is risk dominant. For a symmetric game as in our example, the risk factors are the same for both players, and thus it is sufficient to only compare $p_S^{(i)}$ and $p_H^{(i)}$.

For a game like the stag hunt that allows to Pareto-rank equilibria, Harsanyi and Selten claim that collective rationality makes "risk-dominance considerations irrelevant" [11] since "rational individuals will co-operate in pursuing their common interests if the conditions permit them to do so" (Harsanyi and Selten, 1988: 356). This implies that if there is a single Pareto-efficient equilibrium point, there is no uncertainty about the outcome of the game and, hence, actors will co-ordinate on the equilibrium with the highest payoff for all. Schelling (1960) also supports this perception with his concept of tacit bargaining, which states that if there is a clearly Pareto-superior solution for all, people will coordinate on this focal point even when communication is impossible. A rational player would always want to maximize his expected utility and, consequently, hunters would coordinate on hunting the stag (payoff dominant equilibrium) instead of the hare.[12]

Following this logic, risk dominance would only become relevant when the beliefs, integrated via subjective probabilities[13] over the other player's strategies, imply an uncertain outcome of the game. The view presented above has been challenged in various experiments, which will be described in the next section.

3.2 Experiments

A broad variety of laboratory experiments with coordination games such as the stag hunt test Harsanyi and Selten's (1988) concepts of payoff dominance and risk dominance. Most of them conclude that players often do not coordinate on the Pareto-optimal equilibrium. Van Huyck, Battalio and Beil (1990) show that strategic uncertainty leads to coordination failure because people choose security over efficiency.[14] Also, their experiment suggests that the larger the group of players, the stronger the tendency of coordination failure. In another experiment, an opinion game with a payoff dominant equilibrium and a secure equilibrium, van Huyck, Battalio and Beil observed that "repeated interaction produced simple dynamics that

[11] Harsanyi (1995) later revised his assumption that players always choose the payoff dominant equilibrium over the risk dominant equilibrium and proposed to only use multilateral risk dominance as an equilibrium selection criterion for non-cooperative games.

[12] Aumann (1990) rejects this self-enforcing logic by arguing that non-binding pre-play communication ("cheap talk") on choosing the payoff dominant equilibrium does not lead players to actually pick this equilibrium in a stag hunt.

[13] Sudgen (2000) goes a step further, trying to introduce normative expectations into conventional games by including higher order strategies.

[14] Risk dominance was not explicitly tested in Van Huyck et al. (1990).

converged to the inefficient equilibrium" (Van Huyck, Battalio and Beil, 1991: 903). Schmidt *et al.* (2003) found that a change in the payoff structure of the game exerts less influence on equilibrium selection than a change in the risk structure. Battalio, Samuelson and Van Huyck (2001: 758) altered optimization premiums in order to investigate convergence towards the inefficient risk dominant equilibrium in a stag hunt game. Cooper *et al.* (1990; 1992) reject the notion of Pareto-dominance and showed that dominated strategies can have an influence on equilibrium selection. Straub (1995), who performed repeated two-person coordination games, concludes that "coordination failures are a replicable empirical regularity and that risk dominance is crucial in explaining coordination failures" (Straub, 1995: 352). The experiments mentioned above show that agents have difficulties coordinating on the Pareto-optimal equilibrium. Thus, the experiments display the limitations of deductive equilibrium selection principles.

4. A stag hunt of brown and green investment

4.1. Game-theoretic descriptions for problems of climate change mitigation

As outlined briefly in Section 1, the common approach when discussing climate change in economics is to compare short-term mitigation costs (i.e. accepting a welfare reduction) with the long-term benefits of avoiding damages due to climate change (see e.g. Stern, 2007). Usually it is assumed that in a business as usual scenario the important changes that are likely to cause relevant damages are expected for the second half of the 21st century (Pachauri *et al.*, 2014) while mitigation costs to avoid these damages start accumulating today. This reasoning builds on well-established concepts such as the tragedy of the commons (Hardin, 1968) or the logic of collective action (Olson, 1965). In game theory, it is often formulated in a prisoner’s dilemma (see e.g. Carraro, 2003; Nordhaus, 2015): In a world with limited capacity to absorb additional CO_2 in the atmosphere that at the same time incentivizes actors to burn fossil fuels, we are trapped in a situation with the only Nash equilibrium being that everyone makes use of the resources in an unsustainable way and chooses not to mitigate, i.e. defect. We do not believe this game theoretic representation to be particularly useful in the context of green investment. Time horizons for investments are usually much shorter than 50 years, leaving investors stuck in a mismatch described as the tragedy of the horizons (Carney, 2015). Such investment decisions are rarely motivated by physical climate damages in the future, but by achieving returns in the present. While some green investments might only reap their benefits in the next decades, e.g. due to a lack of regulatory instruments like a relevant carbon price or carbon tax, others, such as wind and PV investment, can already be profitable today (McCrone *et al.*, 2017). Since we believe the underlying strategic decisions of investors to be guided rather by considerations of risk and return (which might partly depend on technological progress and partly be triggered by certain policies and regulations) than by avoiding long-term damages due to global warming, players could expect others to coordinate on green investment – and thus, believe in a stag hunt. Also, adding to technical progress and spillover effects, the promise of global benefits can influence investment decisions. While for a single person a transition is costly, a tipping point from where it is beneficial to transit can be reached. This idea, e.g. laid out by Barrett (2003) is represented in our model. Gerlagh and van der Heijden (2015) describe a similar mechanism in a dynamic stag hunt where if the majority of the group coordinates on the transition, it is beneficial for each player to follow this strategy.

If, as outlined above, the picture of the prisoner's dilemma does not capture the situation of investors well, other representations might be more suitable. In this paper, we suggest using another game theoretic setting to discuss green investment. Our basic model aims at illustrating how assumptions about payoffs in a game where investors are faced with choosing between different technologies can take the form of a stag hunt. The idea is not to provide quantitative evaluations for a specific economy, but to identify a game structure that can later help to discuss the influence of coordination mechanisms such as social norms, narratives and signals.

4.2. An exemplary stag hunt

Let us assume that investors can choose to invest in one of two available technologies: a new green and an established brown one. Both investments are connected with a respective payoff P which depends on the player's own investment and on the behaviour of the others. The more players invest in a technology, the higher their payoffs become. In the model, this represents increased acceptance for and maturity of a technology, making the investment more profitable as, e.g., unit costs decrease (economies of scale).[15] [16] There is a major difference between the two technologies: Since the established technology is mature and widespread, [17] returns on investments do not depend very strongly on what other investors do, whereas for the new technology option, total investments are crucial for gaining acceptance and diffusion.

We define our investment game as follows: There are n equivalent players (investors) with two possible strategies – S_G and S_B – to choose from. S_G means to invest a certain amount I in the green technology, while S_B means investments of the same amount I in the brown technology. This means the total investment of player i is either ($G_i = I$, $B_i = 0$) if he chooses strategy S_G, or ($G_i = 0$, $B_i = I$) for strategy S_B. The investor’s payoff has two components: One relates to the investor’s own engagement and consists of a return on investment proportional to the invested quantity (with factor r) as well as of investment costs (factor c). The other component is the investor’s return, proportional to the total investments in the respective technology (including the investor’s own engagement). The payoff P_i of player i is then given by

$$P_i = (r_g - c_g)G_i + \frac{\gamma}{n}\sum_{j=1}^{n} G_j = gG_i + \frac{\gamma}{n}\sum_{j=1}^{n} G_j \qquad (1)$$

if S_G is chosen, and

$$P_i = (r_b - c_b)B_i + \frac{\beta}{n}\sum_{j=1}^{n} B_j = bB_i + \frac{\beta}{n}\sum_{j=1}^{n} B_j \qquad (2)$$

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[15] With respect to investment, technical progress through learning by doing, i.e. increase by overall investment, exhibits the game theoretic structure of a prisoner’s dilemma. This discussion is beyond the scope of this paper and thus shall only be sketched briefly: In economic growth models, technological progress is often assumed to be exogenous, and is e.g. modelled to be exponentially increasing over time (Moore’s Law). However, there is empirical evidence that one of the main drivers of productivity growth is “learning by doing”, i.e. productivity increases faster the more output is produced, or proportionally to the capital stock. Usually, it is assumed that this productivity growth is the same for all producers, i.e. if induced by the expansion of the capital stock of one firm it benefits all the others as well. Barro and Sala-i-Martin (2004) showed that if every firm (owning a small capital stock compared to the overall capital stock) neglects the impact of its own investment on productivity growth, investment is lower than in the optimal case. For this situation, Barro and Sala-i-Martin suggest internalizing this external effect, e.g. through a subsidy for investments, financed by the revenues of a tax on consumption.

[16] An IPCC special report links the cost decrease, e.g. for wind energy, to learning and higher production or capacity via experience curves (Edenhofer et al., 2012).

[17] Binmore (1994) defines the less risky equilibrium in a stag hunt as the „state of nature“ – comparable to our brown strategy – while an agreement for a social contract is defined as riskier but beneficial – relating to our green strategy.

if player i chooses S_B, i.e. for example in case of 10 players with four of them investing in green and the other six investing in brown, the payoff for a player i investing in green is given by by $P_i = gI + \frac{\gamma}{10} \cdot 4I$.

Here, γ, β, g, and b are the constant parameters that account for the respective returns. Since we assume that for the established technology, returns on investments do not depend very strongly on other investors, whereas for the new technology option total investments are crucial, we consider the brown technology to be the established one and the green one to be the new technology. Thus, we choose $\gamma > \beta$ and $b > g$.

To give an example of the resulting game structure, for $n = 3$ players and $I = 1$, $\gamma = 7$, $\beta = 2$, $g = 4$, and $b = 8$, the payoffs for player i playing S_G or S_B are given in Fig. 2. Here, the parameters shall only serve as examples for the case of a new and an established technology, and thus do not have a concrete empirical foundation.

		Other players		
		S_G, S_G	S_G, S_B / S_B, S_G	S_B, S_B
Player i	S_G	11.0	8.7	6.3
	S_B	8.7	9.3	10.0

Figure 2 Payoffs of player *i* in the green and brown investment game.

This game has two pure-strategy Nash equilibria, a "green" payoff-dominant equilibrium (all players choose to play green) and a "brown" risk-dominant one (all players choose to play brown). The green equilibrium is strictly Pareto-superior and results in the highest possible payoff for all players. We assume that the players maximise their expected utility, which is based on the payoffs of the game and on beliefs, i.e. player i develops expectations about the behaviour of the other players by assigning probabilities to their possible actions. In our simple model, he or she doesn't differentiate and expects both other players to behave similarly. Let p_G be player i's subjective probability of the other players choosing green, and p_B his or her probability for the others choosing brown. Player i's expected payoff for playing strategy S_j is then given by

$$E[P(S_j)] = p_G^2 \, P(S_j|S_G S_G) + p_G p_B \, \left(P(S_j|S_G S_B) + P(S_j|S_B S_G)\right) + p_B^2 \, P(S_j|S_B S_B) \qquad (3)$$

with $P(S_j|S_k S_l)$ being the payoff for player i playing S_j, given that the other players choose S_k and S_l, respectively.

Payoff dominance as a selection criterion in this case would mean that players automatically select the Pareto-superior equilibrium ($p_G = 1$, $p_B = 0$). Instead, we consider strategic uncertainty to influence equilibrium selection. To evaluate the risk dominant equilibrium, we calculate risk factors for both Nash equilibria as described in Section 3. We assume that players consider the other players as equal, i.e. they assume equal probabilities p_G, $p_B = 1\text{-}p_G$ of playing green or brown for all the other players. For the payoff table given in Fig. 2, player *i* chooses to play green if he or she assumes that the others play green with a probability $p_G > p_G^* = 0.61$, and consistently, chooses to play brown if he or she expects the others to play brown with a probability of $p_B > p_B^* = 0.39$. This means that in this example the Pareto-inferior Nash equilibrium is risk dominant, and in case that a player considers the others to choose brown with a probability of > 0.39, he or she chooses the strategy associated with the Pareto-inferior equilibrium.

The structure of the game is unchanged if we increase the number of players to 101. Fig. 3 shows payoffs of a player investing in green (black line) or brown (grey line) versus the number of others playing green. In this game, two Nash equilibria exist: one if all players choose green and another if all players choose brown. The green Nash equilibrium is Pareto-superior with a risk factor of $p_G^* = 0.67$. The brown equilibrium results in a lower payoff for all players and has a risk factor of $p_B^* = 0.33$.

γ and β determine the slopes of the curves, and g and b shift them vertically. Our assumptions $\gamma > \beta$ and $b > g$ result in a steeper curve and a lower minimum for the case of the player playing green. To invest in brown can be considered less risky as the associated risk factor is smaller than 50%.

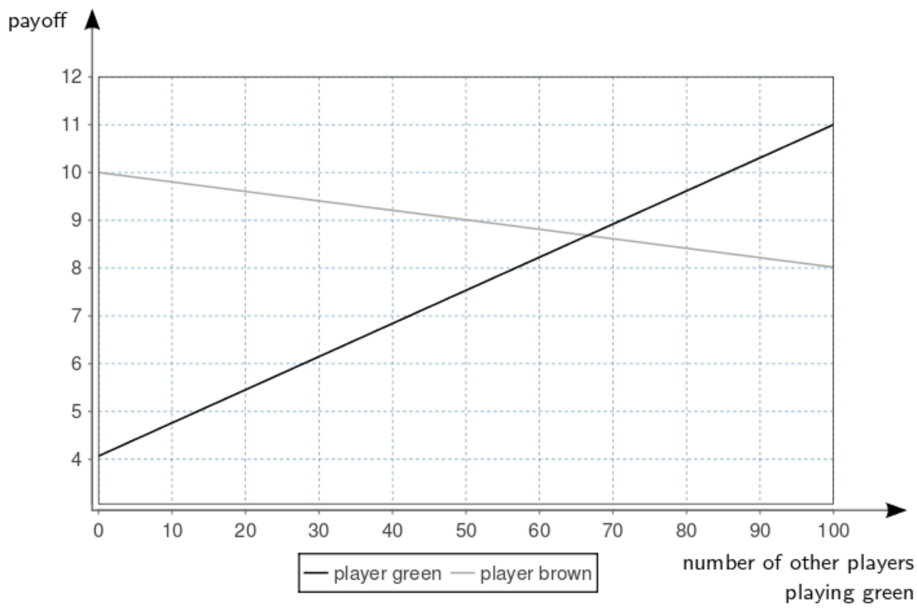

Figure 3: Expected payoffs for one player in a 101-player investment game.

On the left side of the intersection of the two curves, the share of investment in the green technology is too small to make it more profitable than brown investment; while on the right side of the intersection, the total share of green investment is large enough for it to become more profitable for the individual player.

5. Discussion

Mathematical models can point out important underlying mechanisms to real world problems and help to facilitate analogies to similar challenges for which solutions may already exist. If a situation is described as a prisoner's dilemma, free-riding is identified as the main problem. While we do not claim that green investment always needs to be a win-win situation, we emphasize critical-mass effects when it comes to technological change. Under this assumption, a staghunt-like structure with a risk dominant and a payoff dominant equilibrium can be obtained as, e.g., the externality of technical progress. In our simple game-theoretic model of investment decisions between two technologies, the problem of a green investment gap is understood as a coordination problem rather than a problem of free-riding. Perceiving the situation as a stag hunt allows to focus on different solution concepts than in a prisoner's dilemma. Thus, in Section 5.1, we will discuss coordination mechanisms for equilibrium selection of a brown or a green equilibrium. Section 5.2 will relate these ideas to green investment.

5.1 Coordination mechanisms

As discussed before, experiments with stag hunt-like games indicate that, although it would be collectively rational, people are not likely to choose payoff dominance as an equilibrium selection strategy due to a lack of trust in the behaviour of the others. Van Huyck, Battalio and Beil believe that rational decision makers in economies with multiple equilibria will be influenced by strategic uncertainty[18] "even in situations where objectives, feasible strategies, and institutions are completely specified and are common knowledge" (Van Huyck, Battalio and Beil, 1991: 885f). Schelling, even though adhering to the concept of focal points, acknowledged that "the principles relevant to successful play, the strategic principles, [and] the propositions of a normative theory, cannot be derived by purely theoretical means from a priori considerations" (Schelling, 1960: 162). If more than payoffs are considered to have an influence on players' choices, other coordination mechanisms,[19] such as social norms (Nyborg *et al.*, 2016; Binmore and Samuelson, 1994; Skyrms, 2008; Burke and Young, 2011; Gintis, 2010), signals or narratives (Jaeger *et al.*, 2012; Wolf, Schütze and Jaeger, 2016; Morgan, 2012) could influence players' expectations.

In our simple model, we assume that players choose their strategies evaluating expected payoffs. Expected payoffs are determined by payoffs and subjective probabilities (see Eq. (3)). Thus there are two entry points for such mechanisms:

1. *A change in the game, i.e. the payoff function (Eqs. (1) and (2)).* This would, e.g., correspond to subsidies for green investment as a coordination mechanism, which in the model would be represented by a larger g.

[18] Strategic uncertainty among rational actors has been described by many scholars, among them Keynes (1936) with his concept of the beauty contest.
[19] Cooper and John state that "if there was a mechanism for agents to coordinate their activities, they could achieve a better (cooperative) equilibrium" (Cooper and John, 1988: 448).

Increasing *g* shifts the blue curve upwards (Fig. 3) and, thus, reduces the risk factor for the green equilibrium. [20]

2. *A change of players' expectations.* The subjective probabilities assigned to the behaviour of the others are crucial for the investors' choice of strategy. There are many attempts to deduce these probabilities endogenously from the structure of the game alone (Binmore, 1994; Harsanyi and Selten, 1988; Sudgen, 2000). However, since our model is not a stand-alone tool to draw lessons from, we consider it useful for discussing how to influence subjective probabilities exogenously, because they are crucial for the question on which side of the tipping point the players will find themselves.

Combinations of both options could be effective. For example, feed-in-tariffs for renewables or similar measures that support green investment could reduce the risk factor of the green equilibrium by altering the payoff table – and thus the structure of the game. At the same time, they can influence players' subjective probabilities on the likelihood of other players to choose green, due to a stronger belief in the transition and future profits from green investment (see e.g. Dufwenberg, Gächter and Hennig-Schmidt (2011) and Tversky and Kahneman (1981) on the effects of framing in decision making, and specifically concerning environmental contexts, Gerlagh and van der Heijden (2015), Pevnitskaya and Ryvkin (2013) and Cason and Raymond (2011)).

Beckert (2009: 247) supports this argumentation by saying that it is only possible to resolve coordination problems, "if market actors are able to form stable expectations with regard to the actions of other market actors and future events relevant for their decisions, and if they consider the expected outcomes to be sufficiently in their material interest and normatively acceptable".

In the context of the choice of green investment in our simple model, the question is how to make investors expect that the others will invest in green.[21] There are several approaches that consider influencing players' expectations exogenously: Cachon and Camarer (1996) conclude that framing payoffs as gains or losses could alleviate coordination failure in repeated play. Corsetti, Guimaraes and Roubini (2006) discuss that liquidity support by the International Monetary Fund (IMF) can foster coordination in financial crises. Bryant (1994) emphasizes that out of a non-equilibrium situation of an economy, institutions could help actors to coordinate more efficiently than just prices. In Gerlagh and van der Heijden's (2015) stag hunt, an environmental framing of the game leads to twice as many green technologies.

Most examples of such mechanisms take effect in repeated games, where players can learn to coordinate. In a one-shot prisoner's dilemma, players always have an incentive to free-ride. In an infinitely iterated game (see e.g. Blonski, Ockenfels and Spagnolo, 2011; Sherstyuk *et al.*, 2016), players might change their strategy according

[20] This logic was tested and confirmed by Schmidt *et al.* (2003).
[21] Such a mechanism of expectation dynamics has already been investigated in Jaeger *et al.* (2011).

to the behaviour of the others and cooperate. Our one-shot stag hunt-model without repeated interactions cannot describe the transition period itself. Nevertheless, green investment, as discussed above, can be beneficial already today, during the transition.

5.2 Coordination on the green investment strategy

Our paper relates to climate policy, considering how green investment as a contribution to mitigation could be fostered. It is useful to discuss reasons why players might assume that green investments of other players are unlikely. The metaphor of the prisoner's dilemma, as outlined in Section 4.1, can have a negative impact on the expectation whether a transition towards a 2°C scenario is likely to be achieved or not. If we assume that the players of our investment game live in an environment in which the prisoner's dilemma narrative is prevalent in the public discourse, e.g., shaped by civil society, market actors and policy makers, their probabilities for expecting the others to invest in green technologies might be low.

Let us assume that, on the contrary, the players of our investment game live in a society in which the public discourse on climate mitigation is dominated by the idea of a stag hunt, and presuming that there is another possible Nash equilibrium which is characterized by the use of greener technologies that lead to less CO_2 at (at least) the same level of growth. This Nash equilibrium, categorized as a "green growth"[22] trajectory, would be considered a stable state of the economy. In such an environment, our players' probabilities for expecting the others to invest in green technologies would be higher than in the case where climate mitigation is associated with a prisoner's dilemma.[23]

The organizational literature gives insight on coordination mechanisms for firms: Lorenzen (2001) provides an example by distinguishing incentive coordination mechanisms – such as monitoring – and cognitive coordination mechanisms – such as reputational effects. Storper and Salais (1997) name growth opportunities and technological opportunities as two important coordination signals that companies receive.

Coming back to the two options for coordination mechanisms, a framework of possible signals for green investment can be derived. The first option includes policy and market signals that change the parameters of the payoff functions, such as feed-in tariffs or a maturing market. The second option contains signals that relate to social norms, such as civil society pressure, or to leadership, reputation (Ostrom, 2009) and transparency by actors.

[22] By green growth, we mean sustainable growth that combines ecological, economic and social aspects. For an economic assessment of green growth, see Wolf (2016).

[23] Ostrom, in an attempt to update the theory of collective action, supports this positive perspective in saying that "while many instances of free riding are observed in the array of empirical research, a surprisingly large number of individuals facing collective action problems do cooperate" (Ostrom, 2009: 10). The chances of cooperation increase, e.g. if actors have reliable information on costs and benefits of actions, operate within a long-term time horizon, value a reputation for being a trustworthy reciprocator and experience leadership for joint problem solving.

6. Conclusions

Climate change mitigation and the necessary investments to decarbonize the economy can be understood as a social dilemma. Inaction, often characterized as individually reasonable behaviour, leads to a deficient equilibrium. Although the prisoner's dilemma is a more commonly used metaphor in the discourse on climate change, we find that the stag hunt provides an interesting framework for discussing green investment strategies due to its inherent aspects of coordination. If expectations of actors can be reframed towards green growth, e.g. through credible climate policy, narratives or investment incentives, coordination on a Pareto-superior equilibrium could be reached. However, Straub, who described coordination failure as a "conflict between individual rationality (risk dominance) and collective rationality and the inability of agents to select actions as a group" (Straub, 1995: 353), argues that risk dominance will always prevail in a single-shot game without communication. Thus, the study of dynamic stag hunts (Skyrms, 2016), e.g. in the context of well-known growth models (see Steudle *et al.*, 2017 in preparation), as well as the study of coordination mechanisms for investors, provide an interesting basis for further research. Since green technologies are still associated with higher risks, there is an incentive for institutional investors to choose brown technologies. However, our model exhibits a tipping point, where players' assumptions about the probability with which the others invest in the green technology exceed the necessary threshold above which a player considers his or her green expected payoff to be higher than the brown one. Therefore, we conclude that trust and expectations are crucial in achieving the green equilibrium.

