Novel Insights to Facilitating Sustainability through Information Systems

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Valerie Graf-Drasch
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Erstgutachter:	Prof. Dr. Hans Ulrich Buhl
Zweitgutachter:	Prof. Dr. Heribert Gierl
Vorsitzender der mündlichen Prüfung:	Prof. Dr. Yarema Okhrin
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Table of Contents

Please note: Tables and figures are consecutively numbered per chapter, and within Chapters II, III, and IV per section (each representing one research paper). References are provided at the end of each section and each research paper, respectively.

Index of research papers

This doctoral thesis contains the following six research papers:

Research paper P1: Baumbach S, Graf V, Graf V[1], Schafranek M (2018) Individuals' sustainable behaviour along the life cycle of IT.
In: *Proceedings of the 28th European Conference on Information Systems (ECIS), Portsmouth, UK, 2018 (VHB-JOURQUAL 3: category B)*

Research paper P2: Gimpel H, Graf V, Graf-Drasch V (2019) A comprehensive model for individuals' acceptance of smart energy technology: A meta-analysis.
In: *Energy Policy (VHB-JOURQUAL 3: category B),* https://doi.org/10.1016/j.enpol.2019.111196

Research paper P3: Graf V, Graf-Drasch V, Weitzel R, Tiefenbeck V, Fridgen G (2020) Supporting citizens' political decision-making using information visualization.
In: *Proceedings of the 30th European Conference on Information Systems (ECIS), Marrakech, Morocco, 2020 (VHB-JOURQUAL 3: category B)*

Research paper P4: Gimpel H, Graf-Drasch V, Kammerer A, Keller M, Zheng, X (2019) When does it pay off to integrate sustainability in the business model? – A game-theoretic analysis.
Online ahead of print in: *Electronic Markets (VHB-JOURQUAL 3: category B),* https://doi.org/10.1007/s12525-019-00361-y

Research paper P5: Gimpel H, Graf-Drasch V, Laubacher R J, Wöhl M (2020): Facilitating like Darwin: Supporting cross-fertilisation in crowdsourcing.
In: *Decision Support Systems (VHB-JOURQUAL 3: category B),* https://doi.org/10.1016/j.dss.2020.113282

Research paper P6: Graf-Drasch V (2020) Health is wealth – But what about digital technologies? A comparative mixed-methods study.
Submitted to: *Scandinavian Journal of Information Systems (VHB-JOURQUAL 3: category C)*

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[1] Please note that this research paper was published under my old surname "Graf." In the meantime, my surname changed to "Graf-Drasch."

I Introduction[2]

“Earth Overshoot Day” marks the day when humanity has used more resources from nature in a single year than the planet can renew. In 2019, this day was on July 29 and the earliest since taking records (Earth Overshoot Day 2020). There is an overwhelming consensus that this overuse of resources is the main cause of our environmental problems (Cook et al. 2016; Wheeler and Braun 2013). A substantial body of research already points to its associated consequences: Since the 1880s, the globe’s surface temperature has risen by about 1 degree Celsius. Further, according to weather records, the years from 2015 until 2019 have been the warmest of the last 140 years (NASA 2020). This warming trend contributes to the “tipping point” beyond which we cannot reverse the effects of global warming and other massive environmental shifts, such as rising sea levels, dramatically expanding droughts, ocean acidification, and loss of biodiversity (Gholami et al. 2016; Intergovernmental Panel on Climate Change 2019; Oreskes 2004; Pecl et al. 2017).

The implication is clear: Environmental deterioration has become a colossal threat that we must urgently address (Gholami et al. 2016; Plumer and Popovic 2018). To contain the effects of environmental deterioration, leaders, researchers, and environmental activists call for fostering sustainable development (Gholami et al. 2016; Obama 2015; Thunberg 2018; United Nations 2018). Sustainable development is formally defined as “development which meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED 1987, p. 43). Consequently, such sustainable development not only includes environmental, but also social and economic dimensions. Accordingly, sustainability is conceptualized as a three-dimensional construct, comprising the environment, society, and economy – also often referred to as “three pillars of sustainability” (Elkington 1994; Molla et al. 2009; Sarkis et al. 2013).

To strengthen the three pillars, the moral obligation to solve sustainability problems has unfolded in many academic disciplines (Gholami et al. 2016; Seidel et al. 2017; Watson et al. 2010). Thereby, Gholami et al. (2016) highlight that the solution cannot be merited to one single discipline. Rather, the current situation asks for interdisciplinary approaches to solve sustainability related problems. However, the authors point out that in this interdisciplinary approach, a substantial Information Systems (IS) component should be part of the solution

[2] Since it is in the nature of a cumulative doctoral thesis that consists of individual research papers, this section, the beginning of Chapters II to IV as well as the last Chapter V partly comprise content taken from the research papers included in this thesis. To improve the readability of the text, I omit the standard labeling of these citations.

(Gholami et al. 2016). IS arguably hold much potential in accelerating sustainable development (Elliot 2011; Melville 2010; Venkatesh et al. 2019a; Venkatesh et al. 2019b). Focusing on environmental challenges, a decade ago, Watson et al. (2010) and Melville (2010) highlighted that the IS discipline has both the responsibility and the ability to contribute to solutions that reduce the negative environmental effects of human behavior. Acknowledging this, IS scholars adopted sustainability as an important topic in their research. Over the past years, they have made important contributions, advancing our knowledge about how IS can contribute to solving sustainability problems (Seidel et al. 2017; Venkatesh et al. 2016; Walsham 2017). These contributions can be classified into two major research strands: *IS for Environmental Sustainability* and *Information and Communication Technology for Development*. Both streams address the need for sustainability. The strands are briefly explained hereafter.

The first strand, IS for Environmental Sustainability, was defined by the seminal works of Melville (2010) and Watson et al. (2010). The first author defined this strand as “IS-enabled practices and processes improving environmental and economic performance” (Melville 2010, p. 8). This highlights that an IS sustainability perspective includes economic thinking (Watson et al. 2010). The strand is often referred to as “Green IS,” although it also comprises the concept of “Green Information Technology (IT)” (Loeser 2013; Parmiggiani and Monteiro 2018). IS and IT have both been leveraged to support sustainable development (Kranz et al. 2015), however, related literature clearly distinguishes between Green IS and Green IT (e.g., Kranz et al. 2015; Sarkis et al. 2013). Green IS focus on individuals’, groups’, organizations’, and society’s IS usage to support environmentally sustainable practices (Henkel et al. 2017; Henkel and Kranz 2018; Watson et al. 2010). Green IS are defined as a “cooperating set of people, processes, software, and information technologies to support individual, organizational, or societal goals” (Kranz et al. 2015, p. 8). An objective of Green IS is its support of pro-environmental behaviors and actions (e.g., practices and decision-making) on an individual, organizational, and societal level (Henkel and Kranz 2018). Differently, Green IT refers to hardware and infrastructures that can be better managed and designed from an environmental perspective. Thus, Green IT directly contributes to the reduction of negative impacts on the environment (Henkel and Kranz 2018; Kranz et al. 2015; Sarkis et al. 2013).

The second strand, Information and Communication Technology for Development (ICT4D), summarizes research linking the potentials of ICT to international and societal development goals, such as those of the United Nations (United Nations 2019; Venkatesh et al. 2019a; Venkatesh et al. 2019b; Walsham 2017). Accordingly, the strand is dedicated to the broad and impassionate question of whether IS scholars build a better world with ICTs (Sahay 2016; Walsham 2012). The acronym ICT4D is a relatively new label for the research strand, which has a history going back some 30 years and was initially known under the similar acronyms "ICTD" or "ITD" (Walsham 2017). Heeks (2006) and Walsham (2017) similarly describe the history of ICT4D, with IS scholars starting to dominate the field in the mid-1980s. Specifically, in 1988, ICT4D debuted in the IS community at a conference on "social implications of IS in developing countries" in New Delhi, India. The conference was dedicated to the social implications of IS in developing countries (Walsham 2017). Recently, ICT4D experienced an "upswing" at the currently important juncture in time: ICTs have penetrated all corners of the globe and have been extensively used in developing countries (Walsham 2017). To date, ICT4D is a key focus for governmental and non-governmental organizations and for IS scholars, who seek to improve the life, health and well-being of citizens (Molla et al. 2009; Venkatesh et al. 2019a; Venkatesh et al. 2019b).

Even though both research strands have a history going back several years, they are still remarkably fresh in some ways. Particularly, Seidel et al. (2017) recently argued that the IS field has not fully realized the magnitude of the sustainability problem, nor has it reached its full potential (Seidel et al. 2017; Walsham 2017). This is also reflected in scholars' recent classification of Green IS as a still emerging strand (Henkel et al. 2017; Parmiggiani and Monteiro 2018). Considering this, scholars call for increasing Green IS engagement in the years ahead (Gholami et al. 2016; Seidel et al. 2017). In a similar vein, the "upswing" of the ICT4D strand as noted by Walsham (2017) manifests in recent calls for papers of top IS journals (Information Systems Journal 2019; Scandinavian Journal of Information Systems 2020) or an aligned theme of an upcoming IS conference (ECIS 2020 in partnership with HEM Business School 2019).

When describing existing research on the intersection of IS and sustainability, particularly Green IS scholars structure prior studies alongside an *individual*, *organizational*, and *societal level*, since the major aim of Green IS is to support pro-environmental behaviors, sustainable practices, and decision-making on all three levels (e.g., Henkel and Kranz 2018; Melville 2010). This doctoral thesis also uses this structure to describe existing ICT4D research, although the strand's focus primarily is on the societal level and related issues, such as systematic poverty, global health, or gender equality, to state a few examples (Walsham 2017). Figure 1 depicts the three levels. Although the levels are distinct, there is an interdependent relationship between them (as indicated by the dashed lines). Particularly, each level benefits from, but must endure conditions of the other levels (Henkel and Kranz 2018; Melville 2010).

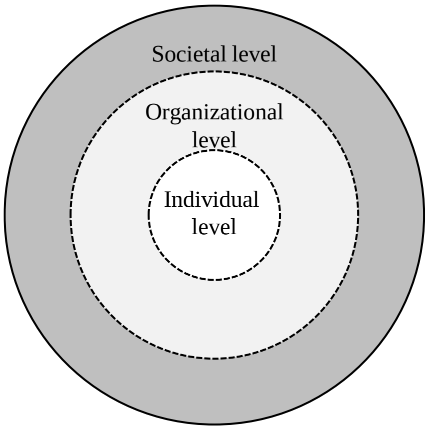

Figure I.1-1. Framework structuring Green IS and ICT4D research (illustration inspired by Elliot 2011)

The research papers included in this doctoral thesis address both research strands, Green IS and ICT4D, and refer to all three levels illustrated in Figure 1. In order to provide an understanding to which concrete topics they are linked and which gaps they address, a brief overview of existing Green IS and ICT4D research is provided in the following. This overview is not intended to be exhaustive. The purpose is to exemplify prior studies on the three different levels, and point to research gaps they left open (at least partly and temporarily). Thereby, the research papers included in this doctoral thesis are linked and explained in more detail in the following chapters.

I.1. Studies on the individual level

There is an overwhelming consensus that human actions are the cause for global warming (Cook et al. 2016). Thus, the individual level is an appropriate place to start taking pro-environmental action (Elliot 2011; Melville 2010; Watson et al. 2010). Accordingly, studies of this level often take an action-oriented perspective and focus on how psychic states about sustainability (e.g., norms, attitudes, or beliefs about the natural environment) translate into concrete individual actions (Henkel and Kranz 2018; Melville 2010). Thereby, particularly individuals' acceptance of Green IS or related technologies have been one center of prior research (Henkel and Kranz 2018). These studies often build on classical theories of technology acceptance, such as the Technology Acceptance Model (TAM, Davis et al. 1989), or develop new theories to investigate acceptance. Examples refer to e-cars (e.g., Barbarossa et al. 2017; Lai et al. 2015), smart meter technology (e.g., Chen et al. 2017; Girod et al. 2017; Wunderlich et al. 2019), E-Books (e.g., Hsu et al. 2017; Salo et al. 2013), public acceptance of carbon capture and storage technologies (e.g., Yang et al. 2016), electricity storage systems (e.g., Römer et al. 2015), or persuasive technologies such as smartphones or wearables (e.g., Brauer et al. 2016).

Although there is already a plethora of research in this field, IS scholars left some gaps open. One example refers to the field's strong previous focus on individuals' acceptance of Green IS before or during usage (i.e., "in-use" phase). Meanwhile this focus has broadened by also considering "pre-use" (e.g., production, or distribution) and "post-use" (e.g., disposal) phases in IS related contexts (e.g., Coffey and Toland 2019; Ixmeier et al. 2019). One research paper (i.e., P1) included in this doctoral thesis contributed to this broadening in the year 2018 (i.e., Baumbach et al. 2018). Another gap refers to the inconsistency of Green IS acceptance models employed in prior research. Scholars disagree which factors may influence Green IS adoption. While some argue for the inclusion of an environmental sustainability construct in their model (e.g., Gerpott and Paukert 2013; Römer et al. 2015; Yang et al. 2016), others do not (e.g., Brauer et al. 2016; Marett et al. 2013). One research paper (i.e., P2) included in this doctoral thesis addresses this gap by synthesizing previous models and providing a comprehensive model in a particular Green IS context.

A further focus of prior research on the individual level has been on individuals in their role as citizens. Citizens are often requested to decide upon complex issues with a diverse information base, which makes it hard to predict consequences. With the proliferation of technological innovations, and with the opportunities to collect, communicate and compute information, individual decision-making even made this situation more challenging (George et al. 2014; Hilbert and López 2011; van Knippenberg et al. 2015). Considering this, particularly citizens' decision-making on sustainability related issues, such as renewable energy, should be supported. However, although a variety of decision-support approaches in environmental sustainability contexts exists for e.g., city planners and policymakers (e.g., Grêt-Regamey et al. 2017; Tuczek et al. 2019) or customers and product users (e.g., Kalbar et al. 2016; Medeiros et al. 2018; Stryja et al. 2017), little is known of such tools in the citizen context. One research paper (i.e., P3) included in this doctoral thesis addresses this gap by supporting citizens' decision-making in a renewable energy context.

I.2. Studies on the organizational level

Organizations are major contributors in realizing gains in sustainability due to their economic turnover and their potential capacity to bring innovations and improvements (Elliot 2011; Melville 2010; Seidel et al. 2013). Consequently, organizations incorporate major levers when tackling environmental issues (Henkel et al. 2017; Seidel et al. 2018; Watson et al. 2010).

Prior research on the organizational level proposes manifold ways how organizations can contribute to solving sustainability issues. In the following, two exemplary ways are pointed out. First, organizations may use the potential of Green IS to mitigate negative environmental impacts by triggering more sustainable organizational practices and processes (Henkel et al. 2017; Henkel and Kranz 2018; Seidel et al. 2013). A plethora of studies investigated these potentials of Green IS (e.g., Bengtsson and Ågerfalk 2011; Hilpert et al. 2013; Marett et al. 2013; Seidel et al. 2013). Further, instead of improving single practices and processes, organizations may use IS for aligning their core strategy with environmental sustainability objectives (Henkel and Kranz 2018). One exemplary approach to do so is by transforming towards as "business model for sustainability," such as "circular business models" (Abdelkafi and Täuscher 2016; Bocken et al. 2018; Geissdoerfer et al. 2018). Although valued by customers (Hamari et al. 2016), such changes in the business model are associated with fundamental shifts within the organization (Abdelkafi and Täuscher 2016; Oghazi and Mostaghel 2018). Thus, organizations should analyze how to translate environmental benefits into economically relevant competitive advantages (Bocken et al. 2018; Bryson and Lombardi 2009; Lloret 2016). One research paper (i.e., P4) is dedicated to the decision problem of organizations when incorporating sustainability elements in their competitive environment.