While the brown and green investment game presented in Section 4 entails a micro-economic perspective through the selection of Nash equilibria among investors, stag-hunt structures can be also used to explain macro-economic states, such as Keynesian coordination failures and equilibrium selection in economies (Goeree and Holt, 2005; Bryant, 1994; Cooper and John, 1988). In Bryant's (1983) model economy, agents only reach an inferior equilibrium although they have rational expectations[24] while Cooper and John (1988: 448) describe coordination failure as the situation where an economy gets "stuck at an inefficient equilibrium with a low level of 'economic activity', even though a better equilibrium exists".

If applied to climate change, the current state of the European economy could accordingly be described as a brown equilibrium. Emissions are still too high, while at the same time the EU is experiencing low growth rates and low investment levels, making it difficult to mobilize capital for the desired decarbonization. The Pareto-optimal green equilibrium could then be described by the concept of green growth (see e.g. Jaeger *et al.*, 2015). If we consider this option as a possible alternative, these two macro states of the economy can also be perceived as a stag hunt: We are stuck in the risk dominant brown equilibrium while there is another payoff dominant green equilibrium out there. As large-scale green investments would be necessary for

[24] In a later effort, Bryant (1994) developed a two-step production game that develops from a prisoner's dilemma into a stag hunt.

achieving that green growth equilibrium, this ‘macro stag hunt’ is clearly related to the considerations sketched in our investors’ model.

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Chapter 5

Signals for 2°C: The influence of policies, market factors and civil society actions on investment decisions for green infrastructure[1]

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Signals for 2°C: The influence of policies, market factors and civil society actions on investment decisions for green infrastructure

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Abstract

The targets of the Paris Agreement make it necessary to redirect finance flows towards sustainable, low-carbon infrastructures and technologies. Currently, the potential of institutional investors to help finance this transition is widely discussed. Thus, this paper takes a closer look at influence factors for green investment decisions of large European insurance companies. With a mix of qualitative and quantitative methods, the importance of policy, market and civil society signals is evaluated. In summary, respondents favor measures that promote green investment, such as feed-in tariffs or adjustments of capital charges for green assets, over ones that make carbon-intensive investments less attractive, such as the phase-out of fossil fuel subsidies or a carbon price. While investors currently see a low impact of the carbon price, they rank a substantial reform as an important signal for the future. Respondents also emphasize that policy signals have to be coherent and credible to coordinate expectations.

Keywords: green infrastructure investment, coordination of expectations, policy signals, green finance, climate change, institutional investors

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1. Introduction

The agreement to keep global warming well below 2°C while "pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels" (UNFCCC, 2015: 3) made at the COP21 in Paris requires major changes in the global investment landscape: Finance flows have to be redirected towards sustainable, low-carbon and climate-resilient infrastructures as well as technologies[1] (World Economic Forum, 2013; Global Commission on the Economy and Climate, 2014; OECD *et al.*, 2015). The New Climate Economy Report estimates an annual investment need for a 2°C compatible infrastructure of US$6.27 trillion until 2030. Calculating with the current infrastructure spending of US$2.5 to US$3 trillion a year, this would leave a global investment gap of at least US$3 trillion annually that needs to be met by private and public actors (Bielenberg *et al.*, 2016). To bring the EU energy infrastructure in line with the 2030 Climate and Energy Framework and the Energy Union (European Commission, 2011), the European Investment Bank estimates a gap of €100 billion annually until 2030 (see Figure 1, Berndt *et al.*, 2016).

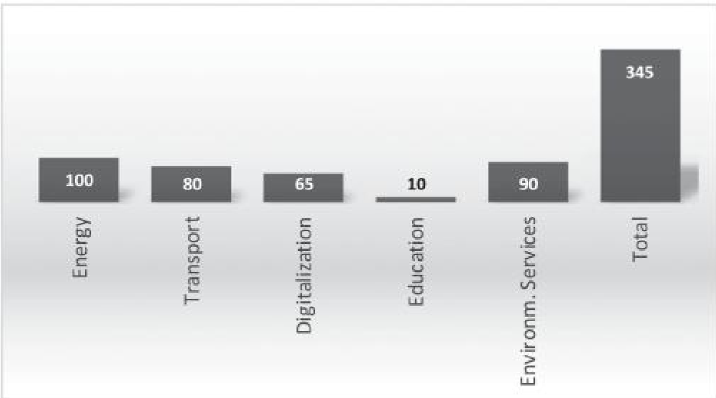

Figure 1 Annual infrastructure investment gap in the EU until 2030 in €bn; Source: numbers assembled from Berndt et al. (2016).

In reaction to austerity measures and lower investment levels in many member states (Della Croce, Stewart and Yermo, 2011; Inderst, Kaminker and Stewart, 2012) [2] after the financial and sovereign debt crisis, the European Commission set up a variety of policy measures to stimulate private infrastructure investment[3], for example the European Fund for Strategic Investment[4] and the Capital Markets Union (Revoltella *et al.*, 2016). To 'shift the trillions' to green infrastructure[5] (Inderst,

[1] The European Roadmap for a competitive, low-carbon economy in 2050 names "various forms of low carbon energy sources, their supporting systems and infrastructure, including smart grids, passive housing, carbon capture and storage, advanced industrial processes and electrification of transport including energy storage technologies." (European Commission, 2011: 5).

[2] Governmental spending on infrastructure in the EU had decreased especially in the highly indebted GIIPS countries Greece, Ireland Italy, Portugal and Spain as well as in the New Member States of Eastern Europe (Revoltella *et al*,. 2016; Egler and Frazao, 2016).

[3] Corsetti, Guimaraes, and Roubini (2006) emphasize that the success of such incentives strongly depends on whether they can coordinate the expectations of investors.

[4] 40% of all supported European Fund for Strategic Investment (EFSI) projects have to be climate-related (European Commission, 2016b).

[5] Climate Action and Energy Commissioner Miguel Arias Cañete emphasized the necessity to "leverage private investments through public support, in particular when it comes to building

Kaminker and Stewart, 2012; Kaminker *et al.*, 2013), European policy makers specifically address insurance companies and pension funds (European Commission, 2015b; European Commission, 2016c). The author takes up this discussion and poses the following research questions: Which signals from policy makers, market players or civil society actors are considered important by insurance companies when they make investment decisions for green infrastructure? And which signals could be important drivers of green investment in the future?

While much of the literature around low-carbon investment deals with policies and incentives that address possible market failures (Zenghelis, 2011), this paper uses a different approach. It analyses green investment as a coordination problem among investors, which, following Beckert (2009: 247), can only be resolved ”if market actors are able to form stable expectations with regard to the actions of other market actors and future events relevant for their decisions, and if they consider the expected outcomes to be sufficiently in their material interest and normatively acceptable”.

To discuss such expectations, game theory, which analyses interactions of agents and seeks for best responses to expected actions of others (von Neumann and Morgenstern, 1947; Harsanyi and Selten, 1988), is a useful tool. The framework developed in this paper to investigate policy, market and civil society signals that influence investment decisions is thus based on game theoretic reasoning. It relates to a model by Mielke and Steudle (2018) which describes investors' decisions for a brown vs. a green technology as a coordination game with two equilibria, where agents have to choose under uncertainty. The model assumes that players choose their equilibrium strategies by evaluating expected payoffs, which are determined by payoffs and expectations concerning the behavior of the other players. Based on this reasoning, policy, market and civil society signals as described in this paper could serve as coordination mechanisms in investors' decision making for green and brown technologies, possibly leading to a tipping point for green investment (Mielke and Steudle, 2018).

Hence, this paper goes beyond the academic literature that investigates the influence of energy policies on investment decisions (Dinica, 2006; Gross, Blyth and Heptonstall, 2010). By focusing on expectations and perceptions (Wüstenhagen and Menichetti, 2012; Chassot, Hampl and Wüstenhagen, 2014) in connection with policy, market and civil society signals, this research extends the model that green investment decisions are primarily driven by energy policies which influence risk and return (De Jager *et al.*, 2008). Also, group dynamics (Shiller, 1995) and social or ethical objectives (Renneboog, Ter Horst and Zhang, 2008) are included in this framework. To answer the research questions above, the largest European insurance companies based on their total assets (Statista, 2016) located in the UK, Germany, the Netherlands and France as well as relevant insurance and investors' associations were asked to rank policy, market and civil society signals according to importance to their investment strategies. The ranking was accompanied by qualitative interviews.

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interconnections and infrastructure, energy efficiency and renewable energy” (European Commission, 2016c).

The paper is organized as follows: In section 2, the background is described. Section 3 elaborates on the method and explains the framework of signals used in the ranking and the interviews. Section 4 presents the results, organized by the respective main topics in the fields of policy, market and civil society signals, followed by a discussion in Section 5. Section 6 concludes.

2. Background

2.1 Green infrastructure and green investment

Infrastructure is a large contributor to global greenhouse gas (GHG) emissions (Qureshi, 2016) and a major component of gross fixed capital formation. To reduce the carbon footprint, carbon-intensive structures have to be modernized or replaced with low-carbon ones such as renewable-energy power plants or smart grids (Boie *et al.*, 2014). Green or low-carbon, climate-resilient (LCCR) infrastructure projects can be defined as ones that mitigate emissions and/or support adaptation to climate change (Corfee-Morlot *et al.*, 2012). This paper specifically considers three areas of green infrastructure that the European Investment Bank has outlined as crucial for the achievement of the 2030 climate targets in the energy sector: (renewable) energy projects, power distribution and transmission projects and energy efficiency improvements[6] (Berndt *et al.*, 2016). To describe finance flows into sustainable technologies or green infrastructures, this paper uses the term green investment (Eyraud *et al.*, 2011; Inderst, Kaminker and Stewart, 2012; World Economic Forum, 2013; OECD, 2013b).[7]

2.2 The role of institutional investors

Several studies discuss the potential of institutional investors[8] to finance green infrastructure (Inderst, Kaminker and Stewart, 2012; Kaminker *et al.*, 2013; Pierpont and Nelson, 2013), for example due to their long-term focus (Della Croce, Stewart and Yermo, 2011; Déau, 2011; Ottesen, 2011). On a global level, McKinsey estimates that private institutional investors could close almost half of the annual infrastructure investment gap of US$3 trillion (Dobbs *et al.*, 2013; Bielenberg *et al.*, 2016). For Europe, the law firm Linklaters calculated the potential allocation of institutional investors towards infrastructure projects at US$100 billion annually until 2023 (Linklaters, 2014). In the EU, the insurance sector is the largest institutional investor with an investment portfolio of around €10 trillion in 2015, of which roughly one percent were invested into infrastructure (Insurance Europe, 2016). Over recent years, the European sector association Insurance Europe noted a "key shift" in asset

[6] While renewables and transmission projects are often large scale and thus of interest to insurance investors, energy efficiency projects are often considered too fragmented and small-scale.
[7] Other terms used in the literature are climate finance (Clapp *et al.*, 2012; UNEP FI, 2014; UNFCCC SCF, 2014; Buchner *et al.*, 2015; Hamilton and Zindler, 2016) or green finance (G20 Green Finance Study Group, 2016).
[8] The definitions of institutional investors vary. Here, they are defined as pension funds, insurance companies and investment companies such as sovereign wealth funds. For a broad discussion of the term, see Çelik and Isaksson (2014).

allocations towards infrastructure, offering several reasons: low interest rates, low returns on traditional assets and "a strong political push in this area, focused on both the creation of infrastructure pipelines throughout the EU and the review of excessive prudential barriers" (Insurance Europe, 2016: 38). Other studies also describe a shift towards so called Alternative Investments,[9] where insurers invest directly in infrastructure projects in order to diversify and increase their returns (Della Croce and Yermo, 2013; McCrone *et al.*, 2016; Offner, 2016). Insurance Europe expects a further increase of infrastructure investment to an average 5–10 percent in portfolios. However, it is not specified whether these are green/low-carbon infrastructure investments such as renewables[10] or brown/high-carbon investments such as highways and airports.

Green infrastructure projects are considered attractive for insurers if they provide stable and predictable cash flows, for example wind and solar projects which have "an estimated 25-years lifespan, with manufacturer warranties, long-term contracts with power purchasers and government support" (Kaminker, Stewart and Upton, 2012: 2). Thus, many large-scale European insurance companies have built up expertise to be able to engage in project investment, focusing on renewables and other infrastructures (Kaminker *et al.*, 2013; Pierpont and Nelson, 2013). During the COP21 in Paris, major insurance companies such as Allianz or Munich Re have announced their intention to increase their sustainable infrastructure investments in various ways – through renewables, green bonds or the integration of ESG (Environmental, Social and Governance) criteria[11] in their investment strategies. At the same time, they have started to take into account possible risks of stranded assets[12] by divesting from coal.[13] Overall, institutional investors with assets of US$24 trillion supported the Paris Agreement in 2015 (Krosinsky and Purdom, 2017).

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[9] In Solvency II, Alternative Investments (AI) refer to an asset class of high risk investments, such as hedge funds, infrastructure and private equity that are associated with high capital charges. They have low correlation with standard asset classes such as bonds or stocks.

[10] The OECD (2013b: 3) defines green infrastructure investment as financial flows into "low carbon and climate-resilient infrastructure (LCCR)" which are "made in companies, projects and financial instruments that operate primarily in the renewable energy, clean technology and environmental technology markets, as well as those that are climate-change specific or ESG-screened. These investments include energy-efficiency projects, many types of renewable energy, carbon capture and storage, nuclear power, smart grids and electricity demand side-management technology, and new transport technologies, for example electric vehicles."

[11] Urwin (2010: 3) distinguishes "integrated" ESG investing if companies generally adopt those criteria for their investment strategies, and "targeted" ESG investing if investors choose to concentrate on products or fields that meet ESG criteria such as renewables.

[12] For an overview of the discussion on stranded assets, which describe fossil assets as being likely to lose their value in the future, see Ayling and Gunningham (2015).

[13] Allianz divests from companies that generate more than 30% of their revenues from coal mining or produce more than 30% of their energy from coal (Tewes, 2015).

3. Methodology

This paper analyses the influence of a range of signals on insurers' green infrastructure investment decisions with a mix of quantitative and qualitative methods, following the explanatory sequential research design (Creswell and Clark, 2011).[14] A three-phase approach was used: First, in a preparatory phase, the author reviewed literature and conducted focus groups and follow-up interviews to derive the research questions, support the development of the signal framework, and choose the sample. Secondly, in the quantitative phase, a ranking was sent to the chosen stakeholders and evaluated. Thirdly, in the qualitative phase, in depth interviews were conducted and evaluated to substantiate the ranking results.

3.1 Preparatory phase

Three focus groups, each with 6–8 participants from industry (e.g. car and machine manufacturers, utilities and transmission operators, ICT and infrastructure companies), from the financial sector (e.g. commercial and development banks, insurance companies) as well as civil society (e.g. unions, foundations and NGOs) were conducted to discuss and weight challenges and opportunities of the energy transition and a decarbonization in Germany and Europe. Stakeholders were in leading positions in their companies or institutions. To discuss in more depth, stakeholders from the insurance, the energy (production and transmission) and the ICT sector were also interviewed individually. Based on these results and a literature review, a framework of signals concerning investment decisions for green infrastructure was designed and used to create a ranking survey with survey monkey.[15] The ranking was chosen over a Likert scale for two reasons: first, it allowed respondents to compare signals instead of judging each item seperately. Second, the ranking procedure was considered to be a better fit in the business and corporate environment of respondents. Thus, the author was hoping to achieve higher response rates. Steinbacher (2015) used a ranking to assess the goals of the renewable energy strategy in Morocco in a combination with semi-structured interviews. In a similar approach, Joas, Pahle, and Flachsland (2014) asked stakeholders from policy, administration, industry, civil society, science and the media to rank goals of the German energy transition according to their importance.[16] Bürer and Wüstenhagen (2009) used a similar approach, asking cleantech investors to rank push and pull energy policies. Next, a sample was constructed that included the following: the largest EU insurance companies, based on their total assets reflecting their investment capacity, as well as five insurance and investors' associations, one on EU level, two on the largest markets (Germany, UK) and two associations with an explicit climate and sustainability focus.

[14] See Rolfe (2006) for a discussion of the distinctions of qualitative and quantitative research.
[15] www.surveymonkey.com.
[16] The ranking procedure can also be linked to the q sort technique used for example to investigate opinions and values concerning politics, psychology, markets or media (Müller and Kals, 2004).

3.2 Quantitative analysis

In the quantitative phase, the author contacted 14 stakeholders – 9 leading employees of investment/sustainable investment departments of insurance companies and 5 directors or leading employees of associations – and asked them to rank the signals in the survey. Twelve stakeholders responded – eight from insurance companies, and four from associations. Overall, the sample represents the largest insurance companies in the EU: Three insurance companies based in the UK, with total assets between US$540 and US$580 billion, two in Germany (US$935 and US$283 billion), two in France that hold assets worth US$ 944 and US$ 433 billion and one in the Netherlands (US$450 billion). All have low-carbon-infrastructure investments such as renewables in their portfolios and are open to discussions on environmental, social and governance (ESG) factors. While some have divisions, or even subsidiaries for renewable investments, others integrate them in their global asset management or work on applying ESG approaches to all investments undertaken in the company.[17] Moreover, four associations participated in the ranking: A German industry association representing 450 insurance companies with total investment portfolios of €1,5 trillion, an EU association that has 35 national associations as members, representing investments of around €10 trillion as well as two climate and sustainability investors' associations, one based in the UK, with 150 members representing assets worth €21 trillion, and one in Germany, representing 47 financial companies.

The framework developed consists of market, policy and civil society signals and thus addresses an institutional dimension, reflecting that investors take into account norms and values or regulation and incentives at the level of their own company, their sector or society (Bergek, Mignon and Sundberg, 2013). It also relates to the risk framework of the Task Force on Climate-related Financial Disclosure (TCFD) that defines climate 'transition risks' for companies as policy risks, legal risks, technology risks, and market changes (TCFD, 2017).

Respondents were asked to rank the importance of the fields market environment, policy environment and civil society from most important (1) to least important (3), both today and in the future, to get an idea of the general importance of the spheres. Subsequently, they received a more detailed list of current and future market, policy and civil society signals to rank from most important to least important (see Table 1 for the signals, and Supplementary data for the questionnaire). Assigning ranks of equal importance for signals was allowed. If a signal was considered irrelevant, a zero could be attributed to it. Respondents could also add signals they thought to be missing (open question) in each field, and suggest future civil society signals (open question). The survey was designed in a target-group specific manner – for insurance companies and with slight differences for associations representing institutional investors from insurance companies, banks or pension funds.

[17] Data and views by the respondents were expressed on condition of anonymity, and the author adheres to this condition. Statements will not be attributed to single companies or entities. Respondents' replies will appear only related to the two distinctions of insurance companies and associations.

The market-based signals were intended to describe the current situation in the Euro- zone, including for example low interest rates, which constitute a challenge for insurance companies (International Monetary Fund, 2016). Storper and Salais (1997) name growth opportunities and technological opportunities as two important signals companies receive. Also, stakeholders mentioned uncertainties concerning the future demand for green infrastructure and growth rates. Since investment in renewables[18] (McCrone *et al.*, 2016) and demand for responsible investment products (KPMG and Alfi, 2015) and green bonds[19] (Cochu *et al.*, 2016; The Climate Bonds Initiative Markets Team, 2017) are growing, respondents were asked about the importance of these trends for their investment decisions. The future scenarios include specific events such as divestments by major market players as has already started to happen among institutional investors in the context of the Paris Agreement (Climate Nexus, 2015; El Alaoui, 2016; Krosinsky and Purdom, 2017). In the policy field, the author's aim was to specify the importance of current policies on the one hand, based on representative support schemes for renewable energy such as feed in tariffs (Bürer and Wüstenhagen, 2009; Groba, Indvik and Jenner, 2011), carbon pricing instruments such as the EU ETS, policy frameworks such as the Energy Union or the EU 2030 Climate and Energy Framework, international climate agreements and financial regulation (Liebreich and McCrone, 2013), for example Solvency II (Corfee-Morlot *et al.*, 2012; Severinson and Yermo, 2012; Kidney, 2015; Cochu *et al.*, 2016). On the other hand, the author wanted to evaluate how specific policies and governance proposals such as EU-wide tax incentives or enhancements for green bonds (Lake, 2015) or a reduction of fossil fuel subsidies (OECD, 2013a) could affect insurers' green investment decisions. Current reform processes such as the Capital Markets Union initiative, and the work on financial disclosure of climate-related risks through the TCFD, were also included. [20]

'Coherent national infrastructure plans in line with climate targets in EU28' were chosen as a signal due to stakeholders complaining about a lack of coherence in EU policies in the preparatory focus groups.[21] Civil society movements were addressed, mainly broken down into engagement and divestment, including measures such as green bond standards (for example the Climate Bond Initiative's Climate Bonds Standards; Kidney, 2015) or ESG criteria for indices (2° Investing Initiative, 2013).

[18] In 2015, a record amount of US$285.9 billion was invested globally in renewable energy (excluding large hydro-electric projects) − 5% more than the year before.
[19] The green bond market has been steadily growing, with an issuance of US$41.8 billion in 2015 and US$81 billion in 2016.
[20] The European Systemic Risk Board has analyzed the risks of a late and sudden low-carbon-transition (ESRB Advisory Scientific Committee, 2016).
[21] For an analysis of the effects of stringency and predictability of environmental policy on investment and innovation, see Johnstone, Haščič, and Kalamova (2010).

Table 1. Signals of influence on insurers' green infrastructure investment decisions.

Signals of influence	Timeframe: *Current situation*	Timeframe: *Future scenarios*	Dimension
Market signals	- Competitor's investment in green infrastructure	- Strong market leader increases green infrastructure investment - Major market players divest from fossil fuels	*External benchmarks*
	- Carbon prices	- Carbon price rises substantially (above €30 per ton CO_2e)	
	- Renewable investment trend	- Renewable energy investment increases rapidly	
	- Performance of major general indices		
	- Performance of sustainability indices		
	- Government bond returns	- Government bonds keep falling into negative	*Macro-economic indicators*
	- Growth expectations (EU and world)		
	- Performance of other Alternative Investment options	- Other Alternative Investments perform poorly	*Internal benchmarks*
	- Risk-return profile	- Green bonds bring higher returns	
Policy signals	- Feed-in tariffs and other energy support schemes	- Feed-in tariffs in all EU28 countries	*EU energy and climate regulation*
	- The EU Emissions Trading System (EU ETS) / Carbon Prices	- Carbon trade reform that causes substantial rise of carbon price (above €30 per ton CO_2e)	
	- National Energy and Climate Plans (NECPs) of major economies	- Coherent national infrastructure plans in line with climate targets in EU28	
	- Unbundling in energy markets	- Unbundling regulation is relaxed to allow investment in transmission and production - Reduction of fossil fuel subsidies in Europe	
	- Solvency II / Basel III	- New asset class for green infrastructure in Solvency II framework	*EU financial market regulation*
	- Capital Markets Union (Revision of calibrations for infrastructure)	- Mandatory climate-related financial disclosure for companies	
	- Paris Climate Agreement		*International climate agreements*
	- Aggregation platforms for energy efficiency projects	- Aggregation platforms for energy efficiency allow large-scale investment	*Financial support mechanisms/ financing instruments*
	- European Long Term Investment Fund (ELTIF)	- Green securitization regulation	
	- First-loss guarantees	- Public incentives for green bonds (e.g. yield premium)	
Civil society signals	- Environmental, Social, Governance (ESG) standards for indices		*Engagement*
	- Green bond guidelines		
	- Public debate on climate change and corporate responsibility		
	- Anti-coal movement		*Divestment*
	- Divestment movement		

The signals' suitability to address climate change or their costs and benefits were not assessed since this would have exceeded the scope of this paper. The ranking results were analyzed with median values for all signals. The arithmetic mean, usually not applied to ordinal data such as rankings, was calculated to allow an additional assessment (see Steinbacher, 2015).

3.3 Qualitative phase

After the analysis of the ranking, semi-structured qualitative interviews with the survey respondents (Gill *et al.*, 2008; Niederberger and Wassermann, 2015) which lasted between 30 and 90 min were carried out for an in-depth discussion of the data obtained and to refine and explain the results (Ivankova, Creswell and Stick, 2006). The interviews focused on topics derived from the individual survey responses, especially when there were contradictory or dissenting answers, but allowed for divergence towards other topics. All interviews were transcribed and coded around the signals according to qualitative content analysis (Gläser and Laudel, 2010; Kuckartz, 2014). Statements were attributed to the signal framework in a deductive approach. This means the data was analyzed with a priori (deductive) codes corresponding to the signals from the ranking. Statements that fit to neither of the codes or that needed to be further qualified were coded inductively (emergent codes).

3.4 Critical reflection of the method

Even though the sample of 12 respondents is by no means representative, the respondents work in leading positions for the largest European insurance companies and insurance associations, making the results relevant in the context of the discussion on green investment decisions in the European Union and the European Climate and Energy Framework. Nevertheless, the responses reflect the opinion of the respondents and not necessarily of the respective company. Moreover, interviewer bias as well as selection bias in the coding procedure cannot be fully avoided. The researcher tried to minimize interviewer bias by following a similar semi-structured procedure in all interviews and by asking open questions. Selection bias was addressed by involving two researchers in the transcription and two in the coding process. Since the data was collected from industry-expert stkeholders, the author acknowledges the challenges that go along with such an approach, ranging from the kind of knowledge produced in such stakeholder interactions to the science-policy-interface that is perceived and used differently by stakeholders and scientists. For a discussion of challenges of stakeholder involvement in science, see Mielke et al. (2016; 2017) and for a specific discussion on close dialogue with industry stakeholders, see Clark (1998).

4. Results

After a brief summary of the preparatory focus groups and interviews (4.1), the results of the ranking (quantitative analysis) and the follow-up interviews (qualitative analysis) will be presented (4.2) along the signal categories policy (4.2.1), market (4.2.2) and civil society (4.2.3). The section ends with a synthesis (4.3).

4.1 Barriers to green investment

In the preparatory phase, focus groups and interviews were conducted (see Section 3). Participants from the insurance sector, from banks and from development finance institutions (DFIs) named regulatory obstacles and a lack of bankable projects and project pipelines as the main barriers to more green investment. More specifically, regulatory uncertainty, defined by the TCFD as transition risk, in the fields of energy, climate and financial markets and a lack of coherence and strategy concerning EU policies and the German Energy Transition were discussed. Solutions were seen in establishing credible and reliable policy incentives as well as financial instruments tailored for green investment. Examples were standardization to simplify project evaluation, aggregation to scale up projects and thus make them more attractive for institutional investors, or risk alleviation measures to allow for long-term commitment or establishment of project pipelines by government entities. These barriers and solutions were taken into account in the creation of the ranking and the interview guidelines.

4.2 Signals for a shift

In the survey, respondents[22] first ranked the strength of influence that the policy and market environment or civil society generally have on their investment decisions concerning green infrastructure. Overall, respondents showed a slight preference for market over policy signals, now as well as in the future. Civil society actions ranked last. Only one respondent ranked civil society signals as the top influence factor for the future. Looking solely at the answers of insurers, market and policy signals were currently equally important to them.

[22] If not stated differently, the median of all answers was calculated to achieve a ranking of fields or signals.

4.2.1 Policy signals

Presently, policies regulating energy markets were seen as having the largest influence on respondents' green investment decisions, since support schemes such as feed-in tariffs were ranked first. Financial market regulation such as Solvency II and the Capital Markets Union came in second and were followed by the Paris Agreement as an international framework. The influence of a carbon price, determined by the EU Emissions Trading System (EU ETS), was considered to be low (see Figure 2).

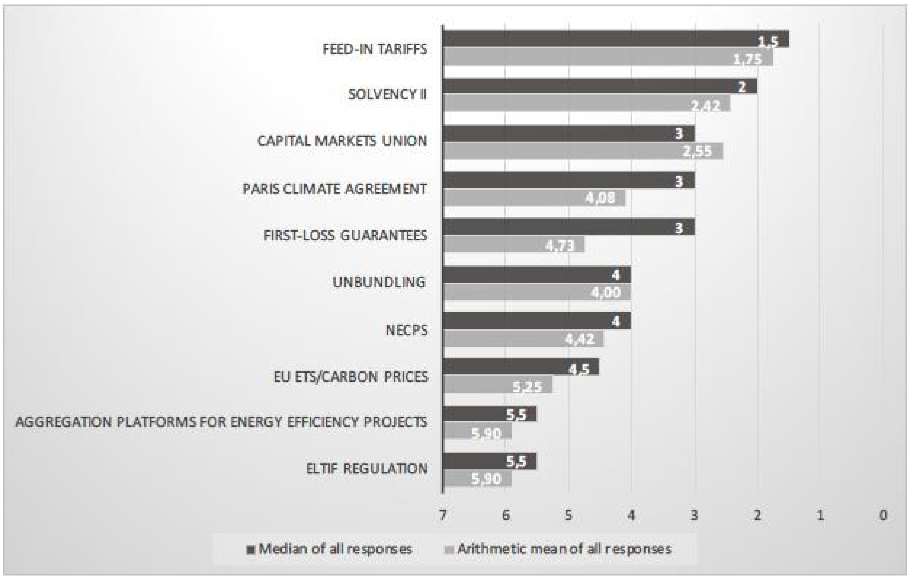

Figure 2 Importance of current policy signals as ranked by respondents, organized by median (average given asa comparison). Respondents could rank from 1 (most important) to10 (least important). NECPs: National Energy and Climate Plans; EU ETS: European Union Emissions Trading System; ELTIFs: European Long-term Investment Funds. Source: own illustration.

For the future, respondents thought that of the given options, a new asset class for green infrastructure (within the Solvency II framework) with adjusted capital requirements would influence their decisions most (see Figure 3), [23] followed by feed-in tariffs for renewables in all EU countries and public incentives for green bonds. The signal mandatory climate-related financial disclosure, which was at the time of the interviews discussed due to the work of the TCFD, ranked low in its expected influence on green investment strategies. The TCFD provided recommendations for a voluntary framework of climate-related financial disclosures which encourage investors and companies to include information along the core elements of governance, strategy, risk management as well as metrics and targets into their financial reporting (TCFD, 2017).

[23] The difference in average and median on the signal 'new asset class for green infrastructure' is due to most respondents ranking this highly, but two ranking it as having low importance (ranks 8 and 10).

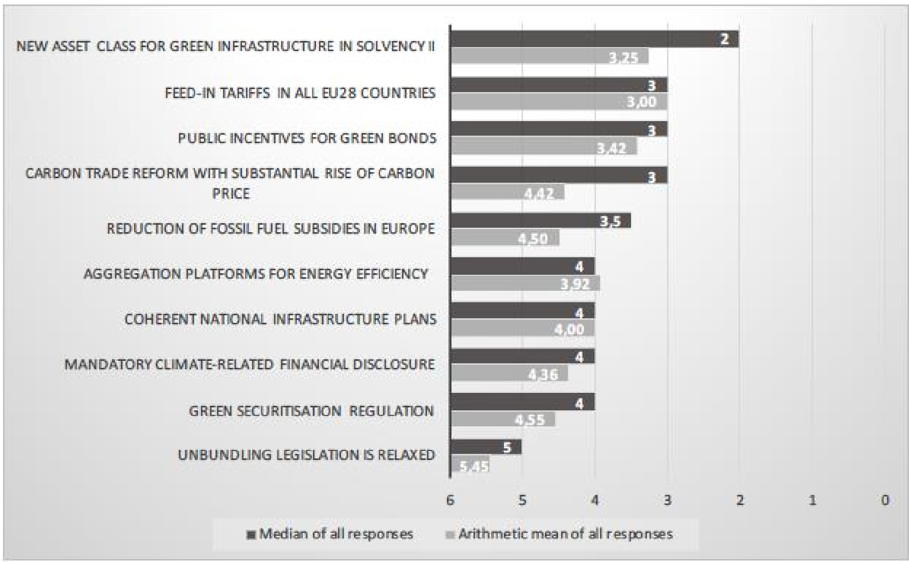

Figure 3 Importance of future policy signals as ranked by respondents, organized by median (average given as a comparison). Respondents could rank from 1 (most important) to 10 (least important). Source: own illustration.

4.2.1.1 EU energy and climate regulation

Stakeholders considered market mechanisms such as feed-in tariffs for renewables[24] as the most important signal for their green infrastructure investment decisions. They mentioned a variety of reasons, the most prominent being that feed-in tariffs have direct impact on projects since they provide for stable cash flows. Regulated infrastructure, due to its guaranteed prices per unit, was thus considered bearing lower risk and hence leading respondents to consider it eligible for lower capital requirements in Solvency II (see Capital Markets Union). Nevertheless, investors would still have to consider policy risks such as the government's credibility, for example "[H]ow likely is this [the feed-in tariff] to be sort of taken away?"[25] A future solution might be an EU-wide system, which was ranked highly by respondents, even though some saw challenges due to current differences in the energy mix or the market structure. The influence of the phase-out of fossil fuel subsidies, which a variety of experts from the energy sector saw as a top priority in a study by Sovacool (2009), received a middle rank among respondents. Insurers ranked it lower than the respective associations.

Even though there was consensus that a more "accurate" pricing of carbon would be an important signal for green investment, its design was a contested issue among respondents. Ideas spanned from a "system that sort of actually fairly values carbon" to a "significant"* carbon price in the EU, including cross-border-tariffs that could have an impact on the evaluation of companies and thus on the capital market.[26]

[24] For a technological assessment of feed-in-tariffs and carbon prices, see Kalkuhl, Edenhofer, and Lessmann (2012).
[25] Respondents frequently mentioned Spain, which radically reformed its feed-in tariff system, as a worst-case scenario. For more detail on its impact on investment, see Ernst and Young (2014).
[26] The current price for certificates in the EU ETS is considered having a low impact (7th rank), one respondent even said it has "zero"* impact.

Nevertheless, two stakeholders mentioned that a high carbon price might lead to divestment, but not necessarily to green investment. Looking at the market signals, the same picture could be found: The carbon price was considered to have only little impact today (rank 6, see Figure 4), while a substantially higher price could matter in the future (rank 3; see Figure 5).

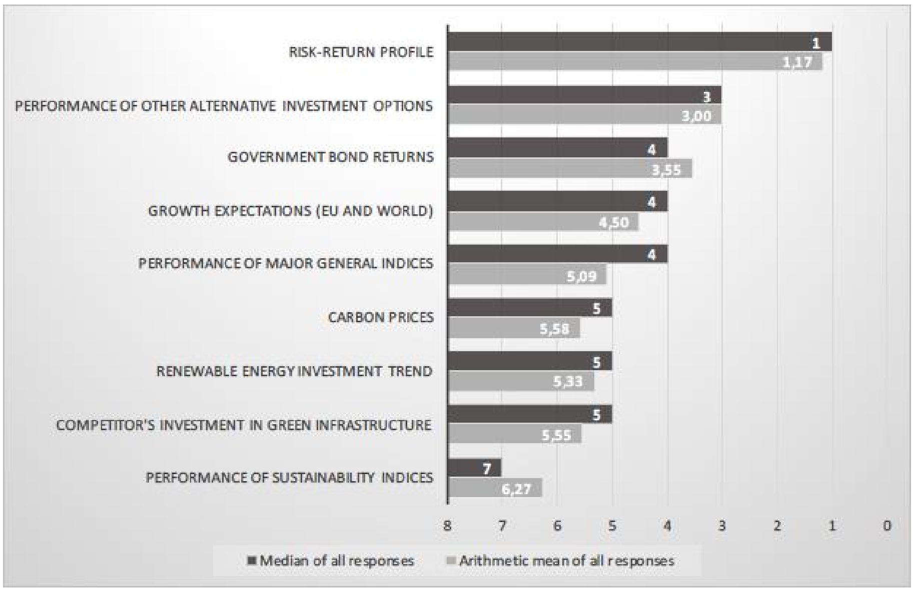

Figure 4 Importance of current market signals as ranked by respondents, organized by median (average given as a comparison). Respondents could rank from 1 (most important) to 9 (least important). Source: own illustration.

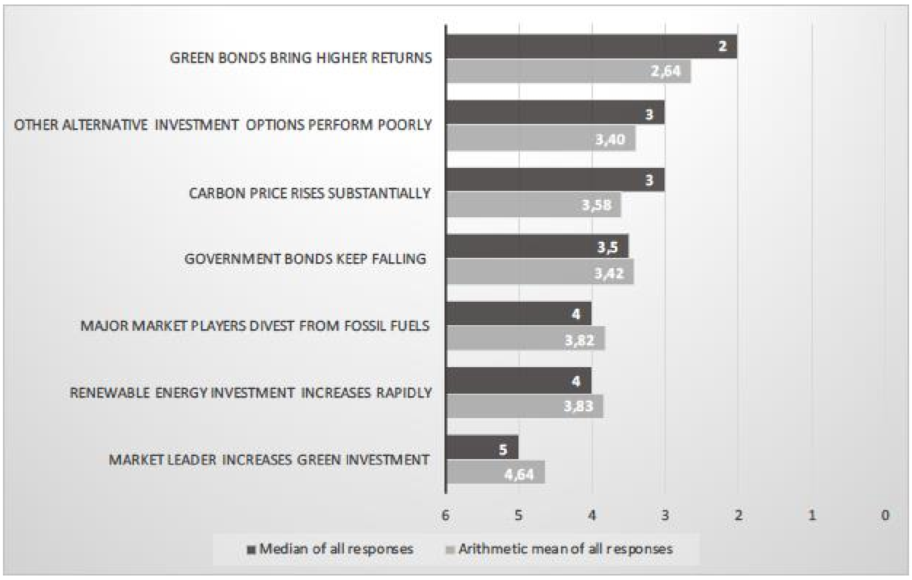

Figure 5 Importance of future market signals as ranked by respondents, organized by median (average given as a comparison). Respondents could rank from 1 (most important) to 7 (least important). Source: own illustration.

4.2.1.2 EU financial market regulation

The European regulatory framework for insurance companies, Solvency II, took an important place in investment decisions (second rank). This is in line with calculations by Braun, Schmeiser, and Schreiber (2017), who show that the capital requirements of the Solvency II standard formula can have a negative impact on insurers' portfolio choices. Further work implies that well-diversified and balanced portfolios are associated with higher capital charges, leading to underrepresentation of certain assets in the portfolios of European insurers (Braun, Schmeiser and Schreiber, 2018).

Accordingly, respondents perceived the Capital Markets Union initiative, which lowered the capital treatment for high quality infrastructure[27] and European Long-term Investment Funds (ELTIFs)[28] under Solvency II, as a "strong driver" for the sector. Insurers brought forward several arguments: Infrastructure, often regulated and providing stable cash flows (for example via feed-in tariffs), is considered to be relatively independent from other asset classes. Also, renewable technologies have matured and can now be "more accurately priced", which should lower risk. One respondent stated that the capital charge for high quality infrastructure could even be lowered further from 30% to 25%.

However, respondents also pointed out a contradiction between policy makers' intention to ensure financial stability with Solvency II by "penalizing" illiquidity with higher capital charges and their simultaneous effort to incentivize long-term investment. One respondent expressed the need to focus on the reflection of "real risks" with Solvency II, instead of using it "for the sake of achieving more investment" through lower capital charges. This relates to a current discussion by an expert group of the European Commission within the Capital Markets Union Initiative[29] on whether low-carbon/green infrastructure investment should explicitly be incentivized by measures in Solvency II. One proposal, a green infrastructure asset class – bringing about a tailored capital treatment for low-carbon investment – was ranked as the most important future policy signal among the given options. Nevertheless, respondents named several difficulties: (a) there is as yet no agreed definition of 'green' or 'sustainable' infrastructure. This makes it difficult to decide where the money should flow. Some companies, especially in the field of infrastructure, provide high and low carbon technologies at the same time; (b) While renewables have become more mature, energy efficiency is stil heterogeneous and thus difficult to fit into classical portfolio structures. This would limit the scope of an asset class for green infrastructure; (c) it might be better to establish an infrastructure asset class first and then, in a later step, assess the proposed investments in terms of green criteria; (d) "a non-political argument" for green infrastructure incentives within prudential

[27] Before the Capital Markets Union (CMU) lowered the charges to 30%, direct infrastructure investments were treated with a capital charge of 49% under the asset class 'Alternative Investments', that also includes private equity or hedge fund investment. For more detail, see European Commission (2016a, or 2015a, 2015b). One stakeholder criticized the administrative burden when trying to qualify for this kind of capital charge, for example due to stress- testing and the possible lack of data.

[28] ELTIFs were introduced to channel capital to energy, transport and housing projects (European Commission, 2015b).

[29] The CMU Action Plan names sustainable investment as an explicit goal, along with support for green bonds and ESG investments (European Commission, 2015a, 2015b).

regulation is necessary. This would be one referring, for example, to lowered risks in renewables investment due to longer track records and technological progress. One respondent objected that due to the short timeframe left to achieve the 2 or 1.5°C scenarios, regulators should take a "brave" step in deciding what is considered "green infrastructure".[30]

Several stakeholders praised the French Energy Transition Law, [31] and one respondent advocated a similar law at EU level and saw the revision of the Institutions for Occupational Retirement Provision (IORP) Directive[32] as a first step in this direction. However, stakeholders gave mandatory disclosure – meaning the required integration of climate-related risks[33] into companies' financial reporting – a low rank. Climate-related financial disclosure has two implications: First, it should increase awareness for climate change in the top management of companies. Secondly, it should lead to a better pricing of financial impacts of climate change, thus allowing for its consideration in business and investment decisions (TCFD, 2017). The respondents ranked mandatory disclosure low (rank 8 of 10) in its possible importance for their green investment decisions. To explain this assessment, stakeholders mentioned concerns about (1) the standards used for disclosure, especially when describing future strategies, (2) transparency, i.e. the willingness of companies to disclose information, particularly on their future climate strategy and exposure, and (3) the quality of the data used. Nevertheless, most respondents considered the work of the TCFD on voluntary disclosure important, for example one said it could "indirectly drive demand for asset managers (…) that are taking these issues into account", and thus foster the allocation of capital in a more "climate-risk-aware" way.

4.2.1.3 Financial support mechanisms/ financing instruments

Stakeholders frequently referred to the fact that general asset allocations could not be changed easily. Since the fixed-income side is the largest in insurers' portfolios, green bonds were perceived as a viable option to scale-up green investment. Nevertheless, stakeholders named three main obstacles to increasing their share[34]: (a) the market is still small, i.e. there is not enough supply, (b) returns are too low, (c) labeling is not transparent or credible ("green washing"). Respondents stated that green bonds were interesting only if they could compete with other bond options. Thus, public incentives for green bonds (i.e. yield premiums or tax incentives) were considered as an important signal to increase green investment (rank 3). In the evaluation of the market signals, higher returns for green bonds were ranked 1st and thus were the most important signal (see section 4.2.2). [35]

[30] This relates to the criteria mentioned under c).

[31] France has set mandatory disclosure requirements for listed companies as well as for institutional investors with Article 173 of the French Energy Transition Law (see https://www.legifrance.gouv.fr/eli/loi/2015/8/17/DEVX1413992L/jo#JORFARTI000031045547).

[32] One of the goals of the revision is to "encourage occupational pension funds to invest long-term in growth-, environment- and employment-enhancing economic activities." (European Commission, 2014).

[33] The TCFD divides climate-related risks into two categories: transition risks and physical risks (TCFD, 2017).

[34] Green bonds can take many different forms, such as corporate bonds or project bonds.

[35] Two respondents stated in the follow-up interview that they had misunderstood the question on the current carbon price. They asked to lower their ranking for the carbon price.

4.2.1.4 International climate agreements

Most survey respondents acknowledged the Paris Agreement to be an important signal (rank 4). For one respondent, it created certainty that “governments are going to take action”. Another saw it as an overarching global framework that could ease uncertainty whether climate policy will be revoked and as a “gating item” when making investment decisions. The inclusion of financial actors and corporations through Article 2.1c[36] added momentum, as one respondent remarked: “The world has understood: If we, the economy, shall be transformed, the crucial element is to redirect financial flows”.*[37] Nevertheless, respondents were unsure about the agreement’s direct effects on the economy and on capital markets: “[W]e need to see (…) the Intended Nationally Determined Contributions (INDCs)[38] translating into specific policy measures across the different sectors”, one stakeholder remarked, referring to energy efficiency, the promotion of electric vehicles, the industrial strategies of countries and the infrastructure that is being financed. Another respondent added that it wasn’t enough to “make a few green investments”* or buy “some green bonds”*, but that disruptive change in many parts of the economy and society was necessary to achieve the climate targets from the production of goods and services to energy, transport and consumption. Also, the upcoming elections in Europe and the US brought about scepticism whether the created “global move” would prevail. Among the respondents from insurance companies, the Paris Agreement was ranked higher (rank 5) than among industry associations (rank 9 of 10). The following section will give an overview of the most important market signals identified in the survey.

4.2.2 Market signals

As expected, the risk-return profile was the major determining factor for investment decisions (see Figure 4), followed by the performance of other Alternative Investment (AI) options that allow for project investment. The impact of sustainability indices, even though considered important for passive investors, was considered minor. Low importance was also attributed to competitor’s investment in green infrastructure. If green bonds brought higher returns, they could be an important driver for green infrastructure investment, as respondents ranked this future market signal first (see Figure 5). Green bonds compete with other fixed-income instruments such as government bonds (see signal ‘government bond returns keep falling into negative’) that serve as a ‘benchmark’. Since investment in green infrastructure projects competes with other options such as hedge funds in the alternative investments asset class, the signal that other Alternative Investment options perform poorly was also ranked highly. Respondents stated – as in the ranking of current market signals – that they barely see an influence of other competitors on their investment decisions in the future. The signal ‘market leader increases green investment’ ranked last, while divestment by major market players ranked 5th of the seven choices.

[36] Article 2.1c states “[m]aking finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development” (UNFCCC 2015: 3) as one of the main measures to tackle climate change.
[37] This quote was translated from German by the author. In the following, all translated quotes will be marked with an asterisk (*).
[38] The INDCs were emission reductions proposed by countries in the preparation of the Paris Agreement.

4.2.2.1 Internal benchmarks

"We've lookedat a lot of renewable energy, becausewe think it makes financial sense.(…) It's not charity", one respondent said. This statement sums up the numerous remarks interviewees made regarding their risk-return[39] focus concerning green investment. Also, it relates to the second most important signal, other Alternative Investment options. However, interviewees claimed there was a lack of green "bankable" projects in Europe, naming several reasons: (a) projects are not well-structured, for example due to a lack of capacity among developers, (b) projects are too small for insurers who prefer larger deals (c) some green technologies are not mature enough yet, (d) banks often stay in projects longer than necessary, thus, decreasing the need for other investors to refinance and (e) proposals of institutional investors are considered being too expensive by project companies.

4.2.2.2 External benchmarks

During COP21, several large insurance companies pledged to increase green investment or to divest from certain brown assets, such as coal, acting as frontrunners. However, the large market players that participated in the survey did not perceive their competitors' asset allocations as being very important for their own investment decisions. The signals 'competitor's investment in green infrastructure' or 'other major market players divesting or increasing green investment' reached only a low rank (see Figures 4 and 5). While insurers said they have an interest in the other market players' actions, some emphasized to be independent in their decisions ("[W]hat our competitors do … . It's (…) interesting, but does it drive our behavior – no".). Reasons given were size ("[W]e are big enough to have our own policy".) or other determining factors, such as their know-how or wanting to keep a competitive advantage. Nevertheless, one respondent remarked that the large corporations could create a signal that smaller financial market actors could follow, while another mentioned that collaborative engagement of investors was helpful. [40] The implications of these results will be discussed in Section 5.