Second, organizations may contribute to sustainability issues by developing concrete solutions. According to literature, one suitable solution approach for so called "wicked" problems such as sustainability is "Crowdsourcing" (Introne et al. 2013; Malone et al. 2017). In crowdsourcing endeavors, organizations can take a central role by actively turning to a large and anonymous crowd for input and/or by operating IS-based platforms to link organizations with the crowd (Geiger and Schader 2014; Rhyn and Blohm 2019). One well-known example of using crowdsourcing for sustainability issues is the "Climate CoLab" at the Massachusetts Institute of Technology (Climate CoLab 2020), which uses the wisdom of the crowd to solve issues related to global climate change. When analyzing literature in the crowdsourcing context, there recently have been some calls to action: Particularly prior studies point to the need to relieving some burden from central actors managing crowdsourcing processes via developing IS-based support (Introne et al. 2013; Ito 2018; Yang et al. 2019). This in turn would translate into improved crowdsourcing processes and associated solutions (Rhyn and Blohm 2019; Zhu et al. 2019). One research paper (i.e., P5) included in this doctoral thesis is dedicated to developing such an IS-based tool for improving crowdsourcing processes and instantiates this tool in a sustainability related crowdsourcing endeavor.

I.3. Studies on the societal level

The societal level captures collective activities addressing sustainability issues relevant to local, national, and international societies (Elliot 2011; Henkel and Kranz 2018). Green IS and ICT4D research strands both address the societal level. However, with respect to the former strand, Henkel and Kranz (2018) recently highlighted that Green IS studies on this level are scarce compared to other levels. Particularly, the authors conducted a literature review on pro-environmental behavior in the Green IS context and identified only one study on the societal-level that matched their search criteria (i.e., Watson et al. 2010).

In contrast and as already highlighted above, ICT4D studies primarily focus on the societal-level. Today, ICT4D is a key focus for government and non-government organizations, and of course for IS scholars, who seek to improve the life, health, and well-being of societies (Venkatesh et al. 2019a; Venkatesh et al. 2019b). Thereby, various studies are in settings of developing countries, such as rural India, and evaluate the effects of improved ICT access in the form of shared kiosks on entire villages (e.g., Venkatesh and Sykes 2013). Such kiosks offer different services and information about ongoing epidemics, preventive healthcare, and automation of health data (Srivastava and Shainesh 2015). Further, research on ICT4D investigates the potential of ICT to alleviate poverty (Jha et al. 2016), address corruption (Srivastava et al. 2016), or combat infant mortality (Venkatesh et al. 2016). Although this research strand has a history of about three decades (Heeks 2006; Walsham 2017), Walsham (2017) recently took stock of existing ICT4D research and pointed to topics therein, which still need to be addressed (further). One research paper (i.e., P6) included in this doctoral thesis catches up with one topic of Walsham’s (2017) research agenda on ICT4D.

I.4. Objectives and structure of this doctoral thesis

The main objective of this doctoral thesis is to contribute to the field of IS as well as sustainability. To this end, this doctoral thesis focuses on the two research strands Green IS and ICT4D and thereby addresses research topics on three different levels: The individual, the organizational, and the societal level. Table I.4-1 provides an overview of the pursued objectives and the structure of the doctoral thesis.

I Introduction	
Objective I.4:	Outlining the objectives and the structure of the doctoral thesis
Objective I.5:	Embedding the included research papers in the context of the doctoral thesis and formulating the fundamental research questions
II The individual level (research papers 1–3)	
Objective II.1:	Improving the understanding of individuals' sustainable behavior along the life cycle of IT
Objective II.2:	Providing a comprehensive model for individuals' acceptance of smart energy technology
Objective II.3:	Developing an IS-based tool to support citizens' decision-making on onshore windfarm extensions
III The organizational level (research papers 4–5)	
Objective III.1:	Improving the understanding of market scenarios and conditions under which it pays off to integrate sustainability in the business model
Objective III.2:	Improving the understanding of crowdsourcing processes and the role of an IS-based tool to yield superior solutions for wicked problems
IV The societal level (research paper 6)	
Objective IV.1	Improving the understanding of digital technologies to contribute to sustainable development across countries
V Results and future research	
Objective V.1:	Presenting the key findings of the doctoral thesis
Objective V.2:	Identifying and highlighting areas for future research

Table I.4-1. Objectives and structure of the doctoral thesis

I.5. Research context and research questions

In the following, the research context of Chapters II to IV including research papers P1 to P6 is motivated. The three chapters reflect the three levels on sustainability as stated above: The individual level (Chapter II), the organizational level (Chapter III), and the societal level (Chapter IV).

In Chapter II, research paper P1 investigates factors determining individuals' sustainable behavior alongside the different life cycle stages of IT. Thereby, the study also investigates the impact of a sustainability factor. Research paper P2 examines existing acceptance models in the context of smart energy technology and strives to synthesize them into a single but comprehensive model. From the individual citizen perspective, research paper P3 examines citizens' decision-making on onshore windfarm extensions. In Chapter III, research paper P4 simulates different market scenarios and conditions to analyze when it is favorable for organizations to transform towards a business model for sustainability. Research paper P5 motivates environmental sustainability as a wicked problem that requires a novel approach to be solved, such as crowdsourcing. It investigates the potential of an IS-based tool to improve crowdsourcing processes. Finally, in Chapter IV, research paper P6 depicts a cross-cultural study in which the potentials of digital technologies to substantially contribute to sustainable development across countries are evaluated. Table I.5-1 provides an overview of the six research papers included in this doctoral thesis.

Level	Research papers
I.1 Individual	**Research paper P1:** Individuals' sustainable behavior along the life cycle of IT **Research paper P2:** A comprehensive model for individuals' acceptance of smart energy technology – a meta-analysis **Research paper P3:** Supporting citizens' political decision-making using information visualization
I.2 Organizational	**Research paper P4:** When does it pay off to integrate sustainability in the business model? – A game-theoretic analysis **Research paper P5:** Facilitating like Darwin: Supporting cross-fertilization in crowdsourcing
I.3 Societal	**Research paper P6:** Health is wealth – But what about digital technologies? A comparative mixed-methods study

Table I.5-1: Research papers included in the doctoral thesis

In the following, the research papers included in this doctoral thesis are embedded in the research context, and the research questions are motivated with respect to the above stated objectives.

I.5.1. Chapter II: The individual level

Research paper P1: *"Individuals' sustainable behavior along the life cycle of IT"*

The current global economic model is characterized by linear material and energy flows from resource extraction to disposal. This "cradle-to-grave" system comes along with environmental sustainability issues, since it adds to a scarcity of resources and increasing waste streams (Coffey and Toland 2019; Ixmeier et al. 2019). P1 analyzes if individuals in their role as customers are aware of environmental sustainability issues alongside the life cycle of IT. This life cycle comprises three central stages: 1) "Manufacturing/Buy," 2) "Use," and 3) "Disposal." In each stage, individuals may choose to behave in an environmentally sustainable manner. Exemplary behaviors refer to 1) paying attention where and how IT was produced before purchase, 2) consciously using IT with the objective to contribute to environmental sustainability, or 3) choosing a sustainable disposal option when disposing IT. The study investigates the factors explaining such individual environmentally sustainable behavior in *each* of the three life cycle stages. To this end, it applies the Theory of Planned Behavior (TPB, Ajzen 1985) as a baseline model and extends it through the addition of an environmental sustainability factor. This factor is derived from prior literature, validated using factor analysis, and then added to the baseline model to investigate its role therein. To the best of the authors' knowledge, neither an environmental factor as a comprehensive construct nor its significant impact on individuals' behavioral intention to behave in an environmentally sustainable manner across IT's life cycle have appeared in research prior to this study. In sum, research paper P1 addresses Objective II.1 from Table I.4-1 based on the following research question:

- *What factors influence individuals to behave in an environmentally sustainable manner across the different life cycle stages of information technology?*

Research paper P2: *"A comprehensive model for individuals' acceptance of smart energy technology – a meta-analysis"*

P2 analyzes individuals' use of "smart energy technology," such as smart meters, and the role of different factors determining this use. Smart energy technology enables an increase in energy efficiency and an integration of renewable energy sources, and therefore offers solutions to current environmental problems. Thus, individuals' use of smart energy technology bears great potential to solve energy-related climate problems (Brandt et al. 2018; Chourabi et al. 2012; Marrone and Hammerle 2018). For getting individuals to increase the use of respective technology, it is central to understand factors potentially driving this use

(Bhati et al. 2017; Egbue and Long 2012). However, related studies on the matter disagree upon the factors explaining individuals' use of smart energy technology. Additionally, existing studies highly differ in their research protocols, since they focus on different cultural contexts coined by varying diffusion phases of smart energy technology. Thus, P2 sets out to synthesizing prior research and respective results. The aim is to develop and validate a comprehensive adoption model via meta-analysis. To the best auf the authors' knowledge, this model was the first of its kind at the time of publication. It considers different technology contexts, within different diffusion phases, across Europe, Asia, and North America. In sum, research paper P2 addresses Objective II.2 from Table I.4-1 based on the following research question:

- *What determines individuals' smart energy technology adoption across contexts, countries, and diffusion phases?*

Research paper P3: *"Supporting citizens' political decision-making using information visualization"*

P3 focuses on individual citizens' decisions making. Citizens' decisions and involvement in public and/or political issues can influence government tasks (Callahan 2007; Simonofski et al. 2019). The emphasis on citizen participation is also stressed by the open government movement and the evolvement of smart cities which both underline the importance of citizen participation (Simonofski et al. 2019). In the context of renewable energy, such as windfarms, research highlights the salient role of citizens' opinion (Wolsink 2000; Wolsink 2007). P3 is the first step of an overarching research goal to develop an IS tool that supports citizens' decision-making. It directly confronts citizens with the consequences of their opinion using information visualization. In the research paper the tool is evaluated in the context of renewable energy i.e., onshore windfarm acceptance in Germany. In this regard, many variables may be of interest and important to consider. Examples refer to local pollution, air-quality, health issues, grid development, storage, CO2-emmissoin, or global warming. Given the plethora of relevant variables, including all of them within one research project simultaneously is challenging, especially with respect to answering a clear-cut research question. Acknowledging this challenge and investigating whether the mechanism on which the IS tool is based produces research-relevant results, the focus of the research paper is on "land use by wind power," which is a current topic in Germany in this context (Bauchmüller 2019; Witch 2019). Within this defined context, we develop an IS tool that visualizes the consequences (number and proximity of wind turbines) on the relative amount of renewable energy selected by users in an online survey in Northern- and Southern-Germany. After submitting a decision during the survey when interacting with the IS tool, citizens were confronted with the consequences. In sum, research paper P3 addresses Objective II.3 from Table I.4-1 by stating the following research question:

- *Does an IS tool influence individuals' decision-making in a citizen context?*

I.5.2. Chapter III: The organizational level

Research paper P4: *"When does it pay off to integrate sustainability in the business model? – A Game-Theoretic Analysis"*

P4 analyzes market scenarios and conditions under which it pays off for organizations to integrate sustainability in their business model. Customers are increasingly concerned about environmental sustainability issues, such as climate change, and thus increasingly demand organizations to adapt accordingly (Hamari et al. 2016). Consequently, organizations commonly evaluate strategic approaches to integrate sustainability in their core business model. One approach to do so is called "Business Model for Sustainability" (BMfS), such as circular business models that weigh environmental and social organizational goals equal to economic success (Bocken et al. 2014; Geissdoerfer et al. 2018; Ghisellini et al. 2018). However, switching from a non-sustainable (i.e., "linear") to a BMfS requires fundamental changes in the whole organization and involves all stakeholders. Stated differently, this is a transition of disruptive nature. Thus, fostering the uptake of BMfS requires a comprehensive and detailed ex ante analysis to evaluate, if advantages are about to outweigh potential disadvantages. Thus, P4 uses game theory to study the market conditions and competitive dynamics that should be considered before innovating business models towards BMfS. This approach complements existing research in this field, which has mainly taken a single-actor or "egocentric" perspective of one focal organization (Breuer et al. 2018), rather than following a multi-actor approach. In sum, research paper P4 addresses Objective III.1 from Table I.4-1 by stating the following research question:

- *When does it pay off for organizations to integrate sustainability in their business model?*

Research paper P5: *"Facilitating like Darwin: Supporting cross-fertilization in crowdsourcing"*

P5 examines environmental sustainability as a wicked problem. Wicked problems ask for multifaceted and novel approaches to be solved, such as crowdsourcing approaches entailing crowd intelligence (Introne et al. 2013; Ito 2018; Malone et al. 2017; Yang et al. 2019).

Crowdsourced solutions work well because crowds may exchange knowledge from different domains, a concept known as “cross-fertilization” (Guazzini et al. 2015; Howe 2006; Potter et al. 2010) Thereby, the “facilitator” of a crowdsourcing system is the primary decision maker when it comes to specifying and managing the crowd (Ghezzi et al. 2018; Lopez et al. 2010; Rhyn and Blohm 2019). The facilitator’s role includes actively managing and “nurturing” cross-fertilization. However, in the light of technological advancements and large-scale data, facilitation proves difficult, especially in one particular type of crowdsourcing – crowdsolving. Thus, scholars recently called for relieving some burden of facilitators and started developing tools for supporting or (partly) automating facilitation (Ito 2018; Yang et al. 2019). Yet, the focus of existing tools is not on fostering the innermost core of crowdsolving endeavors – cross-fertilization. By taking a design science perspective, the study proposes design principles and design guidelines for a decision-support tool aiding facilitators to measure and facilitate cross-fertilization. The tool is prototypically tested in a field study where the crowd is requested to solve sustainability related issues. In sum, research paper P5 addresses Objective III.2 from Table I.4-1 by pursuing the following objective:

- *Develop design principles and design guidelines for intelligent decision-making support tools aiding facilitators of crowdsolving for wicked problems in fostering and managing cross-fertilization in their crowds.*

I.5.3. Chapter IV: The societal level

Research paper P6: *“Health is wealth – But what about digital technologies? A comparative mixed-methods study”*

P6 compares the potential of digital technologies to contribute to the United Nations’ sustainable development goal “good health and well-being” across countries. Particularly, it compares the USA as developed and India as developing country. Currently, both countries differ greatly in the degree to which the goal “good health and well-being” has been achieved yet. While a plethora of ICT4D research focuses on the role of particular technologies to contribute to the development in developing countries (e.g., Jha et al. 2016; Smith et al. 2011; Venkatesh et al. 2019a; Venkatesh et al. 2019b), P6 compares the role of defined types of technologies across a developed and a developing country. The study is a mixed-methods research study. As such, it contains a quantitative and qualitative method. This mixed-methods approach yields insights, which cannot be achieved by one of these two approaches alone. These insights refer to significant differences in the adequacy of digital technologies to address health related targets across countries. In accordance with Objective IV.1 from Table I.4-1, research paper P6 addresses the following research questions:

- *Does the potential of digital technologies to contribute to “good health and well-being” differ between developed and developing countries?*
- *If so, what are the contextual conditions moderating results between countries?*
- *Considering these contextual factors, how can digital technologies contribute to “good health and well-being” in a developed or a developing country?*

I.5.4. Chapter V: Results and Future Research

After this introduction, which aims at outlining the objectives and the structure of the doctoral thesis as well as at motivating the research context and formulating the research questions, the research papers are presented in Chapters II to IV. Subsequently, Chapter V presents the key findings and highlights areas for future research.

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II The individual level

II.1. Research paper 1: "Individuals' sustainable behaviour along the life cycle of IT"

Authors:	Sandra Baumbach, Vanessa Graf, Valerie Graf, Melissa Schafranek
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Ranking of outlet:	VHB-JOURQUAL 3: category B

Abstract:

Information Technology (IT) is both, a cause as well as a solution to environmental degradation. This research paper aims to investigate factors influencing individuals' behaviour along the different stages within the life cycle of IT. We differentiate between three stages, namely "Manufacturing / Buy", "Use" and "Disposal" of IT. The research model builds upon the Theory of Planned Behaviour and extends it through the addition of environmental factors. Further, the research model is applied as a multi group model to all three life cycle stages. We conduct two survey-based empirical studies and find that environmental factors significantly influence an individual's intention to show sustainable behaviour across all three life cycle stages of IT.

1. Introduction

Climate change, waste generation, air pollution, and natural disasters are factors contributing to the worldwide change of the environment and leading to its degradation (Bonini and Oppenheim, 2008). Evidence suggests that environmental problems are mostly human-induced. Accordingly, individual actions need to be adjusted to decrease their environmental impact, as the Intergovernmental Panel on Climate Change states: “Environmental degradation due to human activities continues to occur at an increasing rate with annual emissions of carbon dioxide having increased by 70 percent between 1970 and 2004” (IPCC 2007, p. 5).

Information technology (IT) is historically seen as a contributor to environmental deterioration, since it consumes energy resources and produces both, emissions and waste. Nowadays however, IT is also regarded as an enabler of sustainable processes, services, and products, supporting behavioural adjustments of individuals towards sustainability (Melville, 2010; Watson et al., 2010; vom Brocke et al., 2013). Gartner Inc. (2007) supports this notion by outlining that IT is responsible for about two per cent of global greenhouse gases but, at the same time, has the potential to address reducing the remaining 98 per cent.

Considering this ambiguous role of IT, this research paper is situated on the intersection between IT and sustainability research. We investigate the influence of environmental factors (EN) on individuals’ behaviour towards sustainability along the life cycle of IT. Thereby, we focus on the environmental aspect of sustainability, which is an urgent challenge to address (Watson et al., 2010). By building upon the Theory of Planned Behaviour, combining it with a Life Cycle Assessment (LCA), and extending it by EN along three life cycle stages, we postulate the following research question:

What factors influence individuals to behave in an environmentally sustainable manner across the different life cycle stages of information technology?

With the knowledge about individuals’ perceived importance of sustainability within the different life cycle stages, IT’s potential to decrease environmental damages can be further utilized. As our findings show, IT companies can derive managerial implications in terms of sustainability for their product design, manufacturing, and marketing processes.

To address our research question, we build upon a life cycle of IT consisting of three life cycle stages, namely “Manufacturing / Buy”, “Use”, and “Disposal” of IT. The proposed research model integrates LCA since research has shown that this assessment helps to point out important issues from an environmental perspective (Andrae and Andersen, 2010). Thereby, the multi group model allows an in-depth analysis, assessing individuals' sustainable behaviour across different IT life cycle stages. Individuals' sustainable behaviour within the different stages can be described as follows: Within the first stage, individuals pay attention to the way IT is produced. Within the second stage, individuals apply IT to enhance sustainability. The last stage concerns individuals' behaviour when faced with different options of IT disposal.

The research paper unfolds as follows: In Section 2, we introduce the theoretical background this research builds upon. In Section 3, we develop our research model by conducting a structured literature review. In this section, we also develop hypotheses, which we assess in a two-step approach aka "Study 1" and "Study 2" in the following parts. In Section 4, we apply an explorative factor analysis to analyse *EN*, which we add to the theoretical model. This study ("Study 1") results in a supplementary independent variable as well as two moderating factors. In Section 5, we use a structural equation model to validate the proposed research model ("Study 2"). We conclude the research paper with a discussion of the theoretical and managerial implications in Section 6.

2. Theoretical Framework

2.1. Life Cycle of IT

To demonstrate the role of IT in the context of sustainability, we use a framework called Life Cycle Assessment (LCA). LCA is defined as a comprehensive recognition of the environmental performance of small and distinct product systems considering all aspects of natural environment, human health, as well as resources (Andrae and Andersen, 2010; ISO 14040; Menzies et al., 2007). LCA provides a quantitative evaluation of the environmental impact of products over their entire lifetime (Burgess and Brennan, 2001).

Building upon the LCA framework, there are multiple definitions of a "life cycle" within the literature which share varying degrees of similarity. For example: According to Duan et al. (2009) a life cycle consists of the four stages "manufacturing, distribution, use, and end-of-life treatment". Park et al. (2006) use a similar life cycle definition only differing in the first and last stage, calling it "raw material acquisition" and "disposal". Socolof et al. (2005) introduced a life cycle consisting of only three stages, "cradle-to-grave, use, and disposal". In this model, the stage "cradle-to-grave" includes an upstream and manufacturing process. Additionally, ISO 14040 or SETAC developed another variation of the life cycle definition. Azapagic (1999) presents an enlarged life cycle model which includes eight stages, namely "extraction of raw material, manufacturing, transport, use, reuse, maintenance, recycling, and disposal".

For this research paper, we use an abstracted life cycle model for IT, rooted in a consumer context. Thus, we research literature for detailed sub-stages of product life cycles (e.g., Khasreen et al., 2009, Menzies et al., 2007) which we then aggregate to overarching stages. By aggregation, we mean the combination of detailed sub-stages (i.e., Pre-Manufacturing, Production, and Distribution) to a stage, where consumers can play a key role by showing sustainable behavioural intentions in the context of IT. For the purpose of this study, we define behavioural intention as an individual's conscious decision to behave sustainably, therefore to increase or at least consider the state of their natural environment, with-in the different stages of IT's life cycle. As a result, we find three main stages, namely "Manufacturing", "Use", and "Disposal" (Figure 1), in each of which individuals can behave in a sustainable manner. Thereby, we understand "Manufacturing" as a consumer's attention to the production of IT, which can be considered within the IT purchase process. Hence, the stage captures an individual's behavioural intention to buy sustainably manufactured IT. In alignment with the outlined context and definition, we rename the first life cycle stage "Manufacturing" to "Manufacturing / Buy". The second stage concerns an individual's behavioural intention to use IT with the aim of increasing sustainability. An increased sustainability can either be due to adjusting energy-saving settings of IT or to buying "Green-IT". The third stage focuses on the way IT is disposed, the investigated intention is thereby described as the be-havioural intention to dispose IT sustainably.

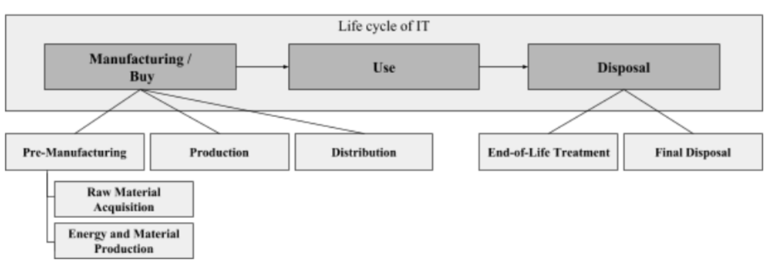


Figure 1. Proposed life cycle of IT

2.2. Theory of Planned Behaviour

To analyse an individual's behaviour regarding IT, we build upon the Theory of Planned Behaviour (TPB). The theory originates from the field of psychology and links an individual's beliefs to an indi-vidual's behaviour. Specifically, TPB proposes that people act or behave in accordance with their inten-tions (Ajzen, 1985; Ajzen and Fishbein, 1980). Figure 2 shows the factors that impact behavioural inten-tion, according to TPB.

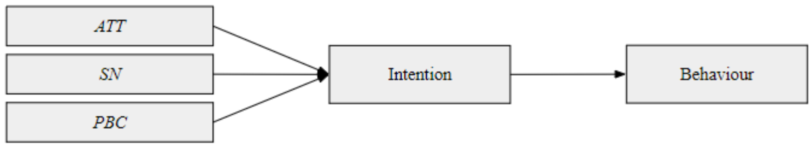


Figure 2. The Theory of Planned Behaviour (Ajzen, 1985)

Note: ATT: Attitude, SN: Subjective Norms, PBC: Perceived Behavioural Control

The factor *Attitude (ATT)* is defined as the degree to which a person evaluates or appraises the behaviour in question favourably or unfavourably. The factor *Subjective Norms (SN)* is defined as the perceived social pressure to behave in a certain manner. Finally, the factor *Perceived Behavioural Control (PBC)* is defined as the individual's perceived ease or difficulty of behaving in accordance with his or her intentions. *PBC* is assumed to reflect past experiences as well as anticipated impediments and obstacles. Accordingly, an individual's intention to behave in a certain way is positively correlated with an individual's *ATT*, *SN* and *PBC* regarding the behaviour in question. Knowing this, we focus on investigating intention within this research study as it is an acknowledged predictor for an individual's future behaviour (Armitage and Conner, 2001).

The original TPB does not only consistently exhibits high explanatory power and predictive validity in terms of the percentage of variance explained (see Godin and Kok, 1996 and Sutton, 1998 for meta-analytic reviews), but has also been applied in manifold application contexts. More specifically, TPB as a research model does not lose explanatory viability when explaining behaviour in both fields of research, sustainability and technology. Previous research has shown, that TPB is applicable to a sustainable IT context. The theory is used to explain sustainability use cases such as recycling (e.g., Boldero, 1995; Cheung et al., 1999; Taylor and Todd, 1995b), and composting (Taylor and Todd, 1995b). Also technology-related issues such as the usage of mobile applications is explained by applying the theory (e.g., Yang, 2003). Moreover, TPB can also be applied to analyse behavioural intentions at the intersection of sustainability and technology related research. As such TPB is employed to explain behaviour regarding energy conservation (Harland et al., 1999), consumer adoption of cleaner vehicles (Lane and Potter, 2007), and smart meters (Guerreiro et al., 2015).

Ajzen (1991) describes the model as open to further extension if additional important proximal determinants are identified and they increase its explanatory power significantly (Conner et al., 1998). Therefore, we aim to add *EN* to the original model to tailor it to the increasingly relevant context of behavioural intentions regarding environmentally sustainable or green behaviour (Chen and Tung, 2014; Ek and Söderholm, 2010; Samuelson, 1990).

3. Development of Research Model

Following Ajzen's (1991) call for further extensions, this research study aims to investigate individuals' perceived importance of environmental sustainability regarding IT. Therefore, we adapt the original TPB model to the sustainability context by combining it with the LCA, resulting in a combined research model. We integrate LCA since research has shown that this assessment helps to point out important issues from an environmental perspective (Andrae and Andersen, 2010). Thereby, our proposed research model allows an in-depth analysis, assessing individuals' sustainable behaviour across different IT life cycle stages. Based on this multi group model, we develop hypotheses before assessing them in the following parts.

3.1. Existing Adaptation of TPB in the Environmental Context

For investigating an individual's intention to exhibit sustainable behaviour within all three life cycle stages of IT, we extend the TPB by EN. With this extension, we follow Tate et al. (2015) definition to specialise the original TPB model. To identify EN, we conduct an exhaustive literature review in scien-tific libraries (e.g., Web of Science) focusing on papers that primarily investigate sustainability as well as technology. The citation search results in 1,135 papers from the sustainability and 1,963 papers from the technological research area.

To ensure the relevance of the results, we apply three selection criteria: First, we include only research studies building upon both research fields, sustainability and technology. Second, specific results are required to provide an environmental extension of the original TPB model. An extension contains the introduction of one or more independent variables or a replacement of a TPB variable. Third, results must contain either an explicit or an implicit definition of the novel factors. The definition could also be in the form of examples or comparably helpful constructs. After eliminating all duplicates, the selection process results in a total number of 19 unique EN from a total of 18 papers.

When looking at the overview of the 19 EN in Appendix B (Supplementary Material A, Table 1), one recognizes that the most often added factors are “Environmental Awareness” (EA), “Environmental Concern” (EC), and “Environmental Knowledge” (EK). However, within the literature, the difference between the factors EA and EC is not clear. Best and Mayerl (2013) state, for example, that EA and EC cannot be differentiated whereas Chan et al. (2015) distinguish both factors and show how they are individually significant. What makes this even more complicated is the fact that there is a panoply of definitions of each factor. Table 1 gives an exemplary overview of this circumstance. Finally, also the way EN is embedded within models differs between multiple authors. Shi et al. (2017) positions EC as pre-factor whereas Tan et al. (2017) uses it as additional direct variable.

Therefore, we conduct an exploratory factor analysis (EFA) with data from 18 papers outlining 19 EN in Section 4 (Study 1). Based on the results of the EFA we decide on the number and composition of the EN that we consider in this paper.

Applied Definition	**Source**
“Environmental Awareness” is the degree to which people are concerned about environmental issues and how easy daily habits can affect the environment.	Wang et al., 2016
“Environmental Awareness” is for example an individual’s concern about the environment, environmental pollution, and about water and pollution.	Engelken et al., 2016
“Environmental Concern” is defined as the degree to which people are aware of problems regarding the environment and support activities aimed to solve them or even engage personally in such activities.	Prete et al., 2017
“Environmental Concern” denotes an individual’s general orientation toward the environment.	Shi et al., 2017

Table 1. Exemplary definitions for “Environmental Awareness” and “Environment Concern”

3.2. Development of Hypotheses

To develop our hypotheses, we build upon existing literature. Thereby, we transfer proven assumptions to our proposed life cycle approach investigating their significances across the three stages. Former re-search indicates that Attitude is a relevant predictor of green and ecological behavioural intentions (e.g., Greaves et al., 2013; López-Mosquera et al., 2014; Olsen et al., 2010; Wang et al., 2014). More specifi-cally, various studies show a positive influence of Attitude on behavioural intention in the context of technology (e.g., Adnan et al., 2017; Corral, 2013; Engelken et al., 2016; Lane and Potter, 2006). Similarly, we expect that Attitude positively influences behavioural intentions regarding sustainable behav-iour in the context of IT. Accordingly, we claim:

> ***H1.*** Attitude *toward sustainable behaviour is positively related to the intention of environmentally sustainable behaviour across the life cycle of IT.*

Ha and Janda (2012), Hori et al. (2013), Petschnig et al. (2014), or Wang et al. (2014), amongst others, show that *Subjective Norms* is strongly linked to sustainable behaviour, as well. Such behavioural intentions, for example, are expressed as energy-saving behaviour, adoption of alternative fuel vehicles, or the purchase of energy-efficient appliances. We expect that *Subjective Norms* positively influences intended sustainable behaviour and develop the following hypothesis:

> ***H2.*** Subjective Norms *is positively related to the intention of environmentally sustainable behaviour across the life cycle of IT.*

Specifically, in the field of green behaviour, *Perceived Behavioural Control* has been studied and confirmed as a significant determinant of behavioural intention (e.g., Albayrak et al., 2013; Chen and Tung, 2014; López-Mosquera et al., 2014). Likewise, we expect that *Perceived Behavioural Control* positively influences sustainable behavioural intentions in the context of IT and develop the following hypothesis:

> ***H3.*** Perceived Behavioural Control *is positively related to the intention of environmentally sustainable behaviour across the life cycle of IT.*

Aung and Arias (2006), Chan et al. (2015), Chen et al. (2016), Peattie (2010), and Rokicka (2002) amongst others, confirm that there is a positive relationship between an environmental factor and sustainable behaviour. For instance, a meta-analysis presented by Chen et al. (2016) indicates that general environmental knowledge and specific knowledge about environmental problems are important indirect determinants (through the activation of responsibility, social norms, and guilt) of pro-environmental intention. For example, Chan et al. (2015) show that consumers with broader environmental knowledge better understand the harm to the environment and are more willing to pay higher prices for environmentally friendly products as compared to less environmentally friendly ones. According to Aung and Arias (2006), "Environmental Knowledge" is a significant factor influencing individual intentions to engage in environmentally friendly behaviours. These findings are consistent with Peattie (2010). Additionally, Rokicka (2002) confirmed the positive influence of "Environmental Knowledge" on consumers' eco-friendly purchase intention.

Studies, by Abrahamse and Steg (2009), Gärling et al. (2003), Stern et al. (1995), Peters et al. (2014), and Wan et al. (2017) show the positive influence of "Environmental Awareness" on behavioural intentions. Wan et al. (2017) indicates that awareness of environmental consequences has a significant influence on individual's recycling intention. This finding is consistent with Stern et al. (1995) and Gärling et al. (2003) who also showed a positive contribution of "Environmental Awareness" to pro-environmental behavioural intentions. Additionally, Peters et al. (2014) confirm that "Environmental Awareness", as the awareness of problems such as climate change or dependence on fossil fuels, exerts an influence on the purchase of a fuel-efficient vehicles. Consistent with Abrahamse and Steg (2009), people believing energy use has negative environmental consequences and feeling personally responsible for these problems have a higher "Environmental Awareness". These people will feel a stronger obligation to help solving environmental problems and are more likely to reduce their energy use.