In terms of benchmarks used, sustainability indices have not yet become mainstream indicators and were thus considered to be of low importance for green investment decisions. "[F]or an individual investment we're going to form our own view (…) of that rather than particularly rely (…) on a sustainability index", one respondent explained. Only one interviewee referred to them as being important for providing information to those who did not want to or could not allocate own resources to the assessment of sustainability criteria.

[39] One respondent named market volatility as another defining signal for his investment decisions.

[40] For example the Climate Bonds Inititative set up a platform to form a coalition for green infrastructure investment across the investment chain (see http://www.giicoalition.org).

4.2.3 Civil society signals

Even though civil society actions were considered least important in driving investment decisions in general (one respondent even attributed no relevance to it at all), some stakeholders acknowledged an increase in pressure from non-governmental organizations that was relevant in terms of reputational risk. One respondent remarked that the company started to look into climate-related risks, because they were "under a lot of pressure" and getting "questions at shareholders meetings". Another interviewee thought that the public debate had changed due to "meaningful data points" that were established on climate-related risks for financial market actors. Nevertheless, customers would not be pressing companies to offer green insurance products, one stakeholder remarked. Looking at the median results, the strongest signal was the public debate, whereas the weakest signals were the divestment movement and the anti-coal movement (see Figure 6).

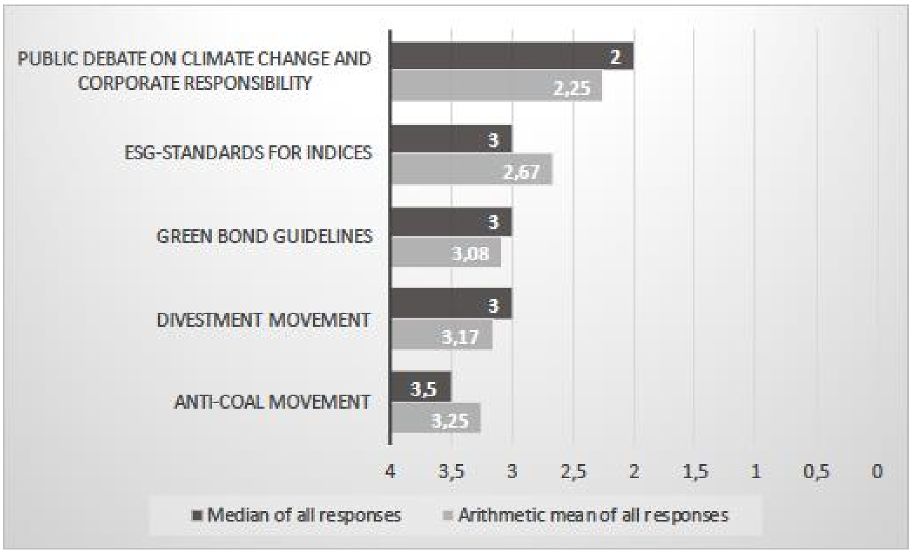

Figure 6 Importance of civil society signals as ranked by respondents, organized by median (average given as a comparison). Respondents could rank from 1 (most important) to 5 (least important). Source: own illustration.

4.2.3.1 Engagement

ESG criteria were identified as important according to most insurers. They referred to a variety of ways to integrate them in their investment decisions, for example through scorecards, heat maps or guidelines that apply to different parts of the portfolio (for example general account assets, specific asset classes) or to different steps in the investment process (due diligence, selection). Some respondents confirmed they actively engaged on ESG matters with analysts and (equity or bond) fund managers. Thus, ESG criteria are meant to address the "tragedy of the horizon" (Carney, 2015), describing the observation that the short-term focus of financial market analysis does not address long-term risks such as climate change. One stakeholder described the establishment of a harmonized ESG framework for the whole company as "very difficult", as client mandates and specifics of investments differed strongly. Thus, instead of "imposing ESG criteria", his company favored industry, sector or thematic ESG guidelines. In the future, another respondent stated, "the mindset of civil society shifting broadly to low-carbon" and major NGOs continuously asking "the right questions" could be important signals for insurance companies.

4.3 Synthesis

As a synthesis, some policy and market signals were perceived as having high relevance today as well as in the future (see Figure 7). Feed-in tariffs and Solvency II regulation stood out on the policy side, as well as the performance of other Alternative Investment options on the market side. Carbon prices, both at market and policy level, were expected to become more important in the future. For Unbundling, the opposite was the case. Competitor's green investment was considered to be of low importance, both today and in the future.

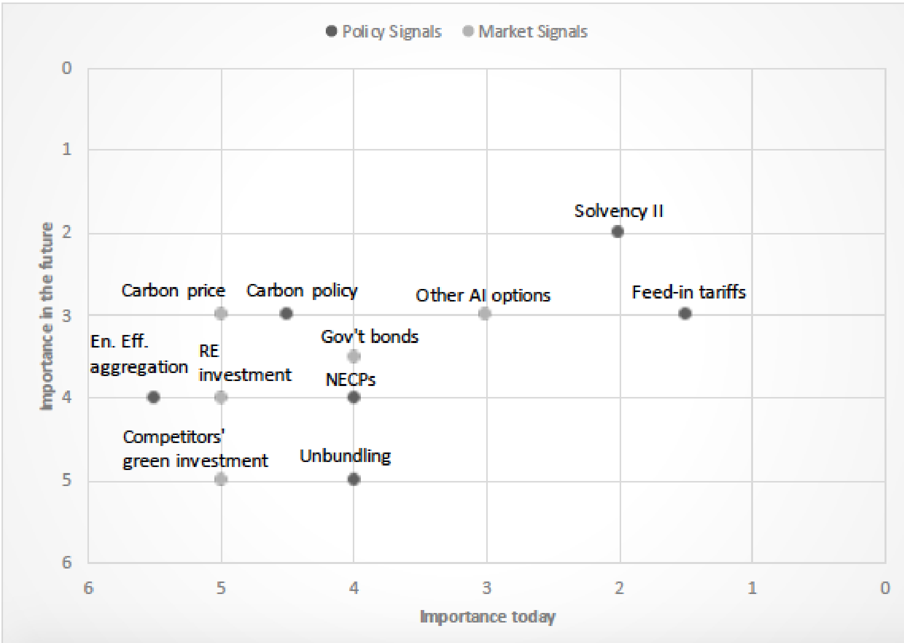

Figure 7 Impact of market and policy signals on insurer's investment decisions, organized by median; Source: own illustration. The signals 'today' and 'in the future' have the same topic, but differ in detail. For example, the policy signal Unbundling means 'Unbundling in Energy Markets' (today); and 'Unbundling regulation is relaxed to allow investment in transmission and production' (future). For a detailed signal description, see Table 1.

5. Discussion

The signals considered important by respondents mainly address the risk-return structure, for example by creating higher revenues or lowering risk for green assets. This is in line with standard literature on investment behavior, following for example Dinica (2006) and De Jager *et al.* (2008). Adding to this, the interviews also showed the importance of expectations, concerning for example reputation and credibility of policies. This corresponds to the game theoretic reasoning described in Mielke and Steudle (2018) and to the extended model of Wüstenhagen and Menichetti (2012) which includes expectations, bounded rationality and path dependencies.

5.1 Risk-return structures

The most important policy signals and market signals in this ranking relate to the discussion on how to make green or low-carbon investment more attractive. Respondents considered feed-in tariffs (today) and lower capital charges in a separate asset class for green infrastructure (in the future) as most important. This corresponds well to the most important market signals 'risk-return profiles' (today) and 'green bonds bringing higher returns' (in the future) and is in line with research on the effects of energy policy on investment levels. Bürer and Wüstenhagen (2009) who let cleantech investors rank energy policies, identify feed-in tariffs as the ones respondents perceived most effective. Wüstenhagen and Menichetti emphasize that lower financing costs for renewables are important levers to increase investment, and thus reason that "policies that effectively reduce (perceived) risk for investors are therefore more likely to result in large-scale deployment of renewable energy" (Wüstenhagen and Menichetti, 2012: 3). However, they add an additional factor – diversifying portfolios – that also explains why insurance companies are interested in renewables (see Section 2.2). This is linked to the idea of a green infrastructure asset class that could provide adjusted capital requirements for low-carbon investment. Currently, a green supporting factor is discussed in the EU that would favor low-carbon investments in prudential regulation. The EU High-Level Expert Group on Sustainable Finance (HLEG) did not recommend such a factor, but stated in its final report that it would require a clear definition of green and brown asset classes with a taxonomy, as well as a quantitative grounding in a risk assessment (EU High-Level Expert Group on Sustainable Finance, 2017: 68). Some interviewees voiced concerns over mixing prudential regulation which has the goal to improve financial stability with political goals such as climate mitigation.[41]

Non-profit organizations and think tanks such as Finance Watch have tried to address this concern by arguing for a brown penalizing factor instead that would make high-carbon investment more risky. Such a brown penalizing factor relates to the idea of a mispricing of climate risks in financial markets (see e.g. Mercer, 2015; Battiston *et al.*, 2017; Thomä and Chenet, 2017). Thomä and Chenet who discuss policy interventions to address this potential mispricing, suggest two entry points: "the design of financial risk models and associated transparency around their results, and

[41] Other actors in the banking sector, such as the Bank of England, stress the importance of integrating climate risks for financial stability reasons (Carney, 2015).

the actual institutions governing risk management" (Thomä and Chenet, 2017: 82). The policy signals 'Capital Markets Union', and 'Solvency II' which ranked second and third, address precisely the question of how to change risk models. In terms of an increase in transparency, the international efforts on disclosure of climate-related risks in order to integrate them more strongly into investment decisions were considered as a sensible step by respondents. Nevertheless, the policy signal 'mandatory disclosure' was ranked low. Here, interviewees voiced concerns over how to achieve high-quality disclosure, for example due to a lack of data or difficulties in standardizing replies of companies and investors as well as a missing willingness to be transparent about future business strategies. However, Article 173 of the French Energy Transition Law that requires institutional investors to disclose their efforts on ESG criteria as well as their alignment with the French energy and ecological regulation and strategy in their annual report (Mason *et al.*, 2016), was named as an important step by a third of respondents.

Also, the results show that carbon prices were considered of lower relevance today due to their low impact and credibility, but they could become increasingly important in the future, meaning that investors expect stronger carbon policies. Thus, a reform of carbon pricing (or taxes) and a reduction of fossil fuel subsidies, two future signals that fit this logic, received higher ranks in terms of importance. However, several respondents see the carbon price as only one of many factors that influence green investment decisions.

Overall, the roles of governments in incentivizing green investment to provide risk- adjusted returns that attract institutional investors, as well as the role of the development banks in alleviating a variety of risks and in aggregating smaller projects, were strongly emphasized. Some stakeholders proposed more public investment, for example to address technology risks or achieve public goals ("… sort of like, (…) putting the man on the moon or, (…) a big government project around cancer"). Others pointed out the need for government support in establishing a pipeline of green infrastructure projects, specified as containing long-term-orientated projects that offer predefined cash flows as well as a "number of security terms" relating to Solvency II, as well as help in mitigating risks for projects that are politically desired. The development banks such as the European Investment Bank (EIB) were criticized by some respondents for crowding-out or competing with institutional investors by financing investment that could be "perfectly financed…by the private market". Accordingly, the DFIs should primarily get involved in early project stages instead, such as construction, or with instruments such as first-loss guarantees (ranked 5th in current policy signals) – especially in projects considered "not bankable" for institutional investors. The British Green Investment Bank was brought up as a positive example, being "very sensitive" regarding the additionality of investments.

5.2 Expectations

Another interesting result was that respondents from large comapanies didn't consider competitor's investment as very important for their decisions. Nevertheless, it was mentioned that smaller companies could follow their example. This leads to two conclusions that also relate to the model by Mielke and Steudle (2018) described in the Introduction. First, the investors' company size is an important factor when discussing tipping points and expectations for green investment. Secondly, this result emphasizes the importance of leadership in combination with credible policy signals. Both were mentioned by respondents.

While almost all respondents saw the Paris Agreement as an important policy signal, they were concerned that the countries, especially the US, would lack leadership in its implementation or even take back their commitment. "[L]eadership on climate is very important. And then (…) that provides a very strong signal to (…) India, to other major economies that also need to decarbonize and can see (…) one, that that's a path that US and China are (..) committed to …"

Also, one stakeholder perceived the actions of the governor of the Bank of England, Mark Carney, who has become a leading figure in the debate on the integration of climate risk in financial markets, as a "strong signal".[42] In terms of credibility, some respondents criticized the unpredictability of political support for investment, due to for example "false priorities" such as building a highway to win elections, or the mismatch of the government/electoral cycle and the project cycle. As a consequence, a majority of respondents emphasized the need for stable and reliable regulation to allow them to proceed with long-term investment, some also wished for a stronger coherence in EU investment, energy, climate and financial market policy or a more sustainable economic policy. The expert group on sustainability within the Capital Markets Union initiative is perceived as a step in this direction, as well as the National Energy and Climate Plans (NECPs)[43] introduced by the Energy Union, which one respondent described as a precondition to establish confidence in policies and provide a "framework in which to take an investment decision".

[42] Some respondents mentioned the Brexit as a factor of uncertainty, i.e. not knowing what the impact on polices would be (Solvency II or access to the European single market). Because insurers are global companies with operations in different markets, several of them stated that the EU will stay highly relevant for them, and they will keep looking into infrastructure projects in all countries.

[43] With the NECPs, member states have to outline how they plan to achieve their climate targets within the Energy Union framework.

6. Conclusions

This paper analyzes the influence of policy, market and civil society signals on green infrastructure investment decisions of large European insurance companies. It purposely goes beyond the assessment of policies and regulation on investment behavior and hence includes a broader spectrum of signals that also consider behavioral aspects such as group dynamics or leadership as well as pressure from the public discourse and civil society movements. Even though the results presented in this paper are a preliminary analysis, since they rely on qualitative methods and a small sample size, they can be a useful basis for larger-scale empirical studies, for example for the formulation of hypotheses and the design of questionnaires. Also, the concerns and expectations voiced by companies and associations can be of valuable interest for current policy discussions within civil society and among policy makers who wish to incentivize investors to green their portfolios and support a decarbonization in Europe.

In their desire for stable returns, respondents from the insurance industry in the European Union ranked support schemes for renewables such as feed-in tariffs as well as the financial market regulation Solvency II as the most important current influence factors for their investment decisions. Feed-in tariffs in all EU countries, a new asset class for green infrastructure in the Solvency II framework and incentives for green bonds received the highest ranks for future policy signals. Thus, respondents favor measures which have a direct influence, for example on cash flows or yields of green investment, over ones that make brown investment more risky such as a fossil fuel subsidy phase out. As future possible market signals, higher-return green bonds and a substantial carbon price were considered important. The public debate on climate change was the most important signal in terms of civil society actions.

The results presented here can thus can give valuable insight concerning climate risk disclosure, carbon price reform and green bond design: A substantial carbon price and the disclosure of climate risks can help to make carbon intensive investments less attractive. To incentivize a shift in investments towards green infrastructure, green bonds can be an important instrument if designed in a competitive, transparent and standardized way. Most importantly, policy signals have to be coherent and credible to coordinate expectations and shift investment strategies. Civil society actors play a vital role in this coordination through their influence on the public debate on climate change as well as their engagement and divestment efforts with insurance companies.

The work presented here clearly invites further research on the role of insurers, but also other institutional investors in financing the low-carbon transition to give more insight on which actors are best suited for this challenge. Also, the discussion on the necessary regulatory steps as well as on the standardization of green investment products that have been led by the European Commission and the TCFC need further grounding in academic research.

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Part III

The role of stakeholders in sustainability science

Chapter 6

Stakeholder involvement in sustainability science – A critical view[1]

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Stakeholder involvement in sustainability science – A critical view

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Abstract

Discussions about the opening of science to society have led to the emergence of new fields such as sustainability science and transformative science. At the same time, the megatrend of stakeholder participation reached the academic world and, thus, scientific research processes. This challenges the way science is conducted and the tools, methods and theories perceived appropriate. Although researchers involve stakeholders, the scientific community still lacks comprehensive theoretical analysis of the practical processes behind their integration – for example what kind of perceptions scientists have about their roles, their objectives, the knowledge to gather, their understanding of science or the science-policy interface. Our paper addresses this research gap by developing four ideal types of stakeholder involvement in science − the technocratic, the functionalist, the neoliberal-rational and the democratic type. In applying the typology, which is based on literature review, interviews and practical experiences, we identify and discuss three major criticisms raised towards stakeholder involvement in science: the legitimacy of stakeholder claims, the question whether bargaining or deliberation are part of the stakeholder involvement process and the question of the autonomy of science. Thus, the typology helps scientists to better understand the major critical questions that stakeholder involvement raises and enables them to position themselves when conducting their research.

Keywords: sustainability science, stakeholder involvement typology, energy transition, transformative research

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1. Introduction

The involvement of stakeholders into science is an expanding trend in an increasing number of research areas, especially in those that besides their technological dimension touch societal, economic and political interests.[1] Due to the complexity of such fields like i.e. the energy transition,[2] the scientific community felt the need to go beyond conventional scientific methods by incorporating non-academic actors' views and knowledge in their research through stakeholder involvement.[3] The concept that is common in the economic realm (mainly to deal with Corporate Social Responsibility strategies) or the political realm (i.e. in decision-making processes) has, thus, been integrated into the broader science environment and especially into new scientific fields such as sustainability science (Kates *et al.*, 2001; Clark and Dickson, 2003; Komiyama and Takeuchi, 2006; Jäger, 2009; Ostrom, 2009; Jerneck *et al.*, 2011; Wiek, Withycombe and Redman, 2011), transformative research[4] (Schneidewind and Singer-Brodowski, 2013; WBGU, 2011; Dietz and Rogers, 2012; Crocket *et al.*, 2013) and transition research (e.g. Kemp and Rotmans, 2009; Geels, 2002; Geels, 2011; Loorbach, 2007; Markard, Raven and Truffer, 2012). These new fields incorporate a broad array of concepts like post-normal science (Funtowicz and Ravetz, 1993), mode-2 science (Gibbons *et al.*, 1994), mode-3 science (Schneidewind and Singer-Brodowski, 2013) or citizen science (Irwin, 1995; Fischer, 1996), as well as transdisciplinary (Hirsch Hadorn *et al.*, 2006; Berger, 2010; Daschkeit, 1996; Scholz, 2000; Bergmann and Schramm, 2008; Jahn, 2008; Nowotny, 1997) and participatory research strategies (Kasemir *et al.*, 2003; Kasemir, Jaeger and Jäger, 2003; Becker, 2006; Robinson and Tansey, 2006; Scholz *et al.*, 2006; Glicken, 2000; Renn, Webler and Johnson, 1991).[5] In this context, the main objective of stakeholder involvement is to tackle the "complexity, uncertainty, and multiplicity of values" and perceptions on controversial issues such as the energy transition, or mitigation of and adaptation to climate change by combining" expert assessments with problem framings of the lay public" (Kasemir *et al.*, 2000).

Lang et al. (2012) refer to objectives of stakeholder involvement by saying that sustainability issues need "the constructive input from various communities of knowledge" − here described as scientists from different disciplines and non-academic actors – to include "essential knowledge from all relevant disciplines and actor groups related to the problem", as well as allowing for the incorporation of

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[1] Schneidewind (2013: 83) defines the integration of the technological, cultural, economic and institutional dimension in transformative research as "transformative literacy".
[2] We define the energy transition as the process of decarbonizing the energy system through a shift from fossil to renewable energy sources.
[3] There is a variety of terms used, ranging from stakeholder dialogues over stakeholder participation and stakeholder engagement to stakeholder involvement; depending on the scientific field and the research context.
[4] The German Advisory Council on Global Change (WBGU) defines transformation research as the analysis of the transformation process. In contrast, transformative research supports the transformation process (Weingart, 2003: 23).
[5] The movement of action research also belongs to these new research strategies (Action Research Manifesto, 2011).

"goals, norms, and visions". Particularly the involvement of citizens is linked to discussions on challenging existing epistemologies of science and the assessment of knowledge production and knowledge validity (Tàbara, 2013: 116). Welp et al. (2006: 170) describe stakeholder involvement in science as the "structured communication processes linking scientists with societal actors such as representatives of companies, NGOs, governments and the wider public", called "science-based stakeholder dialogues".[6] A more pragmatic branch of stakeholder participation engages with the development and implementation of methods and participatory tools, intended to support sustainability learning and the transformation of agents through "effective interfaces between knowledge and action" (Heras and Tàbara, 2014: 379; Cornell *et al.*, 2013: 64). This implies that transformative research does not focus on "intrinsic" scientific discussions, but on solving "extrinsic" societal problems (Strohschneider, 2014: 180). Maasen and Weingart (2005: 2) speak of a "democratisation of expertise", whereas Gibbons (2000: 161), Nowotny (2003) and Nowotny et al. (2001) call for the creation of "socially robust knowledge" through combining research capabilities with other institutions, actors and practices which are relevant for the transition to take place. Schneidewind et al. (2011: 134) add that to generate system, target and transformation knowledge in transformative science, the latter has to integrate "context- and experience knowledge of relevant actors".

Hayn et al. (2003) organize stakeholder input on three different levels: on the analytical level, stakeholders bring in system knowledge through their practical experience; on a normative level they add orientation knowledge through their opinions; and on the operative level they incorporate target knowledge and transformation knowledge by working on solutions with their own set of resources and motivations. Glicken (1999) divides knowledge into three types: "cognitive, experiential, and value-based" where cognitive knowledge stems from technical experts, experiential knowledge comes from people sharing their personal experience and value-based knowledge is related to social interests and social values.

Academic literature describes a wide array of opportunities associated with stakeholder involvement – although mostly related to participatory and decision-making processes that concern for example the implementation of GHG mitigation measures (Kempton, 1991; Löfstedt, 1992), global processes of change (Shackley and Skodvin, 1995) or environmental governance (Renn, Webler and Johnson, 1991; Renn and Schweizer, 2009; Bäckstrand, 2006). Stakeholder involvement is said to increase relevance (Spangenberg, 2011: 283; Hirsch Hadorn *et al.*, 2006: 125; Baumgärtner *et al.*, 2008: 387), legitimacy and credibility (Fiorino, 1990: 228; Cash *et al.*, 2003: 8087; Spangenberg, 2011: 283), ownership (Lang *et al.*, 2012; Spangenberg, 2011: 283; Bäckstrand, 2006: 472), effectiveness (Funtowicz and Ravetz, 1993: 755) as well as the (social) accountability of research (Welp *et al.*, 2006;

[6] A science-based stakeholder dialogue needs to be designed in an open manner such that stakeholders are able to communicate their beliefs as well as constraints or boundary conditions that they feel limit their freedom to act (Kasemir et al., 2000: 181).

Gibbons *et al.*, 1994: 3; Bäckstrand, 2006: 484ff; Lang *et al.*, 2012; Kasemir *et al.*, 2000: 182).

However, criticism can also be found in the literature, mostly concerning the validity and credibility of scientific results, established through stakeholder involvement (Yosie and Herbst, 1998: 4). Concerns relate to co-design – the involvement of stakeholders in the definition of research questions and designs (Schneidewind and Singer-Brodowski, 2013: 121ff) – and the co-generation or co-production of knowledge – i.e. the integration of societal actors' bodies of knowledge into the actual research process and related scientific findings (Schneidewind and Singer-Brodowski, 2013: 316; Pohl *et al.*, 2010: 269). Pohl et al. (2010: 271f) identify three major challenges of this co-production of knowledge: the challenge of power, the challenge of integration and the challenge of sustainability. Related to this, some fear that certain kinds of stakeholder involvement might as well threaten the autonomy of science (Strohschneider, 2014; Bosch, Kraetsch and Renn, 2001: 201; Enserink, Koppenjan and Mayer, 2013: 14). Brandt et al. (2013: 7), who define five challenges[7] of transdisciplinary research projects, criticize that currently there is "no clear set of tools required for different process phases or integration of different types of knowledge" as well as little "practitioner empowerment".

Since participatory or decision-making processes – i.e. labelled as "policy dialogues" by Welp et al. (2006: 172f) – typically do not concentrate on the generation of knowledge, we explicitly do not follow these concepts in this article.[8] We instead follow the distinction between research processes that aim at improving knowledge and evidence and decision-making or management processes as proposed by Mackinson et al. (2011: 19). While we relate to the approach of Renn and Schweizer (2009: 176ff), who developed six concepts of stakeholder and public involvement in risk governance based on "philosophies of participation and collective decision making", we in contrast look at the way stakeholder dialogues between science and society are understood by scientists. This perspective, that we find important for carrying out scientific work with stakeholders, is so far underrepresented in the peer-reviewed literature. In this paper, we establish a typology of scientific perspectives on stakeholder involvement. Section 2 will briefly outline the methodology behind the typology, whereas Section 3 will describe the different ideal types we derive. Section 4 shows an example by applying the typology to the field of energy transition research. In Section 5, we use our typology to analyse and systematize the critique with regard to stakeholder involvement by deriving three continua that enable scientists to position themselves. We conclude by pointing out the critical choices for scientists that arise from this analysis in Section 6.

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[7] Three of the challenges that were evaluated via an analysis of case studies relate to the discussion in this paper: "research process and knowledge production; practitioner involvement; generating impact" (Brandt et al., 2013: 2ff).

[8] Welp et al. (2006: 172) differentiate policy dialogues, multi-stakeholder dialogues for governance, science-based stakeholder dialogues and corporate dialogues, based on their objectives.

2. Methodology

Depending on the perspective one takes, stakeholder involvement practices and the difficulties and critical choices they entail, differ substantially. In order to show this, we establish a typology of ideal types of scientific perspectives on stakeholder involvement. Though in practice there might only be hybrid forms, the development of ideal types has a long tradition in sociological studies. They serve as a research heuristic that stresses and exaggerates distinctive characteristics of a group of cases to disentangle different categories (Kelle and Kluge, 2010: 83). In order to develop our types of stakeholder involvement in science, we apply five criteria of differentiation:

1. Role of the scientist: The perceptions on which role the scientist should take – and in relation to that also the stakeholder – differ widely. This also relates to the question of the autonomy of science (see for example Welp *et al.*, 2006: 180).[9]

2. Objectives: The reasons why a scientist would want to work with stakeholders are diverse – ranging from increasing impact on real world issues to getting insider information or increasing legitimacy (see for example Renn and Schweizer, 2009: 176).[10]

3. Kind of knowledge: Scientists seek to gather different kinds of knowledge when involving stakeholders. Based on other differentiations such as cognitive, experiential[11] and political knowledge (Glicken, 1999: 301f) or system, orientation, as well as target and transformation knowledge (Schneidewind and Singer-Brodowski, 2013: 42ff, 69ff), we structure the kinds of knowledge that scientists can integrate into their research along the range of pure data, information, assessments and normative values.[12]

4. Understanding of science: Scientists have different understandings of good or appropriate science, including not only tools and methods, but also epistemic and philosophical questions (Weingart, 2003: 53ff). Is science a detached system dealing with self-referential questions or does science serve societal needs? Can science be neutral and objective or does it mirror societal developments and conflicts?

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[9] Welp et al. (2006: 174f) distinguish the different types of stakeholder participation in science via their roles in the research process.

[10] Renn and Schweizer (2009) have developed a typology, based on the different views and their objectives concerning stakeholder involvement in decision-making processes.

[11] This term was corrected in this version of the paper.

[12] See also the discussion in Foucault's 'Two Lectures on Power/Knowledge' (1980: 81) where he differentiates erudite and subjugated knowledges, the latter described as "naive knowledges; located down on the hierarchy, beneath the required level of cognition or scientificity".

5. Science-policy interface: The role and impact scientists have – or expect to have – on political decision-making, and, hence, their perceptions of the societal responsibility of science, strongly imply how stakeholders are involved in the research process.

We use the above-mentioned criteria to derive a typology based on literature and practical experiences with stakeholder dialogues in climate change and energy transition research.[13] The latter stem from our own work[14], and from interviews with practitioners that involve stakeholders in their research projects.[15]

3. A stakeholder involvement typology for scientists

Sections 3.1–3.4 describe four ideal types of stakeholder involvement in science: the technocratic, the functionalist, the neoliberal-rational and the democratic type. Section 4 applies the typology to the field of energy transition research in order to illustrate the different types with specific examples.

3.1 Technocratic type

The technocratic type's main objective, when involving "expert stakeholders" (Gupta *et al.*, 2012; Whitmarsh, Haxeltine and Wietschel, 2007: 5), is to improve the scientific research process by broadening the extent of available information. The role of the stakeholder is to provide issue-specific, objective and falsifiable information that fits into the classical way science is conducted according to philosophers of science, such as Popper (1957). Thus, the technocratic view shares certain important characteristics with the literature on expert interviews (Przyborski and Wohlrab-Sahr, 2014: 118ff).[16] If lay people are involved in research processes, it is only indirectly as a source of data (Fiorino, 1989: 293f). They do not provide information themselves –

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[13] There is a wide array of literature describing projects and practical experiences with stakeholder involvement (Wiek et al., 2012, Gooch and Stålnacke, 2010, Bisaro, 2015, Hare and Pahl-Wostl, 2002, Chikozho, 2008, Beierle, 2000), mostly in the context of participatory and decision-making processes.

[14] All authors are active or have recently been active in projects involving stakeholders. The typology is based on experiences from the following projects:
"Investment Impulse for the German Energy Transition in Times of Economic and Financial Crises", funded by the Federal Ministry of Education and Research (BMBF); "Impulse for Europe – Green Growth and Sustainability Skills", funded by the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB); "Bringing Europe and Third Countries closer together through Renewable Energies (BETTER)", funded by the Intelligent Energy Europe Program of the European Union; and the Dahrendorf Symposium 2013 "Changing the European debate: Focus on Climate Change" (joint initiative by the Hertie School of Governance, the London School of Economics and Political Science and Stiftung Mercator).

[15] To add knowledge of other practitioners, we conducted three interviews and two focus groups between April and October 2015 in Germany with participants from Germanwatch, the Renewables Grid Initiative and the Global Climate Forum.

[16] In this context, it is important to note that stakeholders are not themselves the object of study. Instead, a stakeholder accompanies the research process in some way or other (for a similar understanding, see Niederberger and Wassermann, 2015: 12f).

e.g. the interpretation of this data – but lend it to scientists who then use it to extract what they consider relevant for their research (Fiorino, 1989: 298f; Fiorino, 1990: 227). The impact of stakeholders on science is, thus, relatively limited in the sense that stakeholder involvement is expected to feed in additional data and information, but not to define or transform the research question or process.

The ontological difference between scientists, that play an active part in research, and relatively passive stakeholders, involved directly (if experts) or indirectly (if laypeople), is greatest in this view. Scientists determine all the elements of the research process autonomously, including the ways in which stakeholders are involved. Consequently, the scientific sovereignty of interpretation or the primacy of science is kept throughout the research process.

The kind of knowledge that is to be generated by stakeholder involvement is defined from a purely scientific angle. Thus, research questions are derived from intra-scientific debates and controversies rather than societal needs. Consequently, research questions typically focus on the technological dimension of transformation processes rather than on cultural or institutional problems, which are more closely linked to research on implementation (Schneidewind, 2013: 83ff). Stakeholders are involved only on an analytical level, providing data and information rather than assessments and normative evaluations. Moreover, since technocratic research is often based on a linear concept of knowledge transfer (Bergmann, 2014), it tends to neglect questions of implementation and societal impact, like the social robustness of the knowledge it generates. Such a relatively narrow concept of scientifically relevant knowledge is in part due to the understanding of the science–policy interface put forward by the technocratic type. In discussions on scientific consultation in policy or decision-making processes, it is often circumscribed by the idea of "speaking truth to power" (Pohl and Stoll-Kleemann, 2007: 10f) and emphasizes ethical neutrality and technical advice. Science and policy-making are conceived of as separate fields that are not intertwined. Rather, scientific findings are expected to inform policy processes and provide the foundation for policy measures. How these findings can become relevant in the sphere of politics is, however, not discussed in this context. From a technocratic perspective, this is a question that is to be addressed by politicians or activists, but of no immediate interest to science.

3.2 Neoliberal-rational type

The neoliberal-rational type understands knowledge as "merely a 'hook' on which interests hang their case" (Radaelli, 1995: 173). He thus acknowledges the existence of interest and power in science-society interfaces and understands stakeholder participation as a tool for both groups to impose their perceptions and interests on each other. Stakeholders – such as lobby groups or individuals advocating for their specific organizational, individual or political interests – try to channel their views directly into the research process and indirectly into a public discourse or the political arena. Furthermore, stakeholders are interested in getting legitimacy for certain positions through the "objectivity"[17] often claimed by or attached to science (van den Daele, 1996: 297ff). Scientists, on the other hand, are understood as conscious about the differing interests and, thus, are able to use only the knowledge or information they find valid or interesting (Hoppe, 2005: 210).

Following this understanding, the neoliberal-rational type's objective to involve stakeholders is to efficiently obtain data or knowledge he needs for further research. Both, stakeholder and scientist, are aware of the mentioned mechanisms and try to use them for their own purposes. Scientists might also want to channel their results into projects and decision-making processes to ensure impact or application of their research. Another motivation for the neoliberal-rational type of scientist to involve stakeholders, is the perception of an increased chance of being funded by public authorities that support stakeholder involvement (Schneidewind, 2013: 178). The kind of knowledge scientists try to derive from stakeholder involvement depends on the specific discipline, task and methods applied. Knowledge is not bound to pure data or information, but can also include system, normative and creation knowledge.

The phase where stakeholders are involved is not restricted. They might already be part of the negotiating phase between funding partners and scientists. The science-policy interface is, thus, seen as a "battlefield" where both groups follow their specific interests and bargain about all possible aspects, i.e. defining the research question, methods, wording, boundary conditions for modelling exercises, scenarios, possible take-outs, messages and interpretation of results and communication. The roles of scientists and stakeholders and their respective influence on the research process are not pre-defined in the neoliberal "bargaining" concept of stakeholder involvement. Although scientists are expected to have a slightly greater impact on the research process, no ontological difference between the two groups of actors is detected (each has their own interest and wants to succeed). In a sense, scientists are themselves stakeholders who have personal agendas (Brinkmann *et al.*, 2015: 10). These ontological foundations relate to basic assumptions of game theory (Nash, 1950: 155), where rational individuals seek to maximize their utility, defined by individual preferences.

The understanding of science in the neoliberal sense relates to more relativistic concepts of science, such as e.g. Feyerabend (1986). As there are no general rules which scientific reasoning and methods are appropriate, there is no single "right" way to do science. It depends on the actors' perceptions and constellations. A characteristic framing of this neoliberal-rational perspective is the notion of "win-win situations", which explicitly acknowledges the win-lose taxonomy in a positive way. In the neoliberal-rational view, this behaviour is not perceived normatively (good or bad) but as "natural" or "rational". This relates to the rational choice paradigm, (Esser, 1993; Coleman, 1990) after which individuals as well as organizations are perceived

[17] See also the argument of the "scientific seal of approval" used by policymakers; as put forward by Yosie and Herbst (1998: 40).

as rational actors that have fixed preferences and strive for optimal choices – with regard to these preferences (Geels, 2010: 496; Braun, 2013). The group-politics approach sees scientific controversies as the result of the pluralist bargaining on the political marketplace by different kinds of actors (Martin and Richards, 1995). Following that perspective, stakeholder involvement is just another arena for actors, such as governmental bodies, individual citizens, economic, social and environmental interest groups and different kinds of scientists, to carry out the battle of power and authority.

3.3 Functionalist type

The functionalist type is based on an understanding of society as consisting of autonomous social spheres, or systems as introduced by Niklas Luhmann (Luhmann, 1984; Kneer and Nassehi, 2000)[18] and further developed by a number of scholars with regards to social coordination processes (Teubner and Willke, 1984; Bora, 2001; Fuchs, 2013; Mölders, 2013; Mölders, 2014). It takes a social-constructivist perspective and presumes that modern society is predominantly differentiated into functional subsystems – such as the economic, the political, the legal or the science system – that are defined by the kind of relevance criteria or codes, along which the world is observed.

From a functionalist perspective, stakeholder involvement has the objective to irritate the science system with other social perspectives and relevance criteria in order to trigger learning processes that can make science more sensitive for societal problems (Willke, 1983: 25; Willke, 1987: 333). However, these self-reflective processes can only be induced, but never enforced. Hence, stakeholder involvement is perceived as an opportunity or random generator that may, by chance, change the research process.[19] In order to generate occasions of irritation, functionalist scientists attempt to integrate 'representative stakeholders' of different societal logics, e.g. from the economic or political systems or civil society organizations. Stakeholders are typically involved in all stages of the research process in order to increase the probability that change takes place. However, this never guarantees that stakeholders' perspectives are well-reflected and adequately incorporated into the research process.

With regard to the understanding of science, this type suggests that the science system consists of all communication that observes the world through the lens of truth – i.e. if an observation can be regarded as true or false, according to certain theories or methods, which in Luhmann's terms would form the contingent 'programme' of

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[18] We base our discussions on the systems theory as proposed by Niklas Luhmann, because his scepticism of social steering provides an interesting starting point for thinking about stakeholder involvement. We, thus, do not include other prominent systems theoretical approaches in this paper (see e.g. Radcliffe-Brown, 1935, Parsons, 1991).

[19] Mölders (year not specified: 3) describes this probabilistic perception of coordination, which is characteristic for the functionalist view as a "causality of triggering". It is differentiated from a "causality of penetration" that informs most perspectives on governance.

the science system.[20] Compared to the other types, the functionalist has a completely different view on the pre-described roles of scientist and stakeholder since he emphasizes communication over actors. He does not care who observes the world, but only looks at how it is observed (whether communication is considered scientific or not). The kind of knowledge that stakeholders provide always relates to their respective mode of observation, i.e. depending on the systemic relevance criteria the stakeholders use. However, as stakeholders, such as politicians, businessmen or civil society activists, typically act as ‘representatives’ of certain social systems, they tend to observe events from a political (power/no power), economic (payments/no payments) or moral (just/unjust), rather than a scientific perspective (true/false). As such, these observations are merely ‘noise’ to science – unspecified communication that does not (yet) make sense in scientific terms. As science generates ‘order’ from stakeholders’ ‘noise’ by transforming stakeholders’ statements into a scientific kind of information, substantial characteristics of their original meaning might get lost. Consequently, a functionalist attaches relatively low legitimacy to the original stakeholder input. It is this tension between irritation potential and scientific re-interpretation that describes the opportunities and limitations that stakeholder involvement generates from a functionalist perspective.

In the strict sense, the science–policy interface does not exist from this perspective, since science and politics generate meaning in very different and incommensurable ways. There can be no easy, immediate and substantial exchange or coordination across these different systems, but coordination can be achieved indirectly and probabilistically. Stakeholder involvement is a tool to enhance the probability that self-reflective processes are triggered, especially if they follow a so-called “irritation design” (Mölders, 2013: 15f; Mölders, 2014: 24) that takes into account the social, temporal and factual dimensions of system-specific meaning (Luhmann, 2012; Mölders, year not specified: 3f). For stakeholder involvement, this means that scientists should first consider which kind of actors have the greatest impact on the focal system – be it the science or the political system (social dimension) –, for example because they provide relevant insider information or are especially affected by the research questions. Second, scientists should think about the way statements need to be framed in order to become relevant or “readable” (Fuchs, 2013; Mölders, year not specified: 4) in the focal system, for example by explicitly linking opinions to ethical debates that are well-anchored in scientific or political debates (factual dimension). Third, good timing is essential and needs to take into account the temporal structures of different systems, e.g. the length of review processes in science, election periods in politics, quarterly statements in the economy or rapid changes in societies due to salient events.

[20] Accordingly, the economic system is defined by all communications that deal with the question of whether payments can be generated or not. The political system observes the world from the criterion of whether a certain event is relevant for power (gain or loss), which in democratic societies is qualified by the binary distinction of government/opposition.

3.4. Democratic type

For the democratic type, stakeholder dialogues have the objective to integrate actors in society that are touched by a (complex) transformation or sustainability matters (Ward and Dubos, 1972: 232ff; Schneidewind and Singer-Brodowski, 2013: 314ff) into the research process. Especially through the participation of lay people, science can create legitimacy for itself, thus, allowing "for the development of a genuine and effective democratic element in the life of science" (Funtowicz and Ravetz, 1993: 740f). From a democratic viewpoint, extending stakeholder dialogues from experts and scientists to civil society can enhance the quality of the research results (Spangenberg, 2011: 283).

Concerning the kind of knowledge, instead of only taking data and scientific observations into account, subjective probabilities, science- and knowledge-based opinions and ideas are integrated into the research process. Also, networks and relationships are of great importance. Wiek (2007: 55) defines this process as collaborative research, where "scientists and local experts not only exchange relevant information but jointly generate (new) knowledge on the basis of their scientific as well as local expertise (joint research)." By opening all levels of the process to stakeholders, e.g. from the definition of the research questions ("Co-Design")[21] (Schneidewind and Singer-Brodowski, 2013: 121ff, 182, 211, 314ff)) to answering them ("Co-Production"), socially robust knowledge is created (Nowotny, Scott and Gibbons, 2001: 166) to achieve a "democratization of expertise" (Maasen and Weingart, 2005: 53). Tàbara (2013: 114) describes a process of knowledge-building that is "co-decided, co-produced and co-validated in partnership, by knowledge holders in different social-ecological contexts" to allow for social learning that can "meet the pressing challenge of sustainability" (Cornell *et al.*, 2013: 62).

Besides the impact on the way science as such is conducted, the democratic type also looks at the political implications of stakeholder involvement in science. He argues that stakeholder dialogues are used to improve scientists' policy recommendations and make them more relevant since they reflect a broader range of interests from different stakeholder groups in society.[22] Hence, stakeholder involvement is seen as a means to improve the interconnection and exchange processes between science and politics, alias the science-policy interface. Through this transdisciplinary approach (Wiek, 2007; Dressel *et al.*, 2014; Lang *et al.*, 2012), stakeholder dialogues can help bridge the gap between science and society and allow science to adapt to modern complexity (Bergmann, 2014). To be able to fully make use of this instrument, scientists have to approach stakeholders at eye level (Spangenberg, 2011: 283), fostering a dialogue that reflects on their own and on stakeholder's roles. Relating to Habermas' discourse ethics, the democratic type

[21] Nuclear research serves as a good example. In this field, research questions that would have lain in the interest of civil society were not funded in the beginning.
[22] Stakeholder dialogues, thus, also integrate interests that are not represented through powerful lobby groups.

believes that true and valid communication can be achieved if certain rules are adhered to in a dialogue: actors should, for example, have free access and participate with equal rights, implying a power neutrality through the "absence of coercion" (Habermas, 1993: 31) and avoid strategic communication by disclosing their intentions (Kettner, 1993: 169). If this is practiced, the "force of the better argument" can be dominant (Habermas, 1990: 198).

The role of the scientist is to facilitate and moderate the dialogue, bringing together different stakeholders from politics, business, research and civil society in an open arena (relating to the concept of the transition arena of Rotmans, 2003; and Loorbach, 2002). Scientists have to translate the beliefs and languages of the different 'systems' while at the same time creating trust and ownership for the research process.[23] The sense of ownership can foster stakeholders' engagement in the process and increase the chance that research results are taken into account by policymakers. The established cooperation of stakeholders and scientists enables the researcher to follow the implementation of the scientific results and at the same time strengthens the acceptance of political measures in society (Spangenberg, 2011). Through their active involvement, stakeholders are not merely seen as an object of science. Stakeholders can rather influence and shape the research process through their engagement or through other forms of (non)-participation: manipulation, therapy, informing, consultation, placation, partnership, delegation and citizen control (see Arnstein's Ladder (1969)). Consequently, they play an active role and are typically involved in all stages of the research process – from the definition of the research question to the actual implementation of the scientific findings and the derived policy recommendations. This underlines the idea that the democratic type understands science as a tool to support transformation in society and to ensure representation of all people touched by it.[24]

4. Energy transition research through the lens of the typology

The European Union's research funding programme Horizon2020[25] provides a useful framework to explore the different types we discuss here, to understand their implications and to illustrate the main controversies arising from each of them, when dealing with complex transformations such as the energy transition in Europe. The implementation of the societal or political goals to reduce GHG emissions and to increase the share of renewables in energy production in the near future demands scientific research on a large number of technological issues (e.g. smart grids, energy

[23] Tàbara (2013: 115) argues that the integration of other kinds of knowledge production, e.g. arts, can enhance ownership.
[24] In this paper, we explicitly deal with the involvement of stakeholders in science and not in participatory or decision-making processes.
[25] The term "stakeholder participation" was found 25 times in all projects listed in the European Commission's portal of EU-funded research projects (CORDIS), "stakeholder engagement" appeared 35 times, "stakeholder dialogues" 5 times (checked on June 3rd, 2015).

storage or energy efficiency in buildings) as well as 'sociological' issues such as behavioural changes in consumption or mobility that require social acceptance for their success. We briefly describe stakeholder involvement strategies in research processes that deal with the transition towards a low-carbon society in Table 1. The next section presents an outline of the major critical arguments concerning stakeholder involvement in scientific processes and applies the typology to these arguments.

Table 1
Stakeholder involvement in energy transition research.

	Research questions	Stakeholders	Research process	Kind of results	Kind of projects
Technocratic type	Generation: scientifically identified gaps in research	Technical experts (planners, engineers, other scientists)	Generation: scientists collect and evaluate information without direct influence of stakeholders	Generation: no support of implementation, solely scientific communication of results	Pathways, case studies, scenarios, technical projections
	Content: technical questions of the energy transition (wind and solar power, transmission, financial products)		Content: empirical data and information	Content: market assessments, technical feasibility studies	
Neoliberal-rational type	Generation: result of bargaining process of interest groups (including scientists) of the energy transition	All stakeholders with interest in the energy transition (Corporations negatively/positively affected, citizen initiatives, policy makers, NGOs, lobby organizations)	Generation: scientists interpret/evaluate stakeholders' positions during all steps of the research process	Generation: support of implementation to bring results into the political or societal arena (incl. media)	Scenarios (decentral-ized/centralized, role of efficiency, technology development, role of nuclear energy) opinion polls, events, studies
	Content: questions concerning societal needs and particular interests, policy demands, opinions/values		Content: opinions, information, values, interests	Content: policy recommendations, studies	
Functionalist type	Generation: scientifically identified problems	Powerful (and thus vocal) stakeholders from all affected social sub-systems: politics, economy, science, civil society	Generation: scientists involve 'representative' stakeholders in all stages of research process to irritate science system with other social perspectives (random generator)	Generation: enhance probability of self-reflective processes in the science and implementing systems through 'readable' framing and good timing	Studies, events, workshops (Bayesian Risk assessments for investments in different forms of energy production; social acceptance of new technologies (demand-side management, electric cars)
	Content: questions integrating social dimension of the energy transition into science system		Content: system-specific knowledge	Content: translated knowledge such as science-based policy recommendations	
Democratic type	Generation: socially relevant problems arising from dialogue process	All stakeholders affected by the energy transition (Corporations, citizen initiatives, Policy makers, NGOs, lobby organizations, scientists)	Generation: scientists take into account stakeholders' positions during all steps of the research process	Generation: support of implementation through dialogue with stakeholders	Scenarios (decentral-ized/centralized, role of efficiency, technology development, role of nuclear energy) opinion polls, events, studies
	Content: problems that hinder the energy transition/questions that integrate needs of all stakeholders supporting the energy transition		Content: opinions, information, values, interests	Content: policy recommendations, studies, opinion polls, assessments	

5. Discussion

This paper aims at a better understanding of the critique raised against stakeholder involvement in science. Following debates in science and society, we identify three major critical topics: first, the question of the legitimacy of stakeholders' claims as input for scientific purposes. Second, there is the issue of communication processes that can be perceived as ranging from pure bargaining to deliberation, addressing the science-policy interface. Related to this is the more encompassing question of the challenges stakeholder involvement might pose for the autonomy of science.