Lastly, other researchers show the positive relationship between "Environmental Concern" and behavioural intention (Hallin, 1995; Hopper and Nielsen, 1991; Newell et al., 1998; Paladino and Ng, 2013). In their study, Paladino and Ng (2013) provide a literature review supporting that "Environmental Concern" has a positive direct impact on green purchase intentions (Keesling and Kaynama, 2003; Roberts and Bacon, 1997). Additionally, Hopper and Nielsen (1991) confirm that consumers with higher environmental concern are more likely to purchase from socially responsible entities. Consistent with Newell et al. (1998), consumers buy eco-friendly substitutes to express their environmental concern. Moreover, Hallin (1995) concludes that "Environmental Concern" is a reliable factor in predicting an individual's shift toward more environmentally friendly behaviour.

Taken together, we are confident that *environmental factors* are driving environmentally sustainable behaviour and, therefore, develop the following hypothesis:

> ***H4.*** Environmental factors *are positively related to the intention of environmentally sustainable behaviour across the life cycle of IT.*

4. Study 1 – Model Development

The aim of Study 1 is the development of the measurement model for *EN* as a construct. To this end we apply principal axis factoring (PAF) as a form of exploratory factor analysis on literature items. From the resulting items, we develop a questionnaire. Based on the questionnaire's results we validate *EN* in the context of TPB, as explanatory factors for environmentally sustainable behaviour across the life cycle of IT.

4.1. Method

The literature review (see Section 3.1) resulted in 55 items reflecting *EN*. Using content validity assessment we checked if items exhausted their respective domains (Churchill, 1979). Through excluding, renaming, and repositioning procedures the number of items was reduced from 55 to 51[1], as stated in Appendix B (Supplementary Material B, Table 2). To be used in the questionnaire, some of the items' contexts were changed to fit the general context of IT (e.g., items such as "I am concerned about the environment" were adapted to "In the context of technologies, I am concerned about the environment").

From the identified items, measured on a five-point Likert scale anchoring on "strongly disagree" and "strongly agree", we constructed a survey. An independent pre-test with 20 participants was not included in the main survey results (Summers, 2001). Participants were recruited via Amazon Mechanical Turk leading to 302 respondents. With an item to response ratio higher than 1:4 (Hinkin, 1998) and a suggested sample size falling between 100 to 500 (MacKenzie et al., 2011), the sample is sufficiently large for an exploratory factor analysis. There was no evidence of any systematic bias in the survey that could have caused premature abandonment.

4.2. Results

In the PAF, we applied parallel analysis to determine the number of significant factors (Wood et al., 1996; Zwick and Velicer, 1982, 1986). An oblique rotation criterion referenced underlying primary studies where EN factors were correlated. The PAF suggested three factors which accounted for 48% of the total variance in the data.

All items with a major loading lower than the conventionally accepted threshold of 0.7 were eliminated (Urbach and Ahlemann, 2010; Venkatesh et al., 2003). We limit the maximum number of items to four per factor, referencing the TPB model, selecting the items with the highest loadings. Table 2 and Figure 3 show the resulting model consisting of 11 items indicating the 3

[1]All remaining items, although having similar formulations, investigate to some extent different angles of sustainable behaviour. Therefore, we considered the second item and third item (Table 2), since the second item refers to specific issues concerning the environment whereas the third item asks for the individual's general concern about the entire environment.

factors. Table 2 states the loadings, cross-loadings, eigenvalues, percentage of explained and cumulative variance. Appendix B (Supplementary Material B, Table 2) contains further details of all original 51 items.

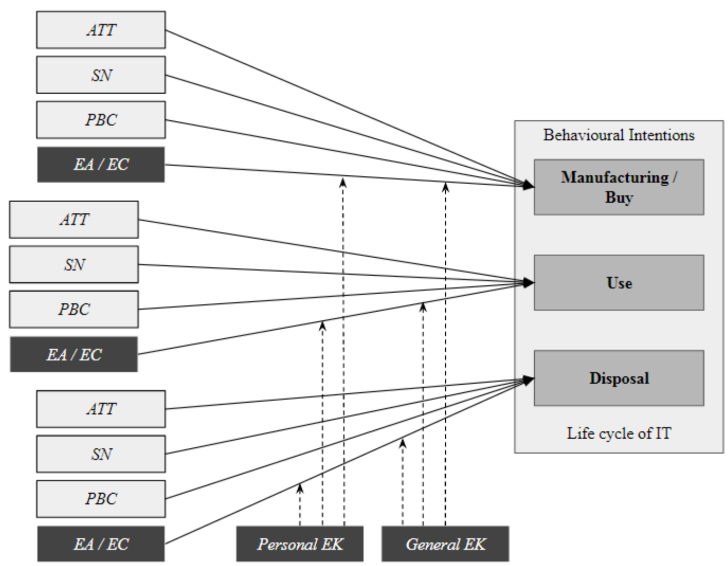
When analysing the main-loadings in Table 2, the resulting factors can be interpreted as follows. The first factor consists of technology-related items originally derived from the factors “Environmental Awareness” (EA) as well as “Environmental Concern” (EC). Due to their similar definitions, we intro-duce a combined factor EA/EC. The second factor builds upon “Environmental Knowledge” (EK) items referring to an individual’s common understanding of environmental related issues (see items 5-8, Table 2). We call this factor General EK. On contrary, Personal EK as a third factor focuses on specifically personal environmental understanding (see items 9-11, Table 2). It is also derived from former EK items.

The two EK factors (General EK, Personal EK) address an individual’s knowledge concerning the envi-ronment and are not limited to understanding the impact of IT. Therefore, we propose both as modera-tors of EA/EC. Both moderators are not adjusted specifically to the IT context.

Items	***EA/EC***	***General EK***	***Personal EK***
When I think of the consequences of IT on the climate, I am very worried.	.92	-.13	-.03
In the context of IT, I am often concerned about environmental issues.	.91	-.11	.03
In the context of IT, I am concerned about the environment.	.89	-.10	.01
When I think about how IT influence our oil supplies, I am very worried.	.89	-.34	.08
Melting of the polar ice caps may result in a flooding of shores and islands.	-.04	.76	.01
Fossil fuels (e.g., gas, oil) produce carbon dioxide (CO2) in the atmosphere when burned.	-.12	.74	.03
I have heard the terms, “sustainable technologies”, “renewable energy”, “green power” or “green electricity” before today.	-.17	.76	.03
A reduced number of species may interrupt the food chain, affecting one subsequent species in the food chain.	-.19	.85	-.02
I know much about sustainability (e.g., energy-saving) tips of daily life.	.04	-.04	.84
I know sustainable methods (e.g., for energy-saving) well.	-.04	.06	.73
I know the meaning of the labels affixed on the sustainable technologies (e.g., energy-efficient devices).	-.06	.04	.71
Eigenvalues	14.81	6.60	3.30
Variance explained	.29	.13	.06
Cumulative variance	.29	.42	.48

Table 2. Loadings and cross-loadings in exploratory factor analysis

The model resulting from the PAF is conceptualised as a multi group model referencing the respective stages of IT’s life cycle. Hence, the resulting model is tested for each life cycle stage as illustrated in Figure 3.



Notes:
ATT: Attitude, SN: Subjective Norms, PBC: Perceived Behavioural Control, EA/EC: Environmental Awareness/Concern, EK: Environmental Knowledge.
Dashed lines illustrate moderating factors.
As a multi group model, the model is applied to every stage within IT's life cycle.

Figure 3. Research model derived from exploratory factor analysis

5. Study 2 – Model Validation

5.1. Method

The original TPB model was measured as proposed by Taylor and Todd (1995a). The variables *EA/EC*, *General EK* and *Personal EK* were measured with new items derived from Table 2. The dependent variable *Behavioural Intention* was measured with three items, also derived from Taylor and Todd (1995a). All items, except the moderating factors (*General EK* and *Personal EK*), refer to the specific life cycle stage. Appendix A (Tables 5 and 6) states items used in the first stage of our three life cycle stages (i.e., "Manufacturing / Buy"). Appendix B (Supplementary Material C, Table 3) lists the items for the other two life cycle stages (i.e., "Use" and "Disposal").

In order to collect data, we developed a questionnaire. The pre-data collection procedure and item measurement were equal to the respective parts of Study 1. The participants answered the questions in the context of the three different stages of the IT life cycle. The order of the stages was randomized to decrease possible bias.

There were 313 respondents. Based on a marker question, fifteen of them did not answer the survey conscientiously and were therefore excluded from our analysis. Hence, the final sample consists of 298 valid responses. The sample size is sufficiently large for the application SEM (Barclay et al., 1995; Cohen, 1992; Hair et al., 2013).

5.2. Results

Building upon Venkatesh et al. (2003, 2012), we applied PLS-SEM by using the software SmartPLS (Ringle et al., 2015). To address common method variance, we used a priori remedies and post hoc detection methods. A priori remedies guarantee anonymity during the data collection process, assuring participants that there are no true or false answers, asking participants for honest answers, and careful wording and scaling the developed items (Podsakoff et al., 2003). For post hoc detection methods, we applied the correlational marker technique (Lindell and Whitney, 2001) and the CFA marker technique (Richardson et al., 2009). For the correlational marker technique, we chose the smallest and second-smallest positive correlation between variables as a post hoc selected marker. For the CFA marker technique, one theoretically irrelevant marker question concerned with medical treatment was subject to the survey. Both assessments indicate the absence of common method variance in our sample.

To address multicollinearity, we examined the correlation table of latent constructs. Table 3 shows the correlation matrix for the second stage, “Use”, within IT’s life cycle. Data for both other stages are to be found within Appendix B (Supplementary Material D, Table 4 and Table 5). Based on the correlations, no significant correlations between *EA/EC* and other latent constructs were found. To further test for multicollinearity, the variance inflation factor values of the latent constructs were inspected. We found them to be around 2.37 with a maximum of 4.47 and, thus, for all independent variables below the critical threshold of 5, suggesting that multicollinearity was not present in the surveyed sample (Gefen et al., 2000). Additionally, the internal consistency reliabilities (ICRs) of the multi-item scales are 0.70 or higher (Gefen et al., 2000) for all factors within all stages of the IT life cycle. Since the AVE values are above 0.50 and higher than the square of the correlations, convergent and discriminant validity are supported (Fornell and Larcker, 1981; Urbach and Ahlemann, 2010). Finally, the Cronbach’s Alpha values are higher than 0.8 for all factors which indicate an excellent level of internal consistency within all three stages.

	"Use"									
	ICR	**Mean**	**SD**	**ATT**	**SN**	**PBC**	**EA/ EC**	**Personal EK**	***General EK***	***Intention***
ATT	.909	.200	.064	.715						
SN	.946	.067	.196	.508	.897					
PBC	.875	.281	.067	.484	.402	.699				
EA/EC	.939	.219	.102	.037	.228	-.012	.795			
Personal EK	NA	.008	.090	.156	.126	.060	.067	NA		
General EK	NA	-.090	.106	-.192	-.170	-.047	-.050	-.164	NA	
Intention	.945	-	-	.475	.497	.469	.303	.211	-.231	.852

Notes:
ATT: Attitude, SN: Subjective Norms, PBC: Perceived Behavioural Control, EA/EC: Environmental Awareness/Concern, EK: Environmental Knowledge.
ICR: Internal Consistency Reliability; SD: Standard Deviation.
Diagonal elements represent AVEs and off diagonal elements correlations.

Table 3. Descriptive statistics – correlations and AVEs – in the IT life cycle stage "Use"

The analysis of significant path coefficients is based on their respective p-values. Results are shown in Table 4. Hereby, "D only" indicates that no interaction terms were included in the model, whereas "D+I" describes the model with interaction terms included. The indices R^2 and Adjusted R^2 indicate the model fit in every life cycle stage.

	"Manufacturing / Buy"		**"Use"**		**"Disposal"**	
	D only	**D + I**	**D only**	**D + I**	**D only**	**D + I**
ATT	.083	.059	.221***	.192**	.297***	.290***
SN	-.180	-.219	.216	.189	-.360	-.336
PBC	.482***	.438***	.278***	.290***	.187**	.192**
EA/EC	.121*	.136**	.249*	.243*	.223***	.222***
EA/EC x Personal EK		-.063		.094		.046
EA/EC x General EK		-.222		-.112		-.046
R^2	.414	.506	.419	.473	.506	.550
Adjusted R^2	.406	.493	.411	.459	.499	.537

Notes:
ATT: Attitude, SN: Subjective Norms, PBC: Perceived Behavioural Control, EA/EC: Environmental Awareness/Concern, EK: Environmental Knowledge.
** $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$*

Table 4. Results of the structural model

The support of the hypotheses varies across the different stages of the life cycle of IT: Within the first stage, "Manufacturing / Buy", H3 and H4 were supported. *PBC* and *EA/EC* significantly and positively impact an individual's intention to buy environmentally sustainably manufactured IT. H1 and H2 are not supported. In total, the research model explains 50.6% of the variance in the intention to buy sustainably manufactured IT. In the second stage of IT's life cycle, "Use", H1, H3, and H4 were supported. Hence, *ATT*, *PBC*, and *EA/EC* influence the intention to use IT in an environmentally sustainable way. Only hypothesis H2 is not supported. Overall, the research model explained 47.3% of the variance within this stage. Similarly, H1, H3 and H4 are supported within the last stage, "Disposal". However, the significance levels slightly differed for *ATT*, *PBC*, and *EA/EC*. Again, only hypothesis H2 is not supported. In total, 55.0% of all variance regarding the intention to dispose IT in a sustainable way is explained by the proposed research model. Overall, results show that *EA/EC* as well as *PBC* are significant across every life cycle stage, whereas *SN* has no significant influence on an individual's intention to behave in an environmentally sustainable manner.

6. Contribution

6.1. Discussion

This research paper is located at the intersection of sustainability and IT research. By adding *environmental factors* to the TPB model and evaluating the new research model along all stages of the life cycle of IT, we adapt the scope of existent TPB application areas.

With Study 1, we apply an explorative factor analysis of environmental factors derived from existing literature, combining both areas of research, sustainability and IT. With the results of the EFA, we show that *Environmental Awareness* and *Environmental Concern* should be combined into one independent variable which we name *Environmental Awareness/Concern*. Moreover, we show that two additional environmental factors, *Personal Environmental Knowledge* and *General Environmental Knowledge*, serve as moderating variables of *Environmental Awareness/Concern*. Together with the original independent TPB variables (*Attitude*, *Subjective Norms*, and *Perceived Behavioural Control*), we derive our research model.

In Study 2, we analyse the structural relationships between the three adapted independent TPB variables combined with our additional variable *Environmental Awareness/Concern*. Further, we include the two moderators to elicit their combined impact on individuals' intentions to behave sustainably within the three life cycles stages, "Manufacturing / Buy", "Use", and "Disposal" of IT. We thereby show the significant, positive influence of *Environmental Awareness/Concern* and *Perceived Behavioural Control* within every life cycle stage (H3 and H4). The significant influence of *Environmental Awareness/Concern* could indicate growing awareness and concern about environmental issues within society. IT could receive more focus as it can be seen as both, a cause as well as a possible solution to many environmental problems. It is conceivable, that an increased level of IT adoption leads to more experience with energy-efficient IT. This may be the basis for explaining *PBC's* significant impact in the model. The difficulty to behave more sustainable along the life cycle of IT decreases, with environmentally friendly technologies becoming ubiquitous. *Attitude* shows a positive relationship toward sustainable behaviour in the context of IT across two out of three life cycle stages (H1). *Attitude* does not significantly influence intention to behave in an environmentally sustainable manner the first stage "Manufacturing / Buy". This lack of significance can possibly be explained by individuals' lacking insights and understanding of sustainable production processes of IT. Arguably, the Manufacturing / Buy stage is the most unintuitive one for an everyday user. Therefore, individuals do either not develop an Attitude toward buying sustainably produced IT or at least it is not important enough to them. Interestingly, *Subjective Norms* never showed a significant influence on sustainable behaviour in the context of IT (H2). A possible explanation could be that the perceived social pressure in the context of buying, using, and disposing IT is rather limited in a sustainability context.

Considering the potential explanations, more research is required to understand the relationship between independent variables and sustainable behavioural intentions along the life cycle of IT.