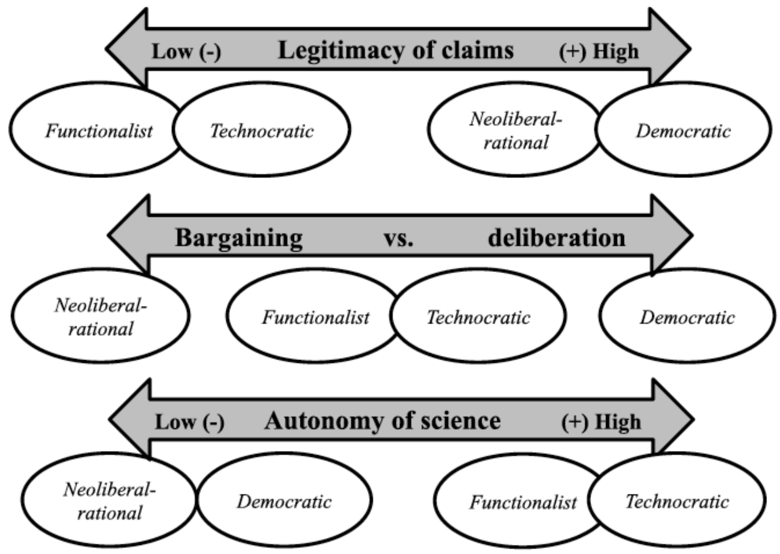

Fig. 1. Critical continua of stakeholder involvement in science.

Using our typology as a heuristic tool, we systematize the critical arguments on three respective continua (Fig. 1), showing the implications the different types have for stakeholder involvement in science. The critique is most strongly directed against the types that are located at one of the ends of the respective continua and, accordingly, it is often issued from a perspective located at the opposite end of that continuum. The legitimacy of claims differs most strongly from the perspectives of the technocratic and the democratic type. When it comes to the question of bargaining vs. deliberation, the neoliberal-rational and the democratic type represent the most divergent perspectives. Concerning the autonomy of science, the critique stems from a rather technocratic or functionalist understanding of science and it is especially directed against the democratic and neoliberal-rational type.

5.1 Legitimacy of claims

When analysing scientific literature and our interviews, we found that one of the most contested problems is the scientific legitimacy of stakeholder input in the research process. The perception of the knowledge that is created through stakeholder involvement in scientific research processes is broadly discussed. How much of the knowledge offered by the stakeholder is relevant and, thus, can be used by the scientist (to answer the research questions) – as data, as opinions, as information? How strong does the scientist distance himself or herself from the claims, ranging from acknowledging all input as honest, to looking through the “objective” lens of science? On a practical level, the difficulty to differentiate between strategic communication and biased information by stakeholders is a major challenge for scientists.

But not only stakeholders might use strategic communication. Funding organizations or researchers may also emphasize “win-win” situations when they want to persuade stakeholders to participate, even if their main motivation is the democratization of scientific processes. Another critical point discussed in the literature is, whether the opening of scientific processes to non-academic actors might threaten scientific sovereignty of interpretation by challenging intra-disciplinary criteria of knowledge production (Weingart, 2011: 135).

On a theoretical level, criticism of the position that scientific knowledge can be described as ‘pure’ or objectively true has been formulated from different angles in the social sciences for a long time. To mention just a few examples, Foucault retraces the co-constitutive relation between knowledge and power (Foucault, 1995: 27). Feyerabend argues that there can be no universal or definitive criteria for scientific methods or theories and that scientific claims are just as valid or invalid as claims from other spheres, such as antique mythology (Feyerabend, 1986: 21, 55ff, 249ff). Constructivist scholars highlight the social embeddedness and observer-dependency of all knowledge (Berger and Luckmann, 1966; von Glaserfeld, 1995). Consequently, the criteria, theories or methodologies which define “valid scientific knowledge” are dependent on the scientific sub-discipline (Strohschneider, 2014: 184).

Relating this to stakeholder involvement, the way claims are treated is dependent on the researcher’s understanding of science. We refer to the critical trade-offs that arise in such situations as ‘legitimacy’ of stakeholder claims, describing the kind of stakeholder knowledge that the scientist uses during the research process and how it is used. The continuum reaches from low legitimacy, seeing stakeholder claims as mere ‘noise’ in the Luhmannian sense, to considering all claims to be honest and true (high legitimacy). Adding to the kind of knowledge, the continuum, thus, also describes how strongly scientists distance themselves from stakeholder input. Applying the four different ideal types to this continuum can help to better understand the critique. The functionalist type stands at the far low end, seeing all claims as unspecified ‘noise’ that is “senseless” unless transformed to the code of the science system. The technocratic scientist believes in the objectivity of science and, thus, expects stakeholders to provide only data (via laypeople) and technical information (via experts). The neoliberal-rational type is characterized by a high legitimacy of claims, since, following the logic of mathematicians like Nash, all players know the rules and act in their best interest. All statements are interest-driven and equally valid (or invalid) and, thus, interests are brought into the research process via inclusion of stakeholder knowledge. The democratic type sees all stakeholder claims or input as honest communication and takes them seriously in the research process. He, thus, takes into account data, information, science- and knowledge-based opinions, ideas, subjective probabilities, networks and values. Following Habermas' theory of discourse ethics, in a perfect speaking situation, there is no strategic communication (Habermas, 1990; Kettner, 1993: 169).

Considering the critique that stakeholder involvement (or the opening of scientific processes to non-academic actors) might pose a threat to scientific sovereignty of interpretation by integrating 'un-scientific' kinds of knowledge and challenging intra-disciplinary criteria of knowledge production, the technocrat and the functionalist would agree, whereas the democratic and the neoliberal-rational type believe that stakeholder involvement enhances scientific results. According to the democratic view, involving stakeholders into the research processes can help to expand the perspective of 'mainstream science' by incorporating the context-specific knowledge and value judgements of those affected by the research. Also, creating solution-oriented knowledge is considered a goal (Lang *et al.*, 2012: 29f). In the case of the neoliberal-rational type, equally legitimate interests would positively contribute to the research process.

5.2 Bargaining vs. deliberation

Another major criticism of stakeholder involvement in science relates to the question of interest-driven vs. deliberative stakeholder communication. How much convergence or divergence exits with regard to "operational codes of science and politics" (Hoppe, 2005: 207)? There is a mismatch between the positive notion of including the affected and concerned into the former 'isolated' scientific research process and the perception of stakeholder involvement as another means to channel specific economic or political interests into research results. The latter is discussed as hampering the 'neutrality' of research. Framed differently, this critique addresses the science-policy interface and, thus, the question whether stakeholder involvement supports a democratization process in science or allows for implicit or explicit lobbying of powerful actors in another societal area. Even if scientists are perceived as conscious, concerning the material interest stakeholders have, they have to rely on their input in the research process (knowledge mismatch). Stakeholder dialogues mostly involve different kinds of actors – ranging from affected citizens to politicians, administrations, NGOs, companies, consultancies and lobby organizations. Actors need time and resources to participate, as well as a strong motivation/interest. As Olson (1965) has shown, interest groups in democratic societies have very asymmetric chances of organizing themselves and voicing their values, interests and concerns. Especially large and dispersed groups, such as citizens, tax payers or consumers, are often unable to form interest groups that match the well-organized interests in society of e.g. economic branches (van de Kerkhof and Wieczorek, 2005: 737ff).

Generally, stakeholder dialogues in science do not involve political decision-making, thus, we do not further elaborate on possible motives in that field, but make one point: Influencing the public discourse by labelling and enriching and, thus, legitimizing specific interest-related positions with the ‘neutrality’ and ‘objectivity’ attributed to science could be a motivation for stakeholders to participate. All this said, the selection bias – concerning who is able and who is willing to take part in a stakeholder dialogue and how scientists choose stakeholders – is a main criticism towards stakeholder involvement in science.

On a more general level, this leads to the question whether stakeholder input is understood as part of a deliberative democracy or as part of the bargaining power play of politics. Depending on the type of stakeholder involvement in science, the views on this critique differ strongly. On the bargaining side, the neoliberal-rational type sees the science-policy interface as a “battlefield” where all actors bargain for their interests (Nash, 1950). Stakeholders can be lobby groups or individuals who try to channel their interests into the research process and indirectly into the political arena. On the other hand, the scientist tries to influence political decisions. Thus, although the neoliberal-rational type understands the process as determined by interest and power, he does not perceive it as a threat or danger to science. The functionalist type, though, is indifferent to both bargaining and deliberation, since he sees no overlap of the political and the science system. Scientific findings might become relevant for politicians if they trigger reflection in the political system through irritation, but that happens only by chance. The technocratic type is slightly closer to deliberation than the functionalist, believing that ‘explaining’ the world instead of convincing political actors is the right way. This bears the underlying idea that science is objective and scientists “speak truth to power” (Pohl and Stoll-Kleemann, 2007: 10f). The democratic type, following Meadowcroft’s (2004) idea of group-based deliberation, lies at the deliberative side of the continuum. Here, the scientist aims at the “democratization of expertise” (Mackinson *et al.*, 2011: 53) and wants people/groups touched by a transition (or the energy transition) to be represented in the research process as well as science to support the (energy) transition. The involvement of citizen-stakeholders might remedy the influence on scientific results by powerful and well-organized interest groups in society. Another aim is to improve interconnection and exchange processes between science and politics. The democratic type understands stakeholder involvement as a way to increase relevance, legitimacy and fairness when certain standards are met. From a more pragmatic view, the so-called democratization of science may decrease the quality of research results. Following our typology, the technocratic and the functionalist type would argue that political goals (e.g. taking binding decisions according to opinions, preferences or value judgements based on voting) cannot be transferred into the scientific realm without fundamentally changing the nature of science. The technocratic type would fear that scientific standards are softened; the functionalist would regard such a tendency as a creeping process of de-differentiation or re-programming by which non-scientific criteria, such as social relevance, substitute or modify the originally scientific criteria of ‘true’ and ‘false’.

5.3 Autonomy of science

When designing stakeholder involvement, the question of the integration of stakeholders in the research process arises. On a meta-level, this can be summarized as a question of the autonomy or primacy of science.[33] Should stakeholders already be included in the definition of the research questions and design process or is it enough to integrate their knowledge later? Literature on stakeholder involvement in science shows that important questions regarding this issue are still far from being answered (Niederberger and Wassermann, 2015: 12; Hanson *et al.*, 2006: 132; Lang *et al.*, 2012: 35ff). How can the relation of scientific and non- scientific knowledge be described (Habermas, 1990)? By which scientific or democratic criteria can different kinds of stakeholder input in the research process be evaluated? Is the evaluation carried out by scientists alone or jointly with the stakeholders? What is the role of the stakeholders: Are they supposed to provide insights and perspectives that can lighten up the blind spots of science, or are they actually doing science themselves? In this context, stakeholder involvement concepts are criticized for their understanding of science and the science-society relationship they entail (Strohschneider, 2014: 180; Weingart, 2003: 99).

With regard to "transformative science" (Schneidewind and Singer-Brodowski, 2013), Strohschneider (2014: 184) identifies four central motives that might lead to the decline of scientific autonomy and pluralism. The most challenging ones are "solutionism" and "de-differentiation". The term "solutionism" describes the framing of research topics as practical problems that scientists try to solve. Strohschneider argues that a solutionist concept of science, which privileges relevant findings over more indirect effects of science (such as basic/foundational research) and questions on design and societal impact over understanding, is reductionist. "De-differentiation" means that the sphere of science is no longer regarded as an autonomous societal arena that defines its own standards and categories, such as the constitution of scientific knowledge or the choice of research topics. Rather, there is a tendency to equate scientific problems with problems of immediate social relevance. According to Strohschneider (Strohschneider, 2014: 183), this solutionist understanding of science, in which epistemic problems are only considered scientifically legitimate if they can be labelled as societal problems, poses a threat to the autonomy of science.

The typology shows that this critique applies most strongly to the neoliberal-rational and democratic type that show a low differentiation of scientists and stakeholders (left end of the continuum) and, thus, low autonomy of science. In the tradition of Feyerabend (1986), the understanding of science as a separate arena of society with distinct and clear criteria of valid knowledge production, as defended by Strohschneider (2014), is no longer taken for granted.

[33] Similar to Hoppe's (2005: 207) first axis "primacy of science" regarding the science-policy nexus.

Consequently, the roles of scientists and stakeholders barely differ, and stakeholders have a much higher impact on research. The neoliberal-rational type, which relates to the ontological foundation of game theory (Nash, 1950), sees no divergence between stakeholder and scientist, since they both act as rational utility-maximizers. The posed research questions, thus, do not only depend on epistemic interest, but also on the possibility to get research funding or to further one‘s material interests through research. Though on different, more morally oriented grounds, the democratic type rejects a differentiation between stakeholders and scientists and opts for integrating everyone affected as extensively as possible – from the definition of the research question to the structuring of the research (Hirsch Hadorn *et al.*, 2006: 125; Spangenberg, 2011: 283). The research questions are not limited to epistemic interest, but aim at offering solutions for socially relevant problems.

In contrast, both in terms of the involvement of stakeholders in the research process and the underlying understanding of science, the technocratic type seems to be closest to a classic understanding of science in the tradition of Popper (1957), who sees a strong qualitative difference between trained scholars and lay stakeholders. The scientist is in charge of the research design and merely consults stakeholders, if he or she feels they can provide useful data or information. The research questions typically deal with intra-scientific debates rather than societal needs. The functionalist type also perceives science as an autonomous arena with distinct relevance criteria that differ substantially from those of the economic or the political system. As in these more classic perspectives on the science-society relationship the motives of “solutionism” and ”de-differentiation” are rejected, Strohschneider’s critique does not apply to them.

6. Conclusions

There is an increasing trend of including stakeholders in research on sustainability or transformations like the energy transition. Though frequently used, little theoretical reflection on the underlying concepts of stakeholder involvement in science by the practitioners themselves exists so far. With the typology described here, this paper tries to fill this research gap by offering a heuristic, self-positioning and decision-making tool for stakeholder involvement in scientific research processes. The differentiation of four different ideal types, linked to the critique that has been voiced among practitioners and in the academic literature, can help scientists to better understand the different concepts of stakeholder involvement and potential pitfalls in designing it. By identifying and analysing three major critical topics with our typology – the legitimacy of claims, the idea of bargaining versus deliberation, and the autonomy of science – we reveal critical choices that every scientist involving stakeholders should be aware of, thus, giving an impulse for further discussion in this field. Our analysis also shows that – even though in literature it is often framed in the notion of the "democratic type" – there is no singular concept of stakeholder involvement. With the application of our typology to the energy transition, we emphasize one of the major fields where stakeholder involvement is strongly used and at the same time link the practical and the theoretical level in the discussion. The tool presented here can only be an aid of orientation, concerning the major critical points of stakeholder involvement addressed in this paper. The complexity of societal transitions will keep challenging science – especially the question of its autonomy among claims of democratization and vested interests and its input between scientific and non-scientific knowledge.

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Chapter 7

Ideals, practices, and future prospects of stakeholder involvement in sustainability science [1]

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Ideals, practices and future prospects of stakeholder involvement in sustainability science

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Abstract

This paper evaluates current stakeholder involvement (SI) practices in science through a web-based survey among scholars and researchers engaged in sustainability or transition research. It substantiates previous conceptual work with evidence from practice by building on four ideal types of SI in science. The results give an interesting overview of the varied landscape of SI in sustainability science, ranging from the kinds of topics scientists work on with stakeholders, over scientific trade-offs that arise in the field, to improvements scientists wish for. Furthermore, the authors describe a discrepancy between scientists' ideals and practices when working with stakeholders. On the conceptual level, the data reflect that the democratic type of SI is the predominant one concerning questions on the understanding of science, the main goal, the stage of involvement in the research process, and the science–policy interface. The fact that respondents expressed agreement to several types shows they are guided by multiple and partly conflicting ideals when working with stakeholders. We thus conclude that more conceptual exchange between practitioners, as well as more qualitative research on the concepts behind practices, is needed to better understand the stakeholder–scientist nexus.

Keywords: stakeholder involvement concepts, sustainability science, ideal types

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1. Understanding ideals and practices of stakeholder involvement in science

The global threats of climate change, rising inequalities, and unsustainable development pose major challenges for science. Emerging scientific fields, such as sustainability science (Kates *et al.*, 2001; Clark and Dickson, 2003; Komiyama and Takeuchi, 2006; Wiek, Withycombe and Redman, 2011) and transformative research (Schneidewind and Singer-Brodowski, 2013; Dietz and Rogers, 2012; Crocket *et al.*, 2013), try to find innovative ways to cope with the "social embeddedness" (Granovetter, 1985: 487), uncertainty (Spangenberg, 2011), and complexity (Klein *et al.*, 2012; Hirsch Hadorn *et al.*, 2006) of these issues that affect the whole of society and thus touch upon a multitude of different interests (Jerneck *et al.*, 2011; Jäger, 2009; Ostrom, 2009; WBGU, 2011; Scholz, 2011). Especially in inter- and transdisciplinary (Hirsch Hadorn *et al.*, 2006; Lang *et al.*, 2012; Bergmann and Schramm, 2008; Jahn, 2008; Scholz *et al.*, 2006; Jahn, Bergmann and Keil, 2012; Mauser *et al.*, 2013) as well as participatory research (Becker, 2006; Glicken, 1999; Renn, Webler and Johnson, 1991), scientists involve stakeholders to incorporate nonacademic actors' views and knowledge (Scholz *et al.*, 2006; Kasemir *et al.*, 2003; Robinson and Tansey, 2006; Glicken, 2000; Scholz, 2000). [1]

While stakeholder involvement (SI) is well reflected in the context of governance and public participation (Renn and Schweizer, 2009; Renn, 2008; Webler, Tuler and Krueger, 2001), its practices (Ison, 2008; Scholz and Steiner, 2015b) and underlying ideals (Scholz and Steiner, 2015a) in scientific research processes that aim at improving knowledge and evidence (Mackinson *et al.*, 2011) – rather than at collective decision- or policy-making – are being critically discussed and are yet to be stabilized. In this context, Brandt *et al.* (2013) see a "lack of coherent framing" and "no clear set of tools required for different process phases or integration of different types of knowledge" when working with transdisciplinary approaches in sustainability science.

In this paper, we want to address this research gap by substantiating existing analyses of conceptual foundations of SI in sustainability science (Mielke *et al.*, 2016), ranging from the codesign of research processes over the coproduction of knowledge, as well as questions on the science–policy interface, to evidence from current stakeholder practices [2]

[1] Stakeholders are here defined as "persons that, besides their expertise, also have an interest in shaping some aspect of reality because they (...) are a part of it. Stakeholders are e.g. representatives of associations, companies or non-governmental organizations" (Niederberger and Wassermann, 2015).

[2] Definitions of codesign differ. We follow that of Moser (2016), referring to stakeholders and researchers designing the research process together.

A web-based survey among scholars and researchers engaged with sustainability or transition research was conducted internationally to shed light on the following research questions:

(i) What kinds of scientists involve stakeholders and how?
(ii) What kinds of ideals underlie scientists' SI practice?
(iii) Do those ideals match the practice?
(iv) How do researchers' ideals concerning SI relate to the types of SI identified in Mielke *et al.* (2016)?

We collected data on scientific fields and researcher profiles as well as on ideals and practices of scientists concerning their understanding of science, the role they assign to stakeholders, their objectives when involving stakeholders, the kind of knowledge they want to gather, and how this knowledge is relevant in the political realm. By using ideal-typical[3] answer choices based on the technocratic, the functionalist, the neoliberal-rational, and the democratic type from Mielke *et al.* (2016), we gathered information on how the typology reflects the ideals of practicing scholars. Moreover, we asked whether scientists see trade-offs between their scientific goals and SI. Finally, the survey addressed the question of necessary improvements that could allow scientists to integrate stakeholders better in the future.

This paper proceeds as follows: the second section describes the theoretical framework the survey is based on and how it is made operational; in the third section, we present and analyze the responses to answer our four research questions; in the fourth section, we discuss results; the fifth section is dedicated to the methods for data collection and analysis and the sixth section concludes with a short summary and recommendations for practice.

[3] We refer to Max Weber's (1968) definition of ideal types.

2. A framework for SI in science

To systematize the various approaches of scientists regarding SI, Mielke *et al.* (2016) developed a theoretical framework based on five criteria of differentiation:

(i) the role of the scientist, including the stages of the research process where he or she involves stakeholders;
(ii) the objectives of SI, including the main reason for involving stakeholders in different stages of the research process;
(iii) the kind of knowledge obtained by SI, ranging from data over information and opinions to normative values;
(iv) the understanding of science, referring to tools and methods perceived as appropriate by scientists, as well as to epistemic and ontological questions; and
(v) the science–policy interface.

According to different positions that scientists can take on these five criteria, Mielke *et al.* (2016) derived four ideal types of SI: the technocratic, the neoliberal-rational, the functionalist, and the democratic type. These types will be elaborated in the next section.

2.1 SI typology

The technocratic type involves expert-stakeholders to receive a broader set of issue-specific, objective, and falsifiable information. The scientist solely defines the research process; its results are expected to inform policy makers, but are not actively promoted. In contrast, the neoliberal-rational type wants to actively promote his research by channeling his results into politics by means of SI. Stakeholders cooperate to influence the public or political arena with a “scientific seal of approval” (Yosie and Herbst, 1998: 40). In this bargaining situation (Nash, 1950), experiential and value-based knowledge (Glicken, 1999) can be obtained. The functionalist type perceives himself as a distant observer of “representative stakeholders” of different societal systems—as introduced by Luhmann (Luhmann, 1984; Kneer and Nassehi, 2000) and others (Teubner and Willke, 1984; Fuchs, 2013; Mölders, 2014) – aiming at triggering learning processes through irritation (Willke, 1987). For the democratic type, SI has the objective to integrate actors that are part of a societal transformation into research via dialogue processes that are moderated by the scientist, creating “socially robust knowledge” (Nowotny, Scott and Gibbons, 2001: 166; Nowotny, 2003) through codesign (Wülser and Pohl, 2016; Page *et al.*, 2016) and the coproduction of knowledge (Polk, 2015; Wiek, 2007; Cornell *et al.*, 2013). Thus, a “democratic element in the life of science**”** (Funtowicz and Ravetz, 1993: 740f) is introduced.

These ideal types described above partly draw on more prominent classifications, such as those created by Renn (2008), Renn and Schweitzer (2009) and Habermas (1968). Renn and Schweitzer (2009) classify "structuring processes that channel public input into public policy making" into six prototypes. In contrast, Mielke *et al.* (2016) classify scientist–stakeholder relationships solely in scientific research processes aimed at generating knowledge. Habermas (1968) describes the interactions between the subsystems of politics and science with three models—a technocratic, a decisionistic, and a pragmatistic model – thus, defining the relationship of the subsystems in policy-making processes. While the typology used here by Mielke *et al.* (2016) takes this relationship into account with its criterion of the science–policy interface, referring to the influence of science on political decision-making and vice-versa, it specifically concentrates on the sphere of science.[4]

2.2 Making the typology operational

To answer our research questions, we developed a web-based survey with the tool Survey Monkey (https://www.surveymonkey.com), posing 30 questions of varying types.[5] The scale of measurement ranged from nominal (open and closed questions) to ordinal. To give our respondents the opportunity to bring in their own ideas, we also employed an open "other" category for most closed questions. The survey was comprised of five sets of questions. Table 1 summarizes these questions and relates them to our research questions.

Table 1. Sets of questions in the survey

Topics	Characteristics queried	Research question
Demographics	Gender (Q1) Nationality (Q2) Level (Q4), type (Q5) and field of education (Q6) Place of work (Q7)	1
SI projects	How often are stakeholders (SH) involved (Q8) Nature (Q9), topics (Q11), and level (Q14) of projects Kind of SH involved (Q10) Kinds of funding (Q12) Methods (Q13)	1
SI ideals	Stages of research process in which SH should be involved (Q15) Role that scientist (S) and SH should play in SI projects (Q17) Kind of knowledge that should be produced (Q18) Reason for stage of involvement (Q16) Main goal of SI (Q19) Science–policy interface (Q20) Understanding of science (Q21)	2
SI practices	Role of S and SH (Q17) Kind of knowledge produced (Q18) Science–policy interface (Q20)	3
Looking ahead on SI	What is needed to improve SI in the future (Q22) Possible trade-offs between scientific goals and SI (Q24) Future involvement of SH (Q23)	2

[4] For example, the technocratic type in Mielke *et al.* (2016) is close to the decisionistic model, since he conceives himself as producing knowledge that is relevant for policy makers, but would not – as in Habermas' (1968) technocratic model – take a prescriptive position in political decision-making.
[5] For the advantages of online surveys, see Diekmann (2007).

The first set of questions covered demographics: for example, nationality and field of education. The second dealt with information on stakeholder projects that respondents carry out, addressing, for instance, topics, funding, and methods used. The third set of questions asked for ideals that scientists have in mind when involving stakeholders in their scientific projects. Here, the questions relate to the five criteria for SI described in this section, whereas the four possible answer items per question reflect the ideal types of SI described above (Table 2). In questions (Q) 16, 19, 20, and 21, respondents could judge the given answer items according to a five-item Likert-scale (Diekmann, 2007; Blasius, 2014; Schnell, Hill and Esser, 2005), ranging from “strongly agree” (5 on the scale) to “strongly disagree” (1 on the scale). The two remaining questions (Q17 and Q18) only allowed selecting one of the four statements without grading it. Questions 17, 18, and 20 were then each accompanied by an open question concerning the respondents’ actual practice in their projects, comprising the fourth set of questions of the survey. In the fifth part of the survey, we wanted to look ahead on SI in science, asking for improvements of SI, for the future inclusion of stakeholders in projects and possible trade-offs between scientific goals and SI. With questions 26–30, we collected feedback on the questionnaire as well as contact information of participants. In the next section, we will present and analyze our results.

Table 2. Making the ideal types operational: Association of answer items and questions

Questions on SI ideals	Answer items related to the ideal types: Technocratic type	Neoliberal-rational type	Functionalist type	Democratic type
Stage (Q15)	Data collection	Data collection/planning phase/analysis of results/ dissemination	Data collection	Data collection/planning phase/analysis of results/ dissemination
Reason for stage (Q16)	To increase the extent and quality of data by consulting issue-specific experts	To find out about stakeholders' interests and feed them into the research process	To test research findings against their perception and practicality in societal spheres	To allow stakeholders affected by the research to give feedback and join deliberative processes
Role (Q17)	Scientist leads the research process; stakeholders are considered issue-specific experts	Scientist is a stakeholder himself and bargains for his or her (scientific) interests in the research process	Scientist observes only from an external position to analyze the perspectives of stakeholders	Scientist facilitates and moderates a cooperative dialogue with affected stakeholders, trying to create trust
Kind of knowledge (Q18)	Objective data and information concerning technologies or scientific problems	Networks and interests of stakeholders	System-specific perspectives and languages	Needs and values of the stakeholders involved
Objective/goal (Q19)	Get better data by involving issue-specific experts	Increase relevance, ensure funding and impact of his/her research	Understand learning processes in science and society	Integrate the perspectives of all actors touched by societal transformations
Science–policy interface (Q20)	Science and policy-making should be two separate fields; policy makers can use the results of scientists	Through the integration of different interests, science can sketch out different paths or courses of action for policy makers	Scientific findings cannot directly be integrated into political decision-making processes but have to be translated by the scientist into information that is useful for policy makers	Science should address the gap between science and society, thus contributing to well-informed, democratically justifiable decisions
Understanding of science (Q21)	It should be autonomous, ethically neutral, and objective	It always depends on perceptions and constellations of the actors that carry it out	It is the societal sphere in which true statements are differentiated from false statements	It should address societal needs and thus support societal transformations

3. Results: Ideals, practices and future prospects of SI in science

First, we give an overview of the current landscape in SI as presented in our sample, through, for example, information on scientific fields, scholars, and institutions which carry out or finance research as well as on methods and tools applied. We thereby address the first research question. Second, we describe how respondents positioned themselves concerning ideals of SI in science, addressing the second research question. Third, we summarize the answers on scientists' practice in their research projects, investigating whether they are in line with their ideals of SI and describing what they perceive necessary to improve SI. This refers to the third research question. Finally, we relate the respondents' opinions to the typology of SI in science by Mielke *et al.* (2016) to answer the fourth research question.

3.1 Current landscape

Our sample, which is methodically described in more detail in Materials and Methods, consists of German and international sustainability scientists working mostly at universities (39%) (all percentages are rounded), as well as in leading research institutions (31%). The survey was conducted in English. While 64% of respondents were German, we overall reached scholars from 18 different countries (for example, Spain, France, China, Ghana, Iran, and Poland). The majority of respondents are researchers at the early stages of their career: almost 80% are 40 y or younger; 40% hold a Master's degree, 35% hold a doctorate. The most common field of education is social sciences (57%). While only 37% of the respondents stated to have studied an explicitly interdisciplinary field, such as sustainability science, 64% described their education as "interdisciplinary." Overall, 73% of the respondents involve stakeholders regularly, for the majority in a transdisciplinary (54%) or interdisciplinary (43%) manner. The stakeholders involved come from a broad spectrum (Fig. 1), with politics at the forefront (84%), followed by civil society (77%) as well as companies (73%). Citizens rank last with 57%. Some respondents specified the types of stakeholders they work with, such as artists, consultants, advocacy groups, faith groups, business associations, and international organizations.

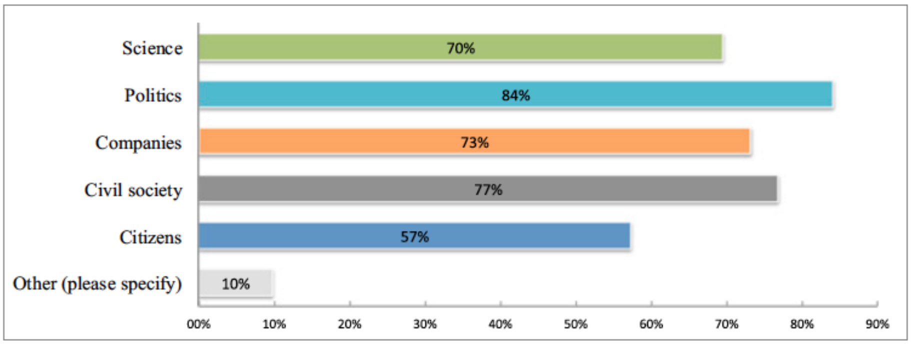

Fig. 1 Frequencies on Q10: "I work with stakeholders from: science, politics, companies, civil society, citizens, other." Multiple answers allowed; total respondents: 82. Source: Survey Monkey.

The main research topics that our respondents deal with are energy (52%) and climate policy (42%). This was expected, since our sample contains mostly responses from sustainability researchers. Almost 50% named other topics: for example, coastal protection, agriculture, digitalization, finance and green business, urban development, or corporate sustainability. Respondents mostly receive funding from public institutions: 56% said their research was inter alia funded by national governments, 44% named European institutions, while 26% have foundations as one of their funding sources. Only 16% are financed by companies. Some named other (mainly public) funders, like universities, municipalities, or international entities like the United Nations. Respondents that said they receive funding from companies did not work on climate policy issues. The latter is, however, prominent among public funders: 41–47% of those respondents that receive some funding from public institutions also work on climate policy issues.

With regard to methodology, workshops (78%) and interviews (72%) are used most frequently (Fig. 2). Cooperation, in the sense of actively collaborating with stakeholders in projects, ranges third, with 61%, followed by surveys and focus groups. Other methods named were, for example, participatory theater, informal personal exchange, and advisory/consultancy. Especially in research institutes, workshops are highly common (89%). Cooperation with stakeholders is most widespread in consultancies (73%) and in universities (69%). The level at which SI is used is primarily national or local (62% each), while the regional level ranks third with 46%. Supranational and international levels are less common (37% and 23%, respectively).

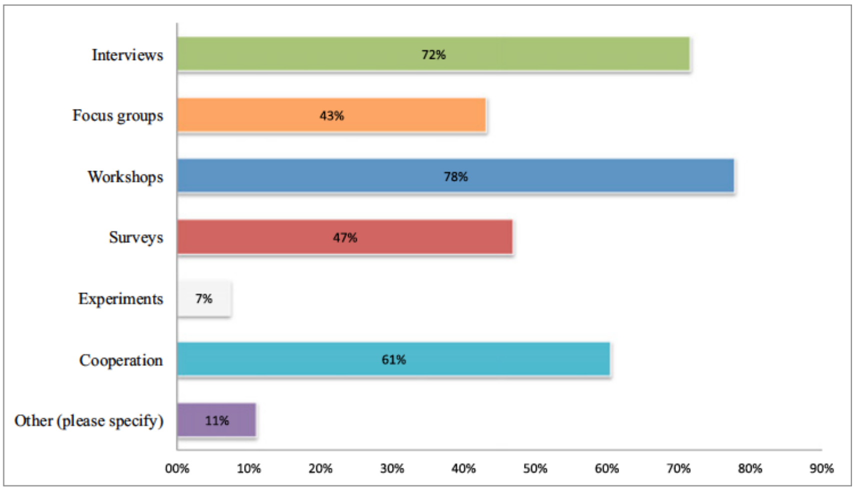

Fig. 2 Frequencies on Q13: "I involve stakeholder mostly through..." Multiple answers allowed; total respondents: 81. Source: Survey Monkey.

3.2 Ideals

To investigate the ideals that guide scientists when involving stakeholders, we asked respondents to pick or grade answer options for questions 15–21. In a first step, we looked at the mode and the median of all answers to identify a trend. In a second step, we analyzed "strong agreement" (grade 5) and "strong disagreement" (grade 1) to describe the respondents' positions in detail (we assembled grades of 1 and 2 as "disagreement" and grades of 4 and 5 as "agreement").

Stages of the research process

When asked in which stages of the research process stakeholders should be involved (Q15; multiple answers were allowed for this question), data collection (90%) was the option most respondents chose, followed by the planning phase (87%) and dissemination (81%). Still, around 66% said they would also involve stakeholders in data analysis, which is the furthest-reaching option of involving stakeholders in the research process. Of all respondents, 44% aim to involve stakeholders in all stages of the research process. When asked why they want to involve stakeholders at a certain stage (Q16), the strongest motivation was "to find out about stakeholders' interests and feed them into the research process," to which 58% strongly agreed and no one strongly disagreed. The strongest disagreement could be found for the statement: "To allow stakeholders affected by the research to give feed-back and join deliberative processes" (4%).

Role of scientist and stakeholder

Regarding the scientist's main role (Q17), respondents had to select one of the four choices. The role of the scientist as a facilitator of dialogues (35%) was the answer chosen most often, followed by the idea of the scientist being a stakeholder himself, bargaining for his interest (27%). Of the respondents, 23% consider the scientist as the leader of the research process, while only 15% think the scientist should be an external observer. This shows a wide divergence of specific roles in SI practices. The different roles are illustrated in Fig. 3.

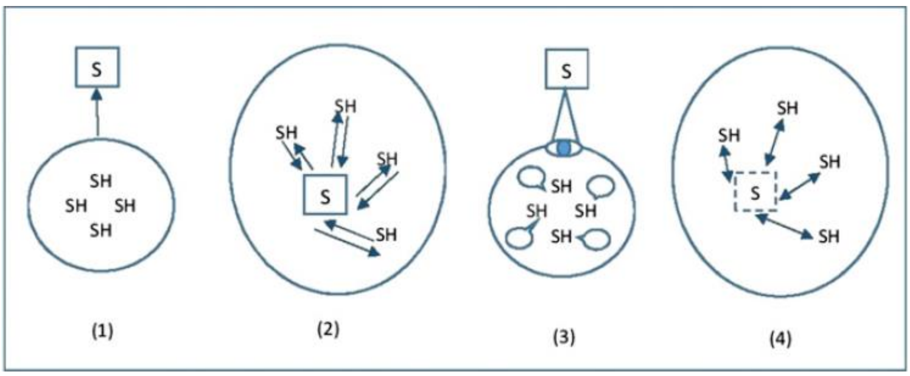

Fig. 3 Role of scientist (S) and stakeholder (SH) in the research process. (1) S leads the research process, SH are considered issue-specific experts; (2) S is a SH himself and bargains for his or her (scientific) interests in the research process; (3) S observes only from an external position to analyze the perspectives of SH; (4) S facilitates and moderates a cooperative dialogue with affected SH, trying to create trust. Source: authors' own illustration.

Kind of knowledge

The kind of knowledge that is produced in SI processes is a highly contested issue. Nevertheless, the responses to Q18 ("According to your understanding of stakeholder involvement in your scientific field: What kind of knowledge should be mainly produced in stakeholder projects?"; total respondents: 70) were clearly leaning toward finding out about needs and values of stakeholders (43%), followed by system-specific perspectives and languages (30%). When looking at the respondents' educational background, finding out about needs and values got the highest agreement among natural scientists, of which 60% chose this option. Only 7% of natural scientists seek "objective data and information" from stakeholders. Social scientists are just as interested in needs and values (38%), as in system-specific perspectives and languages, which 36% of them chose as their favorite option. Engineers favor needs and values (48%) and are the only ones who show strong interest in networks (27%). Scholars with an interdisciplinary background, like sustainability science, think that mainly knowledge on needs and values should be produced when working with stakeholders (46%).

Main goal of SI

The highest agreement could be found for the position that a scientist mainly involves stakeholders to "integrate the perspectives of all actors touched by societal transformations" (55% strongly agreed). Of the respondents, 50% agreed that wanting to get "better data by involving issue-specific experts" is a main goal, while 44% strive to "understand learning processes in science and society." Interestingly, there was barely strong disagreement with any of the statements, which is also reflected in the mode and median values.

Science–policy interface

The perception that "through the integration of different interests, science can sketch out different paths or courses of action for policy makers" was the most agreed to answer concerning the science–policy interface. Of the respondents, 43% strongly agreed to this view, and none strongly disagreed; 42% also strongly agreed that science should "address the gap between science and society, thus, contributing to well-informed, democratically justifiable decisions." The statement that science and policy-making should be two separate fields was the least popular position, with only 9% "strong agreement" and almost 50% "disagreement." This answer also had low values for mode and median.

Understanding of science

Of the respondents, 39% strongly agreed to the understanding that science "should address societal needs and thus support societal transformations." None strongly disagreed with this position; 36% strongly agreed to the view that "science should be autonomous, ethically neutral, and objective." Since we perceived these two positions to be mutually exclusive, we took a closer look at the individual responses. More than one-third of the respondents agreed to both of these positions (values for mode and median also reflected agreement for these positions). This inconsistency will be analyzed in Discussion, below. At the same time, one-fifth of the respondents answered as expected: agreeing to the two statements that lay close together—that science "should address societal needs and thus support societal transformations" and that science "always depends on perceptions and constellations of the actors that carry it out"—and rejecting or being neutral toward the positions that "science is the societal sphere in which true statements are differentiated from false statements" and that "science should be autonomous, ethically neutral, and objective." The most contested statement was the one that "science is the societal sphere in which true statements are differentiated from false statements": 34% of the respondents disagreed or strongly disagreed, while only 8% strongly agreed. This statement also had respective mode and median values.

3.3 Contrasting ideals and practices

The following section compares scientists' ideals with their practice. Additionally, we describe the trade-offs researchers see between scientific goals and SI.

Role of scientist and stakeholder

Most scientists did not see a mismatch between their ideals concerning the relationship between scientists and stakeholders and their practice in past projects. However, some respondents pointed out that, depending on the project, the stages ("different phases need different relations"), intensities, formats, and research questions, the roles vary and, thus, the practice of SI is nothing static. One respondent perceived the roles "as a continuum." Another scientist, who considered himself a stakeholder as well and agreed to be bargaining for his/her scientific interest (neoliberal-rational type answer item for Q17 on the roles), reported on the difficulties to accept these new roles for scientists: "The challenge for scientists is to accept the idea that they are not superior to the stakeholders."

Kind of knowledge

Twenty-one respondents stated that they gained other kinds of knowledge than expected. However, that was not always perceived negatively since some unexpected results were reported to be valuable input. One respondent commented: "System-specific perspectives and languages as well as needs and values were actually produce[d]—but it was important data, too." The mismatch of expected and experienced kind of knowledge came in various combinations, so that some were hoping to get objective data but instead obtained needs and values, whereas others were looking for needs and values and got knowledge about networks and interests instead. Several respondents hinted at the fact that the kind of knowledge gathered depended on the specificities of the project concerned. Two respondents rejected the idea that knowledge can be obtained at all through SI, stating that "the best that can be achieved is mutual understanding" and that stakeholders provide "confusing perspectives." However, the majority of respondents did not see a difference in the expected and the actually obtained kind of knowledge in their projects.

Science–policy interface

When asked about the gap between expectations and experiences in the science–policy interface, several respondents reported a mismatch. One scientist pointed to the learning process that researchers have to go through when using knowledge obtained by SI to consult policy: "It was a joint learning process. The idea that science can educate others unidirectionally is misleading." In several statements, frustration about too little impact on political decision-making was expressed, as one respondent exemplified: "Though, in general I see other professions much more successful in policy-making than science is, thus, being more successful with b[e]ing heard." Another saw "no measurable political impact at all," while a third respondent criticized that "political will is averse to real data when this collides with votes gained or lost." Several respondents mentioned the need for better communication between the two fields: "Scientific results need to be translated into useful information—also consultants, think tanks, NGO [nongovernmental organizations], journalists can have a role in this translation work." This was sometimes also related to a lack of resources for better translation and dissemination activities. One respondent emphasized the need for "social scientists in order to carry out the essential qualitative research necessary to bridge science and policy-making."

Trade-offs between scientific goals and SI

Forty-three respondents acknowledged trade-offs between scientific goals and SI, while 29 explicitly stated they did not experience any trade-offs. Often (n = 9), scientists pointed to problems of timing that led to "less time for peer-reviewed publications," saying that SI "reduces written academic output." This was sometimes weighed against the increase of relevance that might come with successful stakeholder engagement: "[SI] increases—hopefully—the relevance and usefulness of that which is written (and thus also its academic quality)." Besides the time factor, several respondents (n = 11) saw trade-offs between scientific goals and the interests of stakeholders as "the questions relevant to stakeholders do not always match the questions and/or methods that are interesting from a purely academic position." One respondent stated that when working with stakeholders, "objectivity might be more difficult," while another pointed out that stakeholders try "to get the results they need instead of results that make sense." Thus, these respondents think that the autonomy of science is in question when involving stakeholders. Finding the "right" stakeholders was mentioned as being difficult: "Not always desired stakeholders are available and eager to cooperate." This was problematized especially with regards to hidden motives of stakeholders: "Stakeholder involvement relies on the commitment of stakeholders. If they are not reliable or doing it only for fame, money or other crazy motives, then participatory research is doomed to fail."

Furthermore, the disciplinary perspective in the "traditional system/alignment of science in universities" was seen as a trade-off that could produce conflicts, which "emerge between different academic disciplines over the quality of data coming out of stakeholder involvement activities (qualitative vs. quantitative)." One respondent recommended making the trade-offs explicit by dealing with them "in a mixed co-operation between scientists and the stakeholders." Another commented on the quality of SI that is decisive for the existence or absence of trade-offs by stating: "[W]hen it is done well, you can ask scientifically interesting questions that are also interesting and relevant to stakeholders, however, I think there is often a tendency to move towards being service providers to a certain extent and that type of research wi[t]h stakeholders needs to be avoided." Some hints on how to avoid trade-offs were mentioned, such as reflection about the role of stakeholders (e.g., scientists as "experts for methods in need to collaborate with stakeholders as experts for relevance"), conflict resolution methods, and gender issues.

Whether a scholar sees trade-offs between scientific goals and SI also seems to depend on the kind of knowledge that he or she wants to gather: 73% of those respondents that see trade-offs were either looking for stakeholders' "needs and values," the democratic kind of knowledge (42%), or the functionalist kind of knowledge, namely "system specific perspectives and languages" (31%). Scholars looking for "objective data and information" (technocratic kind of knowledge) or "networks and interests" (neoliberal-rational kind of knowledge) were less worried; they only made up 27% of those concerned about trade-offs (15% technocratic and 12% neoliberal-rational). When looking at contingency tables, we found that more respondents from research institutes (61%) recognize trade-offs between their scientific goals and SI than respondents working for universities (57%). Furthermore, of those respondents who work in transdisciplinary projects (52%), the majority (60%) perceives such trade-offs.

3.4 Looking ahead

To find out what scientists consider helpful to improve their work with stakeholders (Q22), we offered six perspectives: more funding, more academic literature on SI, longer projects, a larger pool of stakeholders, fitting tools and methods for SI, and a network of practitioners. Fig. 4 gives an overview on the respondents' assessment.

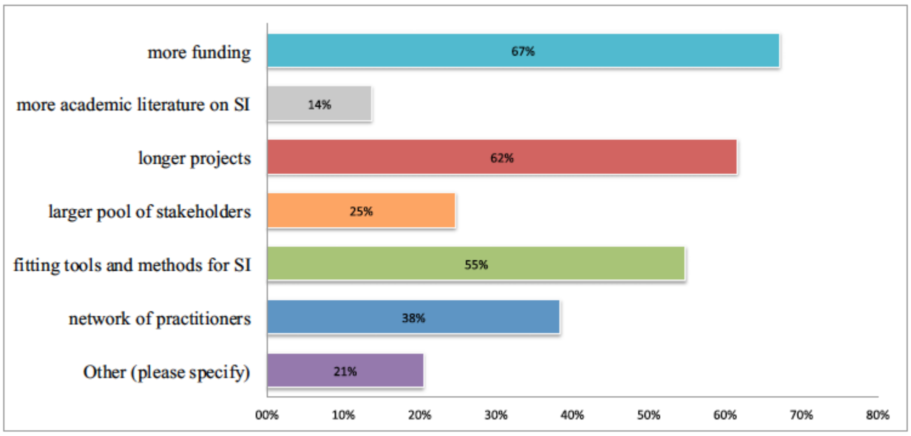

Fig. 4 Frequencies on Q22: "What would you need to improve your work with stakeholders?" Multiple answers allowed; total respondents: 73. Source: Survey Monkey.

In general, one-third of all respondents want to work more frequently with stakeholders in the future, the majority wants to keep the level of involvement the same, and only one respondent would like to integrate stakeholders less frequently.