6.2. Theoretical and Managerial Implications

6.2.1. Theoretical Implications

This paper offers two major theoretical contributions. First, the underlying work contributes theoretically by providing an overview of existing extension factors of the TPB model within a sustainability and technology context. More specifically, our research paper adapts the TPB by environmental influence factors regarding the life cycle IT. Based on 18 studies which already added parts of *environmental factors* before, we conducted an exploratory factor analysis showing that *environmental factors* consist out of two moderating factors, *Personal Environmental Knowledge* and *General Environmental Knowledge*, as well as one additional independent variable, *Environmental Awareness/Concern*. We therefore provide a novel measurement model for *environmental factors*, which we showed was significant for sustainable behaviour in the context of IT. Second, our research paper extends the TPB model by applying it to three life cycle stages of IT. To the best of the authors' knowledge, this research paper is the first one combining LCA and the TPB model and therefore provides further insights into people's intention to behave in an environmentally sustainable manner in the context of IT's life cycle stages. Thereby we show that *Perceived Behavioural Control* and *Environmental Awareness/Concern* significantly impact individuals' intentions to behave sustainably along the entire life cycle of IT. Our research paper reveals that the significance of influencing factors varies across the three life cycle stages of IT.

6.2.2. Managerial Implications

Our empirical findings on sustainability generate two managerial implications. First, Study 2 shows the significant influence of the environmental factors on sustainable behaviour within all three stages of IT's life cycle. This has three implications: First, we find that individuals prefer to buy IT which is sustainably produced. Therefore, IT producers should focus on both, a sustainable manufacturing process and sufficient marketing campaigns that ensure its publicity. Second, by finding individuals' intentions to adopt environmentally sustainable behaviour with the help of IT, products, for example by design, should facilitate this desire. Third, we find that individuals pay attention to the disposal of IT. Therefore, IT should be designed to offer people a simple and convenient way of sustainable recycling. In total, these findings imply that people are finally aware of their responsibility regarding environmental issues within all stages of IT's life cycle. As a second implication, this research paper contributes by increasing the awareness of *Attitude* as an influencing factor along the life cycle stages. With revealing its significances in the stages "Use" and "Disposal", professionals should aim at convincing individuals to increase their sustainability within these two stages. Hence, marketing strategies designed to influence individuals to develop a favourable evaluation of using IT to increase their sustainability as well as disposing IT in a sustainable way should be implemented.

6.3. Limitations and Further Research

Our research study is not without limitations. The first limitation concerns the generalizability of our empirical results. Availability of technology between respondent groups is necessary to assure comparable results. Our research was conducted in the U.S., an industrialized country. Accordingly, IT is widely available. Results may differ compared to countries exhibiting different economic conditions. Additionally, the age of the participants in our sample is not representative of the population as a whole with a mean age of 28 in Study 1 and 29 in Study 2. Therefore, the findings may not apply to a significantly older group of people. Future research can build upon this paper by testing our research model in different geographical areas and cultures, employing a sample with different demographic attributes. Second, the purposes of the surveys were openly introduced in the introduction for Studies 1 and 2. Therefore, sustainable behaviour was described and openly named. Our results may be influenced by this description, and a social desirability bias may have influenced the results. However, we included a control question as well as a marker question to identify and exclude participants who did not answer the survey conscientiously. The third limitation addresses the underlying theory our research model builds upon. We used the origin TPB as a framework which we adapted to a sustainable context, since it has been proven mature and well-suited for research questions at the intersection of sustainability and IT. However, we note that Ajzen and Fishbein have continued updating the origin TPB model (Reasoned Action Approach; Ajzen and Fishbein, 2010). Further research could build upon this updated research model, examining whether this new model adds explanatory power to answer our research question. The last limitation pertains the scope of our research model in two ways: Firstly, for this research study we focused on *environmental factors* as additional independent variable to adapt the TPB. A yet to be answered research question would be to examine a research model not limited to *environmental factors*, but embracing all additional factors introduced within sustainability and technological research and analyse their different significances across the life cycle of IT. Secondly, within this study we focused on investigating the influence on individuals' intention along IT's life cycle as a dependent variable. Future research could apply the research model within different contexts to further broaden the area of application. Additionally, another yet to be answered question relates to the level of detail within the life cycle of IT. Since our study aims to identify the differences of the individuals' perceived importance of sustainability, we use an aggregated, three-staged life cycle of IT to present the major consumers' touchpoints to IT. Building upon our results, further research could use this life cycle approach to investigate differences between the stages of a more detailed life cycle. Figure 1 illustrates an example of a more detailed life cycle referring to Khasreen et al. (2009), Menzies et al. (2007), and Azapagic (1999) amongst others.

7. Conclusion

To the best of our knowledge, up to now, neither *environmental factors* as a comprehensive construct nor their significant impact on individuals' behavioural intentions to behave in an environmentally sustainable manner across IT's life cycle have appeared in prior research. We show that *environmental factors* can be modelled as *Environmental Awareness/Concern* as a direct variable. This variable is moderated by *General Environmental Knowledge* and *Personal Environmental Knowledge*. Furthermore, by analysing the individuals' behavioural intentions to be more sustainable along IT's life cycle, we show that *Environmental Awareness/Concern* has a significantly positive impact within every stage across the life cycle of IT. Overall, we are confident that the results of this research paper open the door to further research opportunities on the intersection of IT and sustainability with broad potential among its manifold facets.

8. Appendix A

Items of Study 2 (SEM)

	Items within the Stage "Manufacturing / Buy"	**Authors**
ATT	Buying sustainably manufactured IT is a good idea.	Taylor and Todd, 1995
	Buying sustainably manufactured IT is a wise idea.	
	I like the idea of buying sustainably manufactured IT.	
	Buying sustainably manufactured IT would be pleasant.	
SN	People who influence my behaviour would think that I should buy sustainably manufactured IT.	
	People who are important to me would think that I should buy sustainably manufactured IT.	
PBC	I would be able to buy sustainably manufactured IT.	
	Buying sustainably manufactured IT is entirely within my control.	
	I have the resources and the knowledge and the ability to buy sustainably manufactured IT.	
Intention	I intend to buy sustainably manufactured IT this year.	
	I intend to buy sustainably manufactured IT within my daily life.	
	I intend to buy sustainably manufactured IT frequently.	
EA/EC	When I think about the manufacturing of IT, I am often concerned about environmental issues.	Wang et al., 2016
	When I think about the manufacturing of IT, I am concerned about the environment.	Engelken et al., 2016
	When I think of the consequences of the manufacturing of IT on the climate, I am very worried.	Peters et al., 2014
	When I think about how IT manufactures deal with our oil supplies, I am very worried.	
Notes: ATT: Attitude, SN: Subjective Norms, PBC: Perceived Behavioural Control, EA/EC: Environmental Awareness/Concern, EK: Environmental Knowledge.		

Items for independent variables included in SEM (Study 2), stage "Manufacturing/Buy"

	Items	Authors
Personal EK	I know the meaning of the labels affixed on the sustainable IT (e.g., energy-efficient devices).	Wang et al., 2014
	I know sustainable methods (e.g., for energy-saving) well.	
	I know much about sustainability (e.g., energy-saving) tips of daily life.	
General EK	Melting of the polar ice caps may result in a flooding of shores and islands.	Tan et al., 2017
	Fossil fuels (e.g., gas, oil) produce carbon dioxide (CO2) in the atmosphere when burned.	
	A reduced number of species may interrupt the food chain, affecting one subsequent species in the good chain.	
	I have heard the terms “sustainable IT”, “renewable energy”, “green power” or “green electricity” before today.	Chan et al., 2015
Note: *EK: Environmental Knowledge.*		

Items for Moderating Factors included in SEM (Study 2)

9. Appendix B

For the Supplementary Material, such as the full list of the extended *EN* with their definition in literature (A), an overview about all items used for EFA (Study 1, B), the results of all EFA items (Study 1, C), and the correlations within the stages “Use” and “Disposal” (D), please see https://www.dropbox.com/s/g0ls681pmsxu1y0/Supplementary%20Material.pdf?dl=0

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II.2. Research paper 2: “A comprehensive model for individuals’ acceptance of smart energy technology: A meta-analysis”

Authors:	Henner Gimpel, Vanessa Graf, Valerie Graf-Drasch
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Keywords:	Meta-analysis; Smart energy technology; Smart grid; Smart energy-saving systems; Technology adoption; Smart city.
Ranking of outlet:	VHB-JOURQUAL 3: category B

Abstract:

Individuals’ use of smart energy technology – i.e., technology that increases energy efficiency or increases the integration of renewable energy sources – holds great potential to solve the energy-related climate problem. However, individuals’ current uptake of smart energy technology is low. If policymakers are to successfully address this issue, it is vital that they understand the determinants of individuals’ smart energy technology adoption. Hence, this paper provides a comprehensive adoption model for smart energy technology, including data from over 4k individuals in Europe, Asia, and North America involved in various technological contexts and phases of diffusion. A meta-analysis identifies Attitude and Performance Expectancy as the primary determinants of individuals’ smart energy technology adoption. Further, results show that Environmental Concern influences all other determinants. Implications for research and policymakers are discussed.

1. Introduction

Today, half of the global human population lives in cities (Sengupta, 2019). By 2050, the proportion of city-dwellers will have increased to two-thirds (United Nations Department of Economic and Social Affairs, 2018). 75% of global energy consumption currently takes place in cities, which also produce around 80% of greenhouse gas emissions. Approximately 8.6% of these emissions are produced by residential buildings and commercial and public services (Harjanne and Kohrhonnen, 2019; Hollands, 2015; The World Bank Group, 2014a, 2014b). All of this evidence suggests that urbanization is driving climate change, one of the most pressing challenges in today's world (Plumer and Popovic, 2018). Yet it is only recently that we have begun to feel the impact of climate change, in the form of wildfires in California of 2018 and crop failures in the US Midwest (Plumer and Popovic, 2018). The stark reality of the situation leaves policymakers i.e., individuals responsible for or involved in formulating policies, eagerly seeking a solution which will mitigate this downside of urbanization (Agarwal et al., 2016; Harjanne and Kohrhonnen, 2019). One promising development is the emergent concept of smart cities. By providing smart energy technology – i.e., technology that increases energy efficiency or increases the integration of renewable energy sources – smart cities aim to improve the management of energy as a natural resource (Brandt et al., 2018; Chourabi et al., 2012; Marrone and Hammerle, 2018). However, for smart energy technology to reach its potential, and, hence, for the smart city solution to work, it needs to be used by individuals (Nam and Pardo, 2011). Given that individuals' acceptance of smart energy technology is crucial in order for the smart city to solve the energy-related climate problem, the current low uptake of smart energy technology on an individual level is worrying (Nam and Pardo, 2011): Even while people often talk about environmental awareness, most are content to continue with their current energy supply method and are somewhat reluctant to accept smart energy technology (Bhati et al., 2017; Egbue and Long, 2012).

Policymakers have several political measures at hand, which would allow them to address the adoption of smart energy technology. In order to select the appropriate measure, an understanding of the key drivers of acceptance is crucial. However, existing literature on the topic does not include a comprehensive set of determinants of individuals' smart energy technology adoption. Rather, each contribution to the literature (e.g., Chen et al., 2017; Gerpott and Paukert, 2013; Girod et al., 2017; Koo et al., 2015; Koo et al., 2013; Wunderlich et al., 2013; Wunderlich et al., 2012) focuses on one technological context, one country, and/or a particular diffusion phase. To address this research gap, our research sets out to answer the following research question:

What determines individuals' smart energy technology adoption across contexts, countries, and diffusion phases?

To this end, we apply a three-step meta-analytical structural equation modelling procedure which involves (1) identifying related previous research and establishing a comprehensive research model, (2) pooling primary data for further analysis, and (3) testing the comprehensive model using the pooled data.

The remainder of this article is structured as follows: The next section provides a brief overview of theoretical approaches to smart cities and smart energy technology adoption. We then pursue meta-analytical structural equation modelling via the three steps outlined below, before presenting the respective results. We discuss our contributions to the literature on smart energy technology adoption and derive policy implications. Lastly, we offer a conclusion at the end of the article.

2. Theoretical background

2.1. Smart cities and smart energy technology

The idea of smart cities dates back to the early 1990s (Hosseini et al., 2018; Marrone and Hammerle, 2018). At this time, Silicon Valley was already home to leading technology companies. In order to establish the area as a strong competitor in the world economy, advanced information systems (IS) were put in place. The local communities, including governments, businesses, and residents, leveraged the IS to transform life and work in significantly positive, livable ways (Lindskog, 2004). Hence, the first smart city (i.e., 'smart valley') emerged (Kavanaugh-Brown, 1995; Lindskog, 2004). Beyond Silicon Valley, smart cities have since developed on a national, international, and global level. And as smart cities themselves have evolved, so have definitions of the term 'smart cities'. Today, a wide array of definitions exists including, e.g., the often-cited definition provided by Giffinger et al. (2007).

Acknowledging fossil fuel consumption as root cause of climate change, this study focuses on the role that IS can play in reducing greenhouse gas emissions (Watson et al., 2010). Hence, we define smart cities, in the context of energy informatics, as icons of sustainable and livable cities, which facilitate technology and serve at least one of two common systems goals of energy informatics of

1) increasing energy efficiency and 2) increasing the integration of renewable energy sources (Goebel et al., 2014; Watson et al., 2010). Further, we name technology serving either one of the two common system goals ‘smart energy technology’. Depending on the goal served, Goebel et al. (2014) define two common themes of energy informatics research:

To increase energy efficiency, smart energy-saving systems are used. By enabling individuals to better measure, control, and understand energy consumption, and react accordingly, and by aligning service output with actual end-user requirements, the overall energy consumption is reduced. One concrete example of a smart energy-saving system, which we will focus on in this study, is an intelligent thermostat. Equipped with sensors, the device measures the location of household inhabitants or tracks their geo-location status via a smartphone application. Based on this information, intelligent thermostats optimize the heating and cooling of homes, e.g., by switching off heating systems when no one is at home.

To integrate renewable resources into a power system, smart grids are built (Goebel et al., 2014; Strüker and Kerschbaum, 2012). Smart grids are electricity grids enhanced with load-controlling, demand-side management technology such as smart meters, an example which we will focus on in this study (Goebel et al., 2014; Wunderlich et al., 2012). Smart meters are electronic devices comprised of a digital electronic meter and a two-way communication gateway between electricity producers and consumers. They collect, store, analyze, and transmit accurate and detailed real-time information about energy prices, consumption, and production in a grid, which enables a shift in the electricity load from times of low supply to times of high supply (Chen et al., 2017; Gerpott and Paukert, 2013; Wunderlich et al., 2012).

Please refer to Table 1 for a summary of definitions of the outlined constructs and their relations. Technology, such as smart energy technology, has been described as important (Caragliu et al., 2011), as central to the idea of the smart city (Nam and Pardo, 2011), and as one of the main economic driving forces of a city (Hollands, 2008). However, it can only reach its potential if it is in use (Nam and Pardo, 2011). This means that for the smart city solution to work, individuals need to adopt smart energy technology (Nam and Pardo, 2011; Wunderlich et al., 2012). From the perspective that individuals’ adoption of smart energy technology is crucial in order for the smart city to contribute to the resolution of the energy-related climate problem, the next section gives an overview of policy measures available to encourage the adoption of such technology.

2.2. Policy measures for smart energy technology adoption

In general, policymakers have a panoply of measures at hand, which allow them to foster the adoption of smart energy technology. Since, however, the number of direct political measures is restricted (Girod et al., 2017), in the following, we outline some indirect policy measures implemented to increase the adoption of smart energy technology in Europe, Asia, and North America.[2]

One example how policymakers may support the adoption of smart energy technology, refers to the establishment of programs that foster the development of smart cities, which use smart energy technology as a central building block. Specifically, policymakers can implement programs to connect international organizations, companies, and governments in order to generate and realize smart and sustainable city projects. These programs come along with capacity-building opportunities, financial access, interdisciplinary practical knowledge, and technological approaches for smart city solutions. On a global level, one example of such a program is the platform United Smart Cities (USC), initiated and operated by the United Nations (UN) with its 193 member states. Similarly, a European Union (EU) example is the European Innovation Partnership on Smart Cities and Communities (EIP-SCC), the umbrella project of smart city policy. Similar to the European example, the Asian program, the Asian Smart Cities Network (ASCN), is a collaborative platform initiated by the ten member states of the Association of South East Asian Nations (ASEAN). A U.S. counterpart is the Smart Cities Initiative, which was announced by the administration in 2015 to encourage investments and pursue collaborations, promoting smart cities as engines of growth and innovation (The White House - Office of the Press Secretary, 2015).

Another example how policymakers may support smart energy technology adoption includes the formulation of energy targets to be reached using smart energy technology. A recent and well-known example setting a clear course in this regard is the Paris Agreement of 2015 (United Nations Climate Change, 2018). Specifically, the Paris Agreement involves a commitment to limit global

[2] The focus on Europe, Asia, and North America results from prior studies dedicated to smart energy technology research which form the data base of this article (also see Table 2 below). Other geographical areas such as, e.g., South America, Africa, and Australia have not been included in any of our primary studies and have therefore not been focused on when discussing the policy implications of our results. We address this issue in our limitations and suggest the topic as a subject for future research.

temperatures increases to less than 2 degrees Celsius above pre-industrial levels by the end of this century. To achieve this goal, nations made legally binding agreements to reduce their greenhouse gas emissions and adapt to the effects of climate change. Such efforts are known as ‘climate actions’ or ‘Nationally Determined Contributions’ (NDCs) (European Commission, 2017; United Nations Climate Change, 2018).

In line with the Paris Agreement, the EU has pledged to reduce greenhouse gas emissions by at least 40% by 2030, compared with levels in 1990. To deliver this commitment, NDCs have been formulated as directives, one of these being the Energy Efficiency Directive of 2012 (Directive 2012/27/EU) and its updates in 2016 and 2018 (European Commission, 2018b). The targets contained in the directive include complying with the Paris pledge, and further goals such as achieving a minimum 32% share of renewable energy, and a 32.5% improvement in energy efficiency (European Commission, 2018a, 2018c, 2011). The directive also determines measures to meet these targets, such as the roll-out of approximately 200 million smart meters to empower energy consumers to better manage their consumption (European Commission, 2018a, 2018b, 2016).

In Asia, the member states of the ASEAN have also agreed to deliver NDCs, although these differ in their scope. For example, Indonesia – a rapidly industrializing nation and the largest economy within the ASEAN – has pledged to reduce greenhouse gas emissions by 29% before 2030, compared with current levels (The ASEAN Post, 2019). In contrast, Singapore – as one of the most industrialized countries in the ASEAN – has pledged to reduce greenhouse gas emissions by 36% before 2030, compared with 2005 levels (Bhati et al., 2017; The ASEAN Post, 2019). In order to make-good on this commitment, Singapore’s government continues to pursue various schemes, policies, and incentives, such as the use of public transport, for example (Bhati et al., 2017).

The U.S. – also originally part of the Paris Agreement –initially agreed to cut greenhouse gas emissions by 26-28% below 2005 levels by 2025 (United Nations Climate Change, 2015). In June 2017, however, the U.S. government announced its withdrawal from the agreement (The White House, 2017) – a decision which, in line with legal notice periods, will become effective in the year 2020 (United Nations Climate Change, 2017).

2.3. Related literature on smart energy technology adoption

In order to select the most appropriate measure of all indirect policy measures available, policymakers need to know the key determinants of smart energy technology adoption. Hence, in the following, we give an overview of literature on the determinants of individuals' adoption of smart energy technology. Hereby, the work of Girod et al. (2017) provides some initial guidance. Aiming to explain the acceptance of novel green consumer technology, of which smart energy technology is a subfield (Kozlovskiy et al., 2016), the authors comprehensively review and analyze relevant literature. Results include the identification of two different approaches to research explaining individuals' acceptance of novel green consumer technology: One of these approaches is based on objective, economic variables (i.e., 'economic models'). The other is based on subjective beliefs (i.e., 'belief-based models'). While economic models have been widely applied in prior research, belief-based models have recently received increasing scholarly attention. A thorough comparison of the two approaches brings the authors to the conclusion that belief-based models now dominate in the context of research into green consumer technology (Girod et al., 2017). Hence, belief-based models are in the focus of our research, too.

Belief-based models have their origins in psychology and sociology: The well-known 'Theory of Reasoned Action' (TRA) (Fishbein and Ajzen, 1975) and 'Theory of Planned Behavior' (TPB) (Ajzen, 1991) originally aimed to explain behavior in relation to beliefs about what one should do, and the consequences of actions (Girod et al., 2017). Eventually, these models were applied to the IS domain in attempts to explain the acceptance of technologies. Other well-known models also emerged, such as the 'Technology Acceptance Model' (TAM) (Davis, 1989), the 'Unified Theory of Acceptance and Use of Technology' (UTAUT) (Venkatesh et al., 2003), and its successor (UTAUT2) (Venkatesh et al., 2012). Belief-based models, as depicted in Figure 1, use 'intention to adopt' as the dependent variable, and two kinds of beliefs i.e., 'technology-specific' and 'personality-specific' as independent variables. Thereby, Girod et al. (2017) suggest that belief-based models include two effects, namely (1) the effect of beliefs on individuals' intention to adopt and (2) the effect of personality-specific beliefs on technology-specific beliefs (illustrated by the numbers 1 and 2 in Figure 1).

'Technology-specific beliefs' are not necessarily linked to one particular technology; rather they convey a more general notion. The literature reports various beliefs about technology. For example, in the past, *Perceived Usefulness* – i.e., the degree to which a person believes that using a particular technology will enhance his or her performance (Venkatesh 2003) – was considered a key determinant of the continued use of smart power meter devices (Koo et al., 2015; Koo et al., 2013). In addition, Wunderlich et al. (2013) outline *External Regulations* or *Coercive Pressure from Influential Others* as technology-specific beliefs significant for smart meter adoption. Gerpott and Paukert (2013) investigate the significance of *Perceived Benefits* in determining the willingness to pay for smart meters. More recently, Chen et al. (2017) found the two technology-beliefs *Perceived Usefulness* and *Risk to Privacy* to be key determinants.

'Personality-specific beliefs' describe how people perceive themselves, and give balance to what is otherwise a technology-focused perspective (Girod et al., 2017). The literature includes various personality-specific beliefs. For example, Girod et al. (2017) pinpoint *Environmental Norms* – i.e., the moral obligation to act – and *Personal Innovativeness* – i.e., the individual's willingness to try out any technologies (Agarwal and Prasad, 1998; Girod et al., 2017) – as personality-specific beliefs that are particularly important in the context of novel green technology adoption. Similarly, Gerpott and Paukert (2013) highlight *Environmental Awareness* – i.e., a consumer's attitude towards environmental protection in general – as a belief that influences the individual's willingness to pay for smart meters.

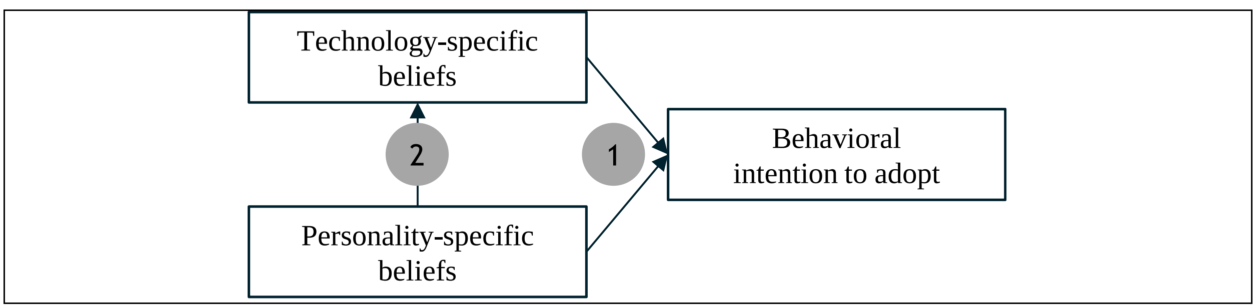

Figure 1. Belief-based model measuring (1) the effect of beliefs on individuals' behavioral intention to adopt and (2) the effect of personality-specific beliefs on technology-specific beliefs

Even though belief-based models have been described as most appropriate for explaining individuals' adoption of green energy technologies, their application sometimes is flawed (Girod et al., 2017). Specifically, belief-based models have been developed using only an isolated selection of beliefs, which results in an 'omitted variable bias' and a misleading focus on beliefs of minor importance. Hence, the literature still fails to determine a comprehensive set of key beliefs which consistently influence the adoption of smart energy technology in different contexts, countries, or diffusion phases. Yet, given the ongoing trend toward urbanization and the effect this has on climate change, it seems vital to address the current research gap. Therefore, this study sets out to establish a comprehensive research model, including a full set of beliefs that have been suggested as relevant by previous research. In line with the findings and reasoning of Girod et al. (2017), we use the belief-based adoption model as a theoretical framework. This will guide the model-building process in subsequent sections.

3. Method

We apply meta-analytic structural equation modeling (MASEM) in order to develop a comprehensive model for individuals' adoption of smart energy technology. MASEM is an established and frequently used method within IS (Alavi and Joachimsthaler, 1992; Dennis et al., 2001; Wu and Lederer, 2009; Zhang et al., 2018) and environmental research (Bamberg and Möser, 2007; Hines et al., 1987; Kloeckner, 2013; Osbaldiston and Schott, 2012). The method includes three steps: (Step 1) the identification of primary studies and establishment of a research model; (Step 2) the collection of correlation coefficients between variables of primary studies, which are pooled into a combined correlation matrix for further analysis; (Step 3) the testing of a structural equation model based on the pooled correlation matrix. Each of these three steps is outlined in detail below.

3.1. (Step 1) The identification of primary studies & establishment of a research model

In order to identify primary studies for inclusion in our meta-analysis, we collect 8,144 scientific works from the two bibliographic online databases 'Web of Science' and 'AIS electronic Library' (AISeL). On the Web of Science platform, we located 6,125 scientific works by entering relevant search terms related to the fields of IS and sustainability. For IS, we entered the keywords 'sustainability', 'sustainable', 'environmental', 'green', 'smart meter', 'smart grid', and 'smart energy-saving systems' in the IS-related Web of Science categories of, i.e., 'computer science information systems', 'computer science interdisciplinary', 'computer science cybernetics', 'computer science artificial intelligence', 'software engineering', 'computer science theory methods', 'computer science hardware', and 'management'. For sustainability, we searched the keywords 'technology AND acceptance' in the sustainability-related Web of Science categories of, i.e., 'environmental studies', 'environmental sciences', 'engineering environmental', 'energy fuels', 'green sustainable science technology', and 'ecology'. Similarly, on July 4 of 2018 we located 1,964 scientific works on the AISeL platform by searching for the keywords 'sustainability', 'sustainable', 'environmental', 'green', 'smart meter', 'smart grid', or 'smart energy-saving systems' in the title, abstract, or subject of scientific works.

In order to identify relevant primary studies in a literature that comprises 8,144 scientific works, two researchers manually and independently searched for literature which met the following criteria:

1) Empirical assessment of a model of smart energy technology acceptance
2) Reporting of definitions and items representing the variables employed
3) Inclusion of correlation coefficients of variables or values which can be converted to correlation coefficients (i.e., discriminant validity values such as squared correlations)

3.1.1. Results

Generally speaking, meta-analyses can include as few as two, or as many as several hundred, primary studies (Card, 2012). The final sample for this research comprises seven primary studies, which are listed alphabetically in Table 1. In total, these seven primary studies provide data relating to 4,003 individuals from countries across Europe, Asia, and North America. The technology context and samples size (*n*) of each primary study as well as the proportional (%) representation of each primary study in the total samples size (*N*=4,003) is also stated in Table 1.

ID	**Study**	**Sample origin**	**Technology context**	**Sample size (*n*)**	**% of total sample size (*N* = 4,003)**
1	Chen et al. (2017)	U.S.	Smart meter technology	711	18%
2	Gerpott and Paukert (2013)	Germany	Smart meter technology	450	11%
3	Girod et al. (2017)	Germany	Intelligent Thermostats	486	12%
4	Koo et al. (2013)[3]	South Korea	Smart meter technology	104	3%
5	Wunderlich et al. (2012)	Germany	Smart meter technology	933	23%
6	Wunderlich et al. (2013) (User sample)	Germany	Smart meter technology	644	16%
7	Wunderlich et al. (2013) (Non-user sample)	Germany	Smart meter technology	675	17%
Total sample size (*N*) (i.e., sum of primary studies' *n*)				4,003	100%

Table 1. Primary studies as input for meta-analysis

[3] Please note that we also identified Koo et al. (2015) as a relevant primary study. However, this scientific work is a follow-up paper by the authors, containing an acceptance model and correlation coefficients identical to those which feature in Koo et al. (2013).

Each primary study includes a correlation table stating the correlation coefficients of variables (see Appendix A for detailed table references in primary studies). Further, the seven primary studies include a total of 43 variables. However, we note that some primary studies include the same variables more than once by employing different measures. Specifically, this means that we are dealing with what Wilson et al. (2016) have termed a ‘complex dataset’, a dataset with more than one measure for a primary variable within studies and multiple measures of a primary variable across studies. Wilson et al. (2016) further explain that whether different operationalizations represent the same variable in a meta-analysis depends on the literature at hand, the nature of the questions addressed by the meta-analysis, and the meta-analysts’ assessment of which operationalizations represent the same underlying variable (Wilson et al., 2016). In order to identify equal variables in the context of our study, two researchers once again manually and independently screened the name, definition, and items of each primary variable (Appendix B). This process reduced the 43 primary variables to one dependent variable, which represents individuals’ behavioral intentions to adopt smart energy technology (i.e., intelligent thermostats and smart meters), and nine independent variables, eight of which relate to technology-specific beliefs, and one of which relates to a personality-specific belief. Table 3 summarizes the process by presenting the nine independent variables and a respective, exemplary definition derived from the literature. Additionally, Table 3 also categorizes each variable as either a technology- or personality-specific belief, as proposed by Girod et al. (2017). Finally, all primary studies employing the respective variables are listed in Table 3.

Variable	Definition	Source	Technology- or personality-specific belief	Employed in primary study with ID…						
				1	**2**	**3**	**4**	**5**	**6**	**7**
Anxiety	Evoking anxious or emotional reactions when it comes to performing a behavior (e.g., using a technology).	Social Cognitive Theory, Bandura (1986)	Technology-specific	✓				✓		
Attitude	An individuals' positive or negative feelings (evaluative effect) about performing the target behavior (i.e., using a technology).	TRA, Fishbein and Ajzen (1975)	Technology-specific			✓	✓	✓	✓	✓
Effort Expectancy	The degree of ease associated with the use of the technology.	UTAUT, Venkatesh et al. (2003)	Technology-specific			✓		✓		
Facilitating Conditions	The degree to which an individual believes that infrastructure exists to support use of the technology.	UTAUT, Venkatesh et al. (2003)	Technology-specific	✓	✓	✓		✓	✓	✓
Habit	Individual routines, among them routines leading to technology utilization.	UTAUT2, Venkatesh et al. (2012)	Technology-specific	✓		✓				
Performance Expectancy	The degree to which an individual believes that using a technology will help them to improve their performance.	UTAUT, Venkatesh et al. (2003)	Technology-specific	✓	✓	✓	✓	✓		
Price Value	Individuals' evaluation of the tradeoff between the perceived benefits of the technology and the monetary cost of using it.	UTAUT2, Venkatesh et al. (2012)	Technology-specific	✓		✓				
Social Influence	The degree to which an individual perceives that important others believe he or she should use a technology.	UTAUT, Venkatesh et al. (2003)	Technology-specific			✓	✓	✓	✓	✓
Environ-mental Concern	The belief that one should act in ways that support or benefit the environment.	Girod et al. (2017).	Personality-specific	✓	✓	✓	✓			

Table 2. Description of independent variables

Based on the information contained in Figure 2, we propose a comprehensive, belief-based research model for smart energy technology adoption, which we present in Figure 2. As suggested by Girod et al. (2017), our model includes two effects, namely (1) the effect of beliefs on individuals' behavioral intention to adopt smart energy technology and (2) the effect of personality-specific beliefs on technology-specific beliefs (illustrated by the numbers 1 and 2 in Figure 2).

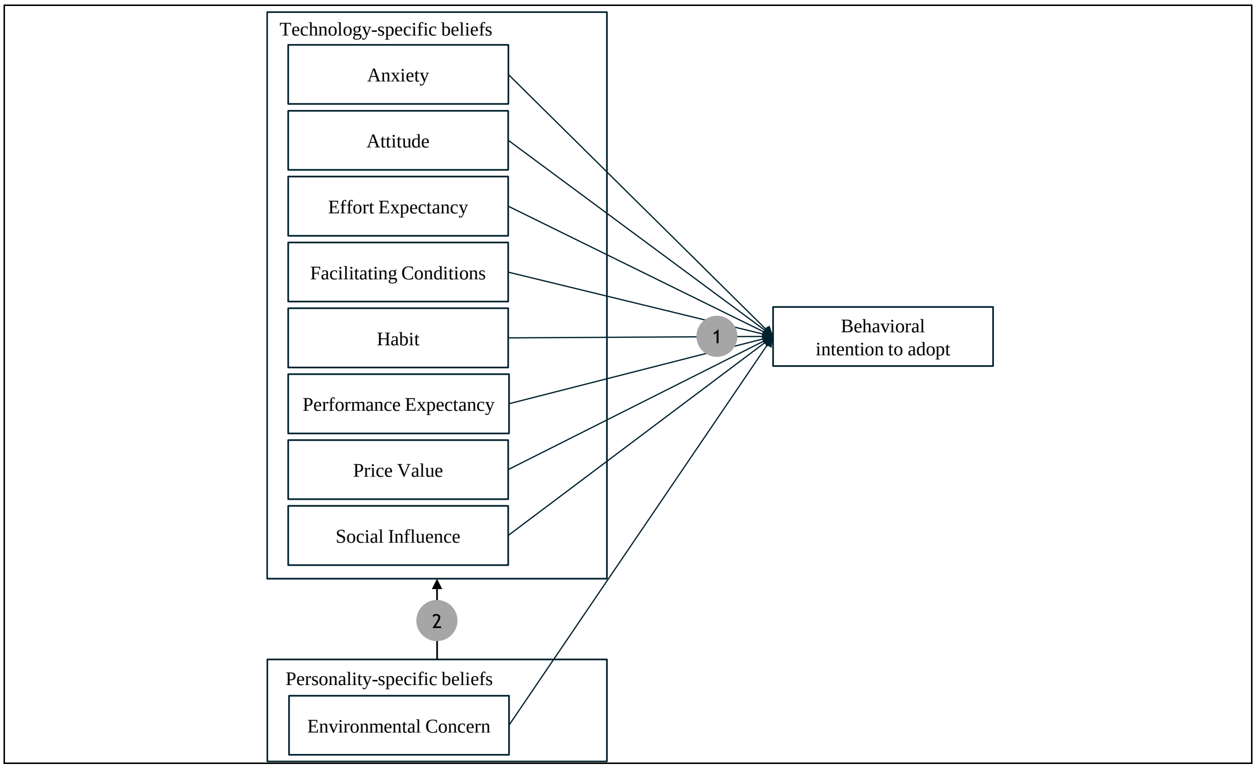

Figure 2. Belief-based research model consisting of variables from the identified primary studies

3.2. (Step 2) Collecting and pooling correlations

Applying MASEM also involves collecting and analyzing the correlation coefficients (r or ρ) from the primary studies. Specifically, correlation coefficients are synthesized into a single pooled correlation matrix. In the case of our study, the 10x10 pooled correlation matrix includes the 9 independent and 1 dependent variables. To present a concrete example, Girod et al. (2017) and Chen et al. (2017) report the raw correlation coefficients of 0.63 and 0.74 between the variables '*Performance Expectancy*' and '*Behavioral intention to adopt*'. Both raw correlation coefficients address the same cell in the pooled correlation matrix. In order to synthesize the raw correlation coefficients (and further raw correlation coefficients in this cell), we applied a 'three-level, multivariate, mixed-effect, weighted meta-regression model' (see Equation (1)). The measurement characteristics of this particular type of regression model (i.e., different operationalizations of constructs between studies, or more than one measure of constructs within studies) account for the sort of complexities described above in Section 3.1 (Wilson et al., 2016).

In Equation (1), the dependent variable r_{ik} represents the observed correlation coefficients i = 1 to 177 from study k = 1 to 7. Each cell in the pooled correlation matrix is represented by a unique independent dummy variable ($Cell_{1ik}, \ldots, Cell_{45ik}$), which takes a value of 1 if coefficient i from study k is assigned to that cell, and a value of 0 otherwise. This serves to assign each effect-size stated in the primary correlation matrices to its 'correct position' in the pooled correlation matrix.

$$r_{ik} = \beta_1 Cell_{1ik} + \beta_2 Cell_{2ik} + \ldots + \beta_{55} Cell_{45ik} + \nu_{0k} + \eta_{ik} + \varepsilon_{ik} \qquad \text{(Equation1)}$$

The use of a no-intercept model allows the respective regression coefficients to be interpreted as pooled correlation coefficients. Furthermore, there are Level 2 random effects capturing random effects of all cells in the pooled correlation matrix, and Level 3 random effects capturing random effects of all correlation coefficients in the pooled correlation matrix. Thereby, the variable η_{ik} refers to Level 2 random effects, and is assumed to be normally distributed with a mean of zero and variance τ ($\tau > 0$). Variable ν_{0k} represents Level 3 random effects for the studies and is also assumed to be normally distributed with a mean of zero and variance ω ($\omega > 0$). The estimation error ε_{ik} for correlation coefficient *i* is also assumed to be normally distributed with a mean of zero and variance of ν_{ik}. The conditional sampling covariance between observed correlations from the same study is approximated by the unconditional Level 2 random effects. It is assumed that the errors at different levels are uncorrelated (Wilson et al., 2016).

To perform our analyses, we use the statistical environment R. As suggested by Wilson et al. (2016), we used the R package 'metafor' (Viechtbauer, 2010) to fit the three-level model, obtain the weighted mean correlation estimates for each cell, and produce the asymptotic covariance matrix. To use sample size weighting with 'metafor', we input the inverse of the sample size in place of variance estimates (see Wilson et al., 2016, p. 8).

3.2.1. Results

The result of the analyses described above is a pooled correlation matrix shown in Table 4. To ensure that there is not too much missing data on the correlation coefficients, we checked whether the matrices were positive definite, which was indeed the case for all matrices (Cheung, 2015, p. 267).

	Anxiety	Attitude	Effort Expectancy	Facilitating Conditions	Habit	Performance Expectancy	Price Value	Social Influence	Environ-mental Concern	Behavioral Intention
Anxiety	1									
Attitude	-.344 ***	1								
Effort Expectancy	-.279 *	.326 ***	1							
Facilitating Conditions	-.250 **	.190 ***	.407 ***	1						
Habit	-.031	.275 *	.065	.145 *	1					
Performance Expectancy	-.430 ***	.408 ***	.375 ***	.263 ***	.067	1				
Price Value	-.271 *	.265 *	.215	.186 *	.110	.237 *	1			
Social Influence	-.329 **	.377 ***	.132	.148 *	.325 **	.280 ***	.285 *	1		
Environ-mental Concern	-.151	.227 *	.125	.143 *	.082	.222 ***	.097	.194 *	1	
Behavioral Intention	-.373 ***	.627 ***	.371 ***	.215 ***	.175 *	.490 ***	.237 **	.395 ***	.266 ***	1

Significance: ***p<0.001, **p<0.01, *p<0.05;

Table 3. Pooled correlation matrix

'Correlation coefficients' are a statistical measure representing the degree of linear association between two measured variables. As Table 4 above states, correlations among the 10 constructs range from -0.430 to 0.627, and the mean correlation of constructs was 0.144. Established thresholds deem absolute correlations ≤ 0.35 to be low or weak, correlations between 0.36 – 0.67 to be modest, and correlations between 0.68 – 1.00 to be strong or high (Taylor, 1990). In terms of the relationship between technology- and personality-specific beliefs and individuals' behavioral intention to adopt smart energy technology, all variables indicate significant correlations.

The variable *Environmental Concern* as only personality-specific belief has positive and negative as well as significant and insignificant relationships to technology-specific beliefs. With regard to the direction, positive relationships indicate that an increase in the first variable would correspond to an increase in the second variable, whereas a negative relationship indicates an inverse relationship. With regard to significance, a statistically significant correlation is not necessarily an important one. Rather, a significant correlation indicates that the higher the absolute value of the correlation coefficient, the stronger the relationship.

In line with this reasoning, the correlation coefficients of the two technology-specific beliefs *Attitude*, and *Performance Expectancy* have the highest modest correlations, accounting for 0.627 and 0.490. As both correlation coefficients only measure an association and do not give a precise interpretation, a further procedure is required in order to define a cause-and-effect relationship between all the variables. Hence, in the next step we investigate the data using structural equation modeling to test the two effects of our belief-based model, which are (1) the effect of beliefs on individual's intention to adopt and (2) the effect of personality-specific beliefs on technology-specific beliefs.

3.3. (Step 3) Structural equation modeling

Based on the pooled correlation matrix (see Table 4 above) resulting from Step 2, we use structural equation modeling for testing our proposed research model. We once again use the statistical environment R and apply the metaSEM package to fit the research model to the data (Cheung, 2015).

3.3.1. Results

Figure 3 shows the estimated model with its regression coefficients for (1) the effect of beliefs on individual's intention to adopt smart energy technology. We find the model to be just identified. Specifically, this means that the chi-square statistic on the model is always 0 and the goodness of fit indices are irrelevant (Cheung, 2015, p. 264). An open Mx status of 0 indicates that the estimations are appropriate (Cheung, 2015, p. 247). This result from our meta-analysis indicates that the proposed model has a robust structure that is able to reproduce a pooled correlation matrix sufficiently well. The model accounts for 49.8 percent of the variation.

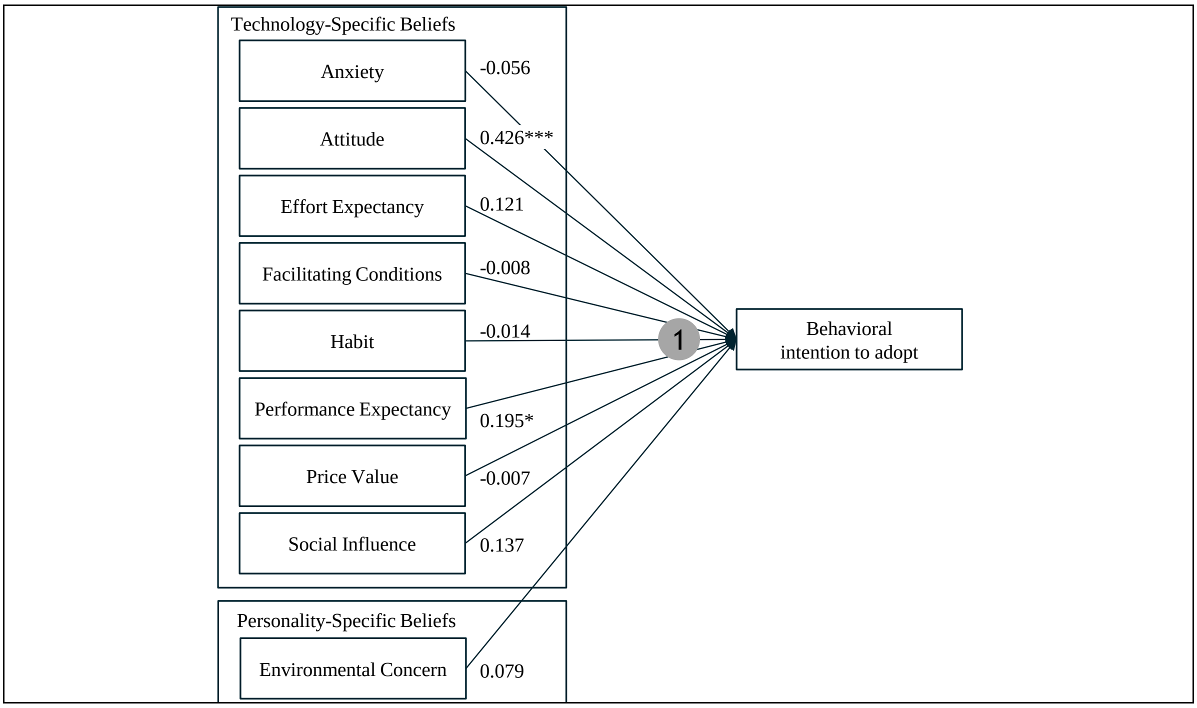

Figure 3. The effect-sizes and significances of (1) the effect of beliefs on individuals' behavioral intention to adopt

Below, we state the results of Step 3 for each determinant, which we then compare to the results obtained by Girod et al. (2017). This is because, Girod et al. (2017) also apply a comprehensive, belief-based model in order to investigate the main determinants of individuals' adoption of intelligent thermostats. We find the following results to be in line with those of Girod et al. (2017):

Attitude is the strongest determinant of individuals' intentions to adopt smart energy technology on the 0.001 level. *Attitude* refers to an individual's feelings about performing a target behavior, i.e., adopting smart energy technology. However, when investigating this determinant more closely, it becomes clear that *Attitude* relates to the enjoyment and pleasure individuals gain from the use of smart energy technology (Venkatesh et al., 2003). Hence, this finding is in line with Girod et al. (2017), who conclude that *Hedonic Motivation*, and, therefore, the 'fun factor', is the most important determinant. Moreover, this finding is consistent with the findings of primary studies included in this work (e.g., Koo et al., 2013; Wunderlich et al., 2013; Wunderlich et al., 2012), and with classical theories of technology acceptance (e.g., Ajzen, 1991; Fishbein and Ajzen, 1975; Venkatesh et al., 2012).

Besides *Attitude*, *Performance Expectancy* appears to strongly determine individuals' intentions to adopt smart energy technology, being significant on a 0.05 level. This is in line with , Girod et al. (2017), who find *Perceived Usefulness* – which, according to Venkatesh et al. (2003), is an underlying construct of *Performance Expectancy* and therefore included therein – to be an important determinant. Moreover, this finding is consistent with the findings of primary studies included in this work (e.g., Chen et al., 2017; Koo et al., 2013; Wunderlich et al., 2012) and with classical theories of technology acceptance (e.g., Venkatesh et al., 2012; Venkatesh et al., 2003).

Girod et al. (2017) find that *Price Value* becomes insignificant as soon as a theoretically grounded belief-based model is applied. Hence, this construct is deemed irrelevant and less important than other beliefs included in the model. Our findings confirm this, as the coefficient *Price Value* featured in our model (-0.007) resembles the coefficient *Price Value* featured in the model by Girod et al. (2017) (-0.008). The authors also classify *Social Influence* and *Ease of Use* as less important variables in their model. We can also confirm these findings, since both *Social Influence* and *Effort Expectancy* – of which *Ease of Use* is an underlying construct (Venkatesh et al., 2003) – appear to be insignificant.

Lastly, we find *Environmental Concern* to be of no significant explanatory value. This observation mirrors one made by Girod et al. (2017), who found that the personal belief *Environmental Norms* was further from adoption than were the technical beliefs. These findings are comparable since *Environmental Concern* is an antecedent of environmental norms, which refers to the willingness to act in ways that are positive for the environmentally (Stern, 2000).

To a greater extent, our research supports the findings presented by Girod et al. (2017) confirming that beliefs have a direct effect on behavioral intention. However, we cannot confirm the significance of compatibility concerns i.e., *Habit* and *Facilitating Conditions* for behavioral intention. Both variables relate to the individual's familiarity with a technology, and are among the most important determinants in the model proposed by Girod et al. (2017). In our model, however, neither appear to be significant determinants of intention or action, to the extent that we observe a negative relationship.

In addition to testing the influence of determinants on the dependent variable of smart energy technology adoption, we evaluated the influence of *Environmental Concern* on the technology beliefs included in the model. Figure 4 states the results of our investigation of (2) the effect of personality-specific beliefs on technology-specific beliefs.

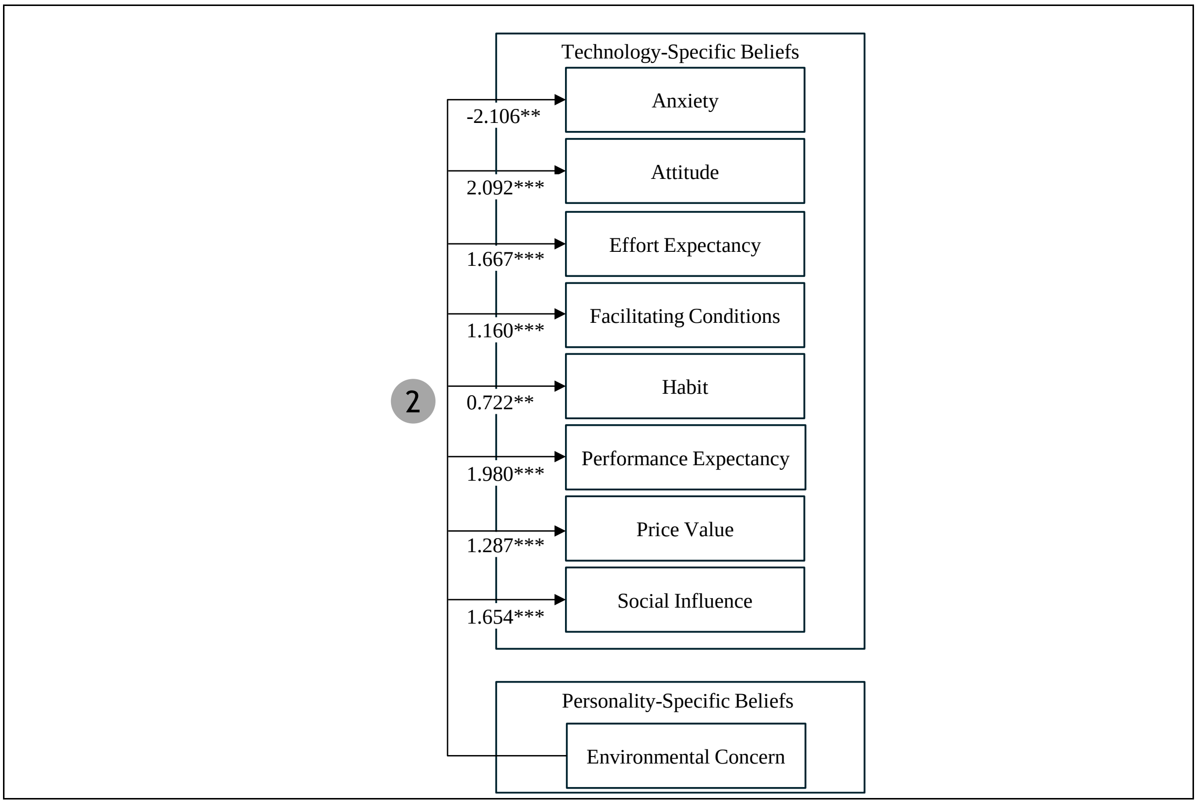

Figure 4. *The effect-sizes and significances of (2) the effect of personality-specific beliefs on technology-specific beliefs*

As Figure 4 suggests, *Environmental Concern* has a largely positive influence on the intention to adopt via previously tested technology-beliefs. Hence, beliefs about technology characteristics are not independent from other beliefs, i.e., *Environmental Concern*. Rather, we find that technology characteristics are influenced by personality-related beliefs, as follows: The coefficients of *Attitude* (2.092***) and *Performance Expectancy* (1.980***) indicate that environmentally concerned individuals particularly enjoy using smart energy technology, as they feel that the technology is extremely useful. Moreover, results indicate that environmentally concerned individuals feel that energy efficient technology has a high price value (*Price Value*) and is easy to use (*Effort Expectancy*). They also feel supported when it comes to their use (*Facilitating Conditions*) and experience social pressure to adopt such technologies (*Social Influence*). All of this is in line with Girod et al. (2017).

However, we cannot replicate Girod et al.'s (2017) finding that people with high environmental concern are less accustomed to using technologies. While their finding may seem counterintuitive, it is supported by earlier work from fellow researchers. For example, Poortinga et al. (2003) found that people who express above-average levels of environmental concern are relatively less willing to adopt measures which enable higher energy saving, and vice versa for people who express low levels of environmental concern. In our case, however, results suggest that environmentally concerned people are willing to adopt smart energy technology. The evidence supporting this finding is that the use of new energy saving technologies is not reported to evoke any anxious or emotional reactions (*Anxiety*) in environmentally concerned people.

There are many possible explanations for our results contradicting the findings of prior studies. It may relate, for example, to the type of technology being evaluated, the measures used, or to the size of our sample. Firstly, the type of technology under evaluation may generate specific results, which, in particular, may explain levels of variation. The model suggested in our paper applies to smart energy technology, including smart energy-saving systems and smart meters, whereas the model developed by Girod et al. (2017) applies only to intelligent thermostats. However, previous studies on the adoption of green technologies such as heating systems have found that belief-based variables indicate higher explanatory power. Secondly, differences in the level of influence had by certain beliefs about technology – i.e., *Habit* and *Facilitating Conditions* – could relate to the different measures of assessment used and their respective objectivity. Thirdly, the difference could also stem from variations in the sample, not only in terms of size, but also in terms of, for example, respondents' cultural background, the timing of the inquiry, and geographical influences. Girod et al. (2017) present a sample consisting of n=1101 participants from Germany. In contrast, our model is based on a sample of 4,003 individuals from different countries, including U.S. and South Korea. This sample includes data from the years 2012 to 2017.

4. Discussion

Individuals' acceptance of smart energy technology is crucial if smart cities are to offer a solution to energy related climate change. However, the reality is that the uptake of smart energy technology so far has remained slow (Bhati et al., 2017). If policymakers are to address this issue and formulate an effective response, a deeper understanding of the key determinants of acceptance is needed. This paper sets out to investigate the determinants of individuals' smart energy technology adoption across contexts, countries, and diffusion phases. In this section, we state the main steps of this undertaking and our respective findings, before discussing the political implications.

Firstly, in order to identify a key set of determinants, we conducted a comprehensive literature review, analyzing over 8,144 scientific studies. In the course of this literature review, we searched for contributions in the field of IS and in the field of sustainability. This interdisciplinary approach enabled us to identify seven relevant primary studies, which draw on data from over 4k individuals in countries across Europe, Asia, and North America. The data spans a range of different contexts in which of smart energy-saving systems and smart meter technology has been adopted, and accounts for multiple phases of diffusion from 2012 to 2017. Reviewing the finding of the seven primary studies from a political perspective, we concluded that: Five out of the seven primary studies investigate individuals' adoption of smart energy technology in a European context, in particular in Germany. One study focuses on North America – in particular, the U.S. – and one focuses on Asia – in particular, South Korea. Further, the Asian study only accounts for 3% in the meta-analytic sample and, thus, may be considered as underrepresented. However, we were unable to detect further Asian studies; neither focusing on China, the leading nation in terms of politically-induced smart meter installations, nor focusing on any other Asian countries characterized by strong political aspirations to increase smart energy technology acceptance (International Energy Agency, 2019). Additionally, we could not find any further studies focusing on the U.S., which is also represented by only one study, but accounts for 18% in the meta-analytic sample. The small number of North American and Asian studies in our sample suggests the need for future research addressing the adoption of smart energy technology in these regions. This observation echoes that of Chang et al. (2016) who draw a similar conclusion concerning Asia following their investigation of renewable energy policies implemented in 16 East Asian Summit countries. Recent political initiatives such as, e.g., the U.S.-ASEAN Smart City Partnership, which was announced in the course of the 6th U.S.-ASEAN Summit in November 2018, may spur efforts in this regard (The White House, 2018).

Secondly, having selected the primary studies, we developed a comprehensive model including all primary belief-based variables. In this aspect, our research is different from the majority of existing studies, which only include select beliefs, leading to 'omitted variable bias' (see Girod et al., 2017). Once built, we applied MASEM to test and validate our model. Results indicate that the structure of the model is robust, and that it is able to reproduce a pooled correlation matrix sufficiently well. This is as a strong indication of the validity of our model. Further, the model explains 49.8% of the variance in behavioral intention to adopt a smart energy technology, which we interpret as indication of the suitability of belief-based models for explaining smart energy technology adoption. Hence, from a political point of view, it is belief-based determinants that should be targeted in the context of smart energy technology adoption, rather than objective economic determinants. In order to influence belief-based determinants, policymakers have direct and indirect strategies at their disposal (Girod et al., 2017). However, the appropriate course of action and therefore the applicability of direct or indirect measures will depend on the specific nature of the beliefs that influence smart energy technology adoption i.e., the specific relevant belief-based determinants.

Thirdly, we analyzed the influence that concrete beliefs have on the adoption of smart energy technology (effect 1). We found that the technology-specific beliefs *Attitude* and *Performance Expectancy* have a significant influence on the individual adoption of smart energy technology. These findings replicate the findings of previous studies and traditional theories of technology acceptance. Furthermore, our findings hold true for different geographical areas within Asia and Europe, different technologies such as smart energy-saving systems and smart meters, and different diffusion phases from 2012 to 2017. Our findings can be used in political contexts to formulate and apply effective strategies to increase the uptake of smart energy technology. However, the extant literature suggests that political efforts have little effect on *Attitude* and *Performance Expectancy* (Girod et al., 2017). Rather, indirect political actions are more likely to be effective, for instance, if firms are offered incentives to become active. An exception is state-owned energy providers, such as KEPCO (Korean Electric Power Corporation) in South Korea. In this specific case, the government may be able to apply direct policy measures.

Fourthly, our research also improves the understanding of the influence that personality-related beliefs have on technology-specific beliefs (effect 2) in a range of different technological contexts. Specifically, we tested the influence of *Environmental Concern*, an antecedent of environmental awareness, on the technology-specific beliefs included in our model. Thereby, we found that *Environmental Concern* has a significant influence on all of the included technology-specific beliefs. In particular, *Environmental Concern* has the highest effect on *Attitude* and *Performance Expectancy*, indicating that environmentally concerned people tend to enjoy the adoption of smart energy technology and feel that these are highly useful in terms of performance. Policymakers should therefore consider the positive influence that *Environmental Concern* has on individuals' intentions to adopt smart energy technology via technology-specific beliefs. One way to engage with this belief would be to run campaigns informing residents about current environmental problems and promoting solutions which focus on individual engagement in pro-environmental action. Further, policymakers can also incentivize firms to target people with high levels of *Environmental Concern*. As more and more firms collect consumers' data, they may be able to more quickly and accurately identify beliefs held by their potential customers.

4.1. Limitations

Like any empirical study, our research is subject to limitations associated with the sample and method. Concerning the sample, we took utmost care to identify all relevant studies during our structured literature review. However, the possibility remains that not all existing studies were included in the meta-analysis. Further, our study builds on the data of seven primary studies which focus on two adoption contexts and 4,003 individuals in countries across Europe, Asia, and North America. As already discussed above (Section 4) the majority of studies investigate individuals' adoption of smart energy technology in a European context, with a focus on Germany, whereas only one study focuses on North America and one focuses on Asia. In particular Asia is fairly underrepresented in our sample, as it only represents 3% of the total sample size (4,003). Thus, the applicability of results in the Asian context should be interpreted with caution, even though a meta-regression with 'sample origin' as moderator variable did not suggest a significant effect of sample origin on correlation coefficients. Further, in terms of generalizability, we cannot guarantee that the relationships identified in our model will match smart energy technology contexts and samples in other geographical areas such as, e.g., South America, Africa, and Australia, which were not included in any of our primary studies. Therefore, further research should investigate the applicability of our model in other settings. To this end, the design of a comprehensive questionnaire is one possible approach.

Concerning the method, it must be noted that the data collected in our primary studies is not specifically from individuals living in smart cities. Empirically, individuals' attitudes to smart energy technology adoption may differ according to their living circumstances, i.e., whether or not they live in a smart city. Thus, future research might test the validity of the model by applying it to two different groups: individuals living in smart cities and individuals living in other areas (e.g., non-smart cities or in the countryside).

5. Conclusion and policy implications

Aiming to increase the future level of energy efficiency and integration of renewable energy sources, this paper sets out to provide policymakers with an improved understanding of smart energy technology adoption determinants. Based on the data from over 4k individuals, we are the first to propose a comprehensive adoption model, which considers the different technology contexts of intelligent thermostats and smart meter technology, within different diffusion phases from 2012 to 2017, across the geographic regions of Europe, Asia and North America.

Our results indicate *Attitude* and *Performance Expectancy* are the main drivers of individuals' smart energy technology adoption. Further, we find that *Environmental Concern* has a significant impact on technology-specific beliefs. From a political perspective, our findings suggest the introduction of indirect political instruments, such as providing firms with incentives to foster smart energy technology diffusion. Moreover, our results indicate that targeting environmentally concerned people by fostering campaigns informing residents about current environmental conditions could be an appropriate political measure to improve individuals' uptake of smart energy technology.

6. Data Availability

The dataset underlying this article was shared using the tool integrated into the online submission process and linked to the open-source online data repository hosted at Mendeley Data. In addition, it is available under this anonymized link: https://www.dropbox.com/s/s9rr4w8zigs7yxx/Data_vFinal.csv?dl=0

7. Appendix

Appendix A. Reference of correlation tables in primary studies

ID	Study	Table number and title	Page
1	Chen et al. (2017)	Table 1: Correlation Matrix among Major Variables	97
2	Gerpott and Paukert (2013)	Table 2: Distribution statistics and intercorrelations of study variables (n=453)	489
3	Girod et al. (2017)	Table 5: Variance inflation factors (VIF), correlations and average variance extracted (AVE)	422
4	Koo et al. (2013)	Table 2: Correlation and Descriptive Statistics	*NA*
5	Wunderlich et al. (2012)	Table 2: Correlations and Measurement Information	9
6	Wunderlich et al. (2013) (User sample)	Table 1b: Correlations and Measurement Information (User Sample)	11
7	Wunderlich et al. (2013) (Non-user sample)	Table 1a: Correlations and Measurement Information (Non-User Sample)	11

Appendix B. Table of constructs and items of primary studies

The table is included in the Supplementary Material. In addition, it is available under this anonymized link:
https://www.dropbox.com/preview/AppendixB_Table%20of%20constructs%20and%20items%20of%20primary%20studies%20(1).xlsx?role=personal

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II.3. Research paper 3: "Supporting citizens' political decision-making using information visualization"

Authors:	Vanessa Graf, Valerie Graf-Drasch, Robin Weitzel, Verena Tiefenbeck, Gilbert Fridgen
Citation:	Graf V, Graf-Drasch V, Weitzel R, Tiefenbeck V, Fridgen G (2020) "*Supporting citizens' political decision-making using information visualization*," In Proceedings of the 30th European Conference on Information Systems (ECIS), Marrakech, Morocco, 2020.
Keywords:	Decision-Making; Decision-Support; Citizens; Information Visualisation; Live-Feedback; Renewable Energy; Wind Turbine Acceptance; Gamification.
Ranking of outlet:	VHB-JOURQUAL 3: category B

Abstract:

Individual decision-making is a complex process. If this process is carried out by individuals, who as citizens make politically relevant decisions, it can have serious consequences at all levels of a society. That is why these decisions need to be made with care and preferably on a broad set of information to reflect citizens' true preferences. However, due to limited attention, citizens often consider only salient aspects in their decision-making. To mitigate unwanted consequences following therefrom, citizens are in dire need of decision support. We address this need by developing an Information Systems (IS) tool. Being based on information visualisation, our IS tool supports citizens by providing instant feedback in terms of illustrated consequences. To ensure a meaningful engagement, the IS tool is designed according to gamification principles. A first instantiation in the context of renewable energy acceptance in Germany yields three key findings: First, we find indications that young, urban, and environmentally aware citizens are willing to accept a high percentage of renewable wind energy. Second, we find indication that the tool influences citizens' decisions making. Third, we find citizens to update, however not completely turn over their preferred level of renewable wind energy after interaction with the tool. This holds true across different cross-sections of the population such as age, gender, education, or ecological attitude. Future political activities considering citizens' updated level of preferences