Not surprisingly, most of the respondents (67%) think that more funding would improve the work with stakeholders, for example, through "funding schemes that support co-design, co-production and implementation of results additional[l]y to the research phase." Some respondents think that funding for travel costs and other expenditures could increase the motivation of stakeholders to participate; 62% consider longer projects as an essential improvement, adding the importance to follow up on project work by "monitoring societal and sustainable effects after project ended" and getting feedback from stakeholders on research results. Some mentioned the role of time to establish trust and foster commitment on both sides as being crucial for good relationships. Furthermore, "the recognition that many time stakeholders might be interested but have other constraints that do not allow them to participate" was mentioned. This lack of understanding can also be located on the scientific side: "A better understand[ing] of the reasons why we do it—science on its own can't change society!" As a solution, several respondents point to the development of methods, such as "toolboxes," for SI that could be integrated into "curricula" or projects. Overall, 55% of respondents perceive the fitting of tools and methods as an important improvement, while only 14% of all respondents were seeking more academic literature on SI.

3.5 Conceptualization of practices

In our questionnaire, we asked researchers to position themselves regarding the five defining criteria in questions 16–21. For every question, we offered four answer items that each represent a view associated with one of our ideal types: item A for the technocratic, B for the neoliberal-rational, C for the functionalist, and D for the democratic type (Table 2). However, since these types were designed as a heuristic tool to conceptualize debates on SI rather than offering an empirical description of practices, we did not expect respondents to behave in an ideal-typical way. Rather, we wanted to derive common ground and critical points regarding the ideals that guide scientists to answer our fourth research question.

We took three steps to analyze the relationship of the typology with the scientists' answers [for this analysis, we only used complete datasets (n = 59)]. First, we looked at the level of agreement within a type. To do so, we calculated the relative frequency of grades given in all respondents' type-related answers in questions 16, 19, 20, and 21, which provides the type score. For the technocratic type score, we counted the amount of grades that respondents gave for the technocratic items (grade 1 was chosen 16 times, grade 2 was chosen 29 times, grade 3 was chosen 53 times, grade 4 was chosen 57 times, and grade 5 was chosen 81 times) and divided these absolute frequencies by the amount of all grades given for the technocratic type (n = 59 and four items per type lead to 236). Fig. 5 shows that agreement within the democratic type (81%) was highest, followed by the neoliberal-rational type (76%). Expressed disagreement was highest within the technocratic type (19%).

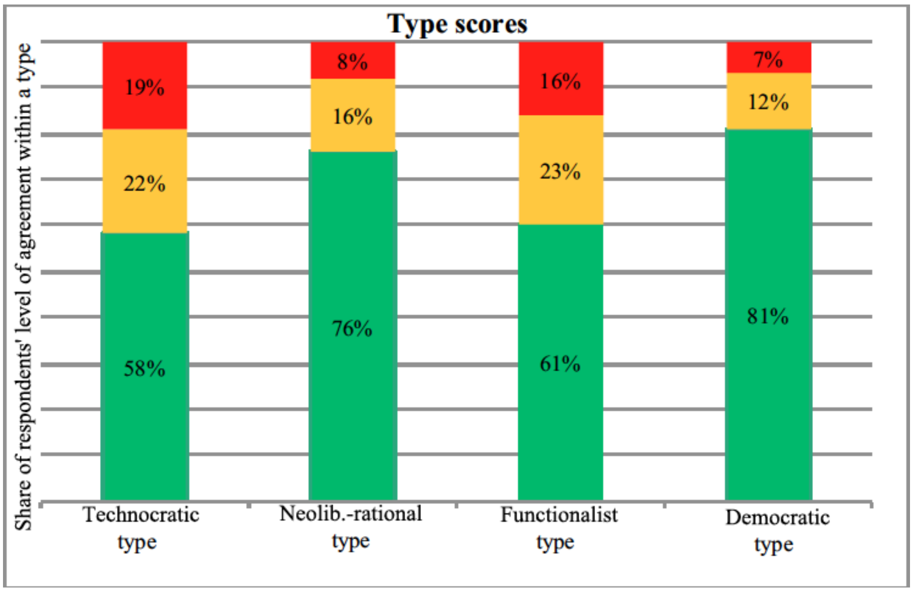

Fig. 5: Type scores show the level of agreement within a type across all respondents; agreement in green (grades 4 and 5), neutrality in yellow (grade 3), and disagreement in red (grades 1 and 2). Absolute frequencies (counting the amount of grades 5, 4, 3, 2, and 1 that respondents gave for each type's items) were divided by the amount of all grades given per type (59 respondents graded 4 items per type, amounting to 236 grades). Source: authors' own illustration.

Second, we examined the level of respondents' agreement over all types. It was measured by the absolute frequency of a certain grade per type, divided by the amount of that grade over all types. For example, the distribution score for strong agreement was calculated as follows: over all types and questions, respondents chose grade 5 (strongly agree) 362 times. Of this total, 31% (112) were attributed to some democratic position, while 27% of strong agreement was expressed with regard to the neoliberal-rational (97), 22% (81) to the technocratic, and 20% (72) to the functionalist type. As Fig. 6 shows, overall disagreement was highest for the technocratic type, while agreement was highest for the democratic type.

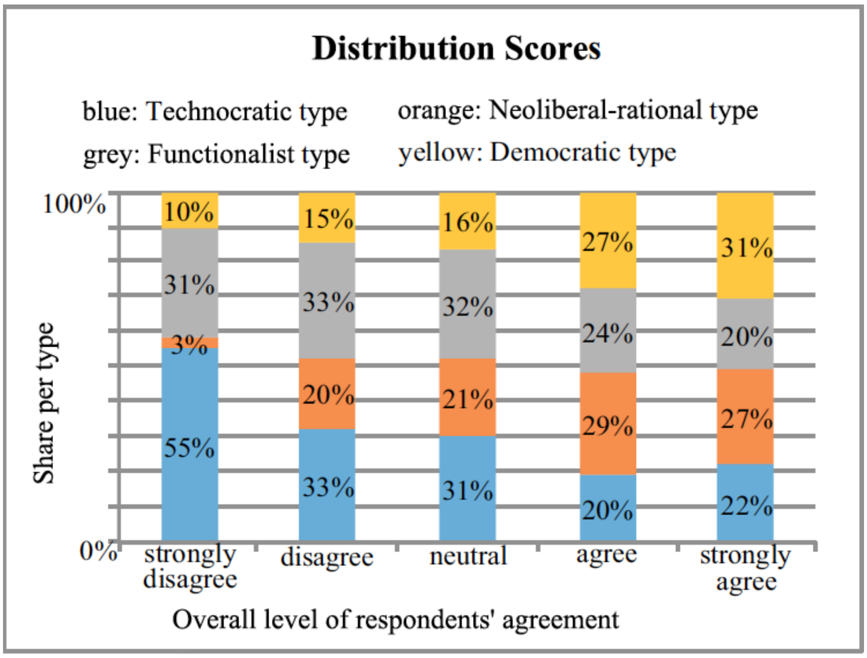

Fig. 6: Distribution scores show the overall level of agreement across all types. Agreement or disagreement was measured by the absolute frequency of a certain grade per type, divided by the amount of that grade over all types. Source: authors' own illustration.

Due to the strong disagreement to the technocratic type, we took a closer look at the technocratic responses. The main reason for the strong disagreement with this type is the statement concerning the science–policy interface (75% of strong disagreement in the technocratic answers) that "science and policy-making should be two separate fields" (Fig. 7). This also holds true for the functionalist, where the strong disagreement within the type mainly stems from the rejection of the answer concerning the understanding of science, being the "societal sphere in which true statements are differentiated from false statements" (67% of strong disagreement within functionalist answers).

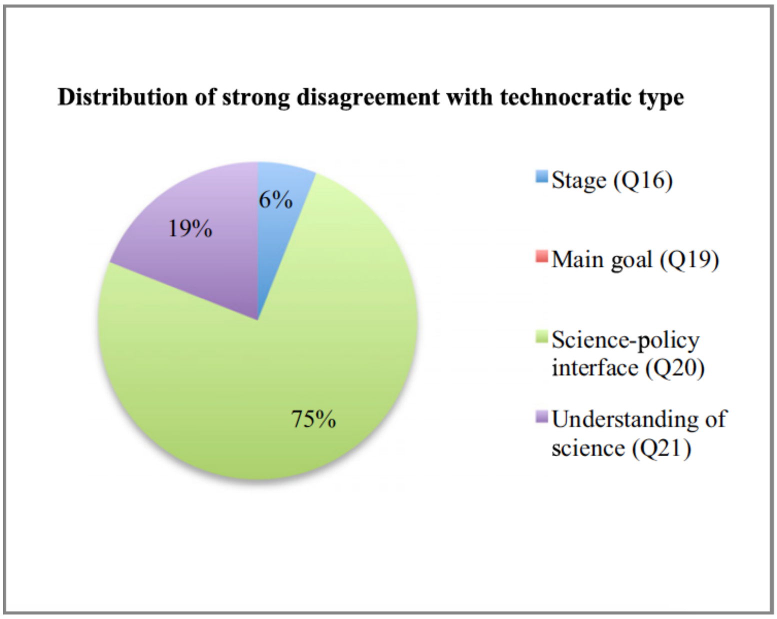

Fig. 7: Distribution of strong disagreement with technocratic type. The technocratic main goal had 0% strong disagreement. Source: authors' own illustration.

In a third step, we took a closer look at correlations among the sum scores related to the four ideal types of SI in science to see whether and how strongly researchers' positions were connected and to evaluate the discriminatory power of the types. Drawing from our typology, we assumed the types to represent certain, internally coherent positions on SI in science. Expressed in terms of the sum scores, by which we measured the overall agreement for a certain type, we would have expected the respondents to have a high sum score for one of the four types and lower sum scores for the others, thus implying negative correlations. This hypothesis was only partly supported by the data depicted in Table 3: while we found a significantly negative correlation between the technocratic and the democratic positions (−0.29), we found positive correlations between the technocratic and functionalist positions (0.28) as well as between the functionalist and the neoliberal-rational positions (0.24). The negative correlation between the democratic and technocratic sum scores shows that a person who takes a democratic position on SI in science tends to reject the technocratic view on SI and vice-versa. We discuss this observation in the following section.

Table 3. Correlations among the respondents' sum-scores across all types

	Technocrat	Neoliberal-rational	Functionalist	Democrat
Technocrat	1	0.06	0.28*	−0.29*
Neoliberal-rational	0.06	1	0.24†	0.15
Functionalist	0.28*	0.24†	1	0.2
Democrat	−0.29*	0.15	0.2	1

*Significant at the 5% level.
†Significant at the 10% level (*P* value of 0.080).

4. Discussion

The data collected in our survey give an overview of current practices and ideals in SI and show important trade-offs when involving stakeholders, ranging from time conflicts over the possible loss of the autonomy of science to quality conflicts concerning the research results. However, the picture of current practices of SI in sustainability science drawn from our data might be biased due to the socio-demographic structure of our sample: most of the 89 scientists are in earlier career stages (age between 20 and 40 y), and work with stakeholders in inter- or transdisciplinary projects (this might be due to our snowball sampling procedure). Even though the majority of respondents were of German nationality (64%), our results are transferable to and relevant for a broad international scientific audience. Roughly half of the respondents work on projects that are carried out at the supra- or international level, while about the same number receives funding from European Union institutions. Furthermore, the scientific standards discussed herein are shared by the global sustainability science community.

Concerning the links between researchers' ideals of SI and our typology, a discussion of results is necessary. While we found the democratic and the neoliberal-rational perspectives to be most prominent among our respondents, the level of agreement was quite high across all types. This hints at scientists using hybrid forms of SI, which also becomes apparent in the fact that many respondents agreed to three or more of the four options offered in our typology questions, and thus to three or more types. Especially concerning the reason for the stages at which stakeholders are involved and the scientist's main objective, the majority of scientists showed mixed conceptions. Table 4 summarizes this pattern.

Table 4. Percentage of respondents who agreed to three or more options of questions 16, 19, 20, and 21 (of $n = 59$)

Question	Topic	Percent of respondents, %
16	Motivation to involve stakeholders at a certain stage of the research process	85
19	Main objective	71
20	Science–policy interface	51
21	Understanding of science	27

This result could be due to several reasons. The positions offered might have been perceived as being unclear. This became especially apparent in the question on the understanding of science (Q21), where more than one-third of the respondents agreed to both the democratic position that science "should address societal needs and thus support societal transformations" and the technocratic view that "science should be autonomous, ethically neutral, and objective" at the same time. Three respondents specifically referred to the answer choices in Q21 as being not mutually exclusive, ambiguous, and too similar.

The results also hint at a lack of conceptual clarity among practitioners, especially on the question concerning the understanding of science. Another reason for the high agreement to seemingly mutually exclusive positions might be that scientists work with stakeholders in different, sometimes even contradicting ways at the same time, taking diverse roles within different stages of the research process (addressed in Q15 and Q16; here divided into planning phase, data collection, analysis of results, and dissemination), or having varying understandings of science (Q21) in different projects. Both topics relate to discussions on codesign and coproduction in transdisciplinary research processes and are highly disputed in the literature (see e.g. Hirsch Hadorn *et al.*, 2006; Polk, 2015; Wiek, 2007 for a discussion of challenges). While authors like Cornell *et al.* (2013: 60) opt for a highly integrative stakeholder approach that includes "collective problem framing" and "societal agenda setting," others like Lang *et al.* (2012: 28) take a more moderate position, by emphasizing "collaborative problem-framing" as well as "co-creation of solution oriented and transferable knowledge." The difficulty of aligning these goals, roles, and understandings is reflected in the trade-offs presented the Looking Ahead section, above.

Nevertheless, we were able to find interesting correlations. First, there was a significantly negative correlation between the technocratic and the democratic position (–0.29). Since the data showed a strong negative tendency for the technocratic answer to the science–policy interface question, we tested this item's correlation with the democratic sum score and found an even stronger negative correlation of −0.39. This only partly corresponds to the typology used. Mielke *et al.* (2016) acknowledge a distance between democrat and technocrat concerning the science–policy interface, but the neoliberal-rational type is designed to be furthest away from the democrat on this matter (see "bargaining vs. deliberation" in Mielke *et al.*, 2016). Second, we found a positive correlation between the technocratic and functionalist position (0.28). This is reflected in the typology, as these positions were designed to be closest to each other concerning the science–policy interface (see "bargaining vs. deliberation" in Mielke *et al.*, 2016) and regarding the understanding of science science (see "autonomy of science" in Mielke *et al.*, 2016).

5. Materials and methods

To reach our respondents, we used a snowball sampling technique (Goodman, 1961; Przyborski and Wohlrab-Sahr, 2014; Ritchie, Lewis and Elam, 2003) as a first step. We accessed scientists that were already in contact with us, and then asked these scientists to pass on our survey within their networks. Additionally, we approached networks of sustainability scientists ourselves. The contacts included sustainability scientists working in leading research institutes for climate, environment, and economics (e.g., Potsdam Institute for Climate Impact Research, Helmholtz-Centre for Environmental Research, German Institute for Economic Research, Fraunhofer ISI, National Aeronautics and Space Research Centre of the Federal Republic of Germany), as well as in respective departments in universities (e.g., University of Bielefeld, Eberswalde University for Sustainable Development, Freie Universität Berlin, Technical University Berlin, Leuphana University). We also addressed different networks in which these scientists are associated[1], as well as relevant foundations (e.g., Mercator and Böll-Foundation) and nongovernmental organizations (e.g., Germanwatch), which deal with sustainability transitions. The survey was online from July 7 to November 15, 2016 and was closed after 89 responses. Since the data were anonymized, informed consent procedures and approval by an ethics committee were not needed.

To make sure our items were constructed consistently within the types, we calculated item-total correlations (Everitt, 2002) for each type.[2] The range for the technocratic type's items was between 0.51 and 0.83, for the neoliberal-rational from 0.42 to 0.55, for the functionalist from 0.38 to 0.56, and for the democratic type from 0.61 to 0.75, showing internal coherence of the types constructed. To test reliability, we used a split-half reliability test (Diekmann, 2007), showing values between 0.61 and 0.72 for the technocratic, functionalist and democratic items, respectively. Only the scale for the neoliberal-rational type had a negative reliability measure (–0.08). Following Kim and Stoel (2004), we consider measures above 0.5 as being reliable. The low value for the neoliberal-rational type is assumed to be due to the item "understanding of science." To ensure content validity (Diekmann, 2007), we reviewed literature on sustainability science, interviewed experts in the field, and performed a pretest with practitioners. The survey and the full data sheet that the analysis is based on as well the tests developed are provided in *SI Appendix* and Dataset S1.

In our analysis of the current landscape and practices, we mostly used relative frequencies and qualitative interpretation for open questions. The percentages relate to the number of responses within each question (e.g., Q1 had 88 responses, Q3 had 87). For the Likert-scale questions, only respondents that replied to all four items of a

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[1] E.g., Förderschwerpunkt Sozialökologische Forschung (a group of scientists that is funded by the socio-ecologic program of the German Ministry of Education and Research; https://www.fona.de/en/society-social-ecological-research-soef-19711.html), Strommarkt-Verteiler (a German network of energy professionals in academia, policy-making, industry, and nonprofit organizations; www.strommarkttreffen.org/english)

[2] Diekmann (2007) uses the item-total correlation test to find out whether items show another dimension that leads away from the intended one, attributed to all items ("Fremddimension").]

question were counted to ensure comparability. Furthermore, we employed contingency analysis (Backhaus *et al.*, 2016) as a multivariate statistical method to investigate interconnections among the scientists' positions on different criteria and concepts of SI. For a deeper analysis of our ordinal data in the Likert-scale questions,[3] we calculated:

(i) type scores for the technocratic, neoliberal-rational, functionalist, and democratic items to check the agreement within a type;
(ii) distribution scores to see how agreement and disagreement were distributed across the types; and
(iii) correlation coefficients (correlations used were significant at the 1% or 5% level) (Diekmann, 2007) among the sum scores to investigate how the types were related. We calculated the sum scores for the each type by summing up a respondent's answers for the respective type's items in questions 16, 19, 20, and 21. Thus, they reflect the level of agreement to the respective type.

[3] There is an ongoing scientific debate whether Likert-scales can be interpreted as interval data; we have followed the interpretation of Diekmann (2007).

6. Conclusions

The findings presented in this paper offer an overview of current practices and ideals of scientists working with stakeholders. The survey shows that SI has become a common practice in inter- and transdisciplinary research projects and that there is common ground on how it should be carried out. While a broad array of nonacademic actors is involved, stakeholders from politics and civil society are at the forefront. Mostly, stakeholders are involved through workshops and interviews or in cooperative processes. Although energy is the most frequent thematic issue, the topics are broad, ranging from agriculture over resource efficiency to climate policy and mobility. Our respondents involve stakeholders at all stages of the research process, but find data collection and planning the most prominent points for involvement.

When looking at ideals, the main role of the scientist is seen as being a facilitator of dialogue. The kind of knowledge that is supposed to be obtained consists of needs and values of the stakeholders involved, which corresponds with the most agreed-on main goal of integrating the perspectives of those actors that are affected by transformations. In relation to the policy world, scientists want to use SI to better sketch out paths for policymakers. The respondents most strongly agreed that science should address societal needs and support transformations. Nevertheless, divergences between scientists' ideals and their practices concerning SI became apparent. Respondents wish for political impact, but many consider it being limited when looking back on their projects, partly due to different expectations of stakeholders and scientists, a lack of motivation on the stakeholder's side, a lack of funding, or follow-up on results. Many also see a trade-off between their scientific goals and SI, saying that SI gives them less time to concentrate on their academic publications, admitting to not always be sure how the knowledge obtained through SI can be scientifically used, and fearing to be influenced by stakeholders to a point that threatens scientific autonomy.

Respondents also indicated a need for improvement, mainly hoping for increased funding, more time, and better-fit methods. These trade-offs and improvement needs hint toward a lack of conceptualization in SI. The latter also became apparent when we related the survey results to the typology established in Mielke *et al.* (2016). Although we found a preference toward the democratic and the neoliberal-rational type, there was high consent with all types, even among those that were designed to be mutually exclusive. This underlines the need for further qualitative research on SI as well as for conceptual tools for scientists that involve stakeholders. Heuristic conceptualizations like the typology can help to reflect on trade-offs before conducting research and, thus, may help to resolve some of the conflicts scientists named in our survey.

Since respondents called for better-fit methods, there should be more training (Wiek, Withycombe and Redman, 2011; Clark *et al.*, 2016) on how to perform SI in scientific research at universities and within projects. Moreover, the repercussions that SI might have on research questions, codes, language, tools, and methods should be better reflected, as scientific practices and concepts change over time.

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Statement of contribution

Chapter 2: All authors contributed to the conceptual design of the paper and the development of the narrative. Richard Rosen (Section 2), Sarah Wolf (Sections 1, 3), **Jahel Mielke** (Sections 1, 4) and Franziska Schütze (Section 4) wrote the paper. Carlo Jaeger supported the design and framing of the manuscript through many discussions. All authors contributed to editing the manuscript.

Chapter 3: Franziska Schütze, Steffen Fürst, **Jahel Mielke**, Gesine A. Steudle, Sarah Wolf and Carlo C. Jaeger contributed to the framing of the research question and specified the changes in the GEM-E3 model. Steffen Fürst analysed and visualized the data. Franziska Schütze conceptualized and wrote the paper with contributions from the other authors.

Chapter 4: **Jahel Mielke** developed the idea for the model and the paper. She summarized the debate in game theory as well as its implications for the model (Sections 1, 2). Gesine A. Steudle wrote the model description (Section 3). Both authors developed the model together and contributed to discussion (Section 4) and conclusions (Section 5), as well as to editing the manuscript.

Chapter 5: Developed and written by **Jahel Mielke**.

Chapter 6: **Jahel Mielke** initiated the idea for the paper. All authors contributed to the conceptual design, framing of the research question and specifying the typologies. **Jahel Mielke** wrote the introduction and literature review, the cases for the energy transition section, part of the typology, part of the discussion and the conclusion. Hannah Vermassen wrote part of the typology and part of the discussion, Saskia Ellenbeck wrote the methods section, part of the typology and part of the discussion. Blanca Fernandez Milan wrote part of the typology and developed Figure 1. Carlo Jaeger supported the design and framing of the manuscript through many discussions. All authors contributed in editing and discussing the manuscript.

Chapter 7: All authors contributed to the idea and design of the survey and the paper. **Jahel Mielke** conceptualized the paper, summarized the state-of the art in sustainability science and designed the tools for analysis. **Jahel Mielke** and Hannah Vermassen analyzed and evaluated the data. Saskia Ellenbeck analyzed the qualitative responses and contributed to writing Section 3. **Jahel Mielke** wrote Sections 1, 2 and 5 and contributed to writing Sections 3, 4 and 6. Hannah Vermassen contributed to writing Sections 3, 4 and 6. All authors discussed and edited the manuscript.

Tools and resources

All chapters of this thesis were written with Microsoft Office Word 2011 and 2016. References were added using the reference manager Endnote Web as well as the plug-in Cite While You Write for Microsoft Office Word. This document was prepared using LaTeX, particularly TeXstudio. In some chapters, additional resources were used for data analysis, model implementation and generating graphical output, as indicated:

Chapter 3: Simulations were done with GEM-E3 and implemented in GAMS. Figures were generated with JFreeChart.

Chapter 4: The model was implemented with Scala and Figure 1 was plotted with Scala.

Chapter 5: Data was collected with Survey Monkey, coded with MAX-QDA and analyzed with Microsoft Excel 2011. Figures were plotted with Microsoft Excel 2011.

Chapter 6: Figure 1 was made with Microsoft Power Point 2011, Table 1 with Eclipse.

Chapter 7: Data was collected with Survey Monkey and analyzed with Microsoft Power Point and Microsoft Excel 2011 as well as with SPSS. Figures 1, 2, 4, 5, 6 and 7 were plotted in Microsoft Excel 2011, Figure 3 was made in Microsoft Word 2011.

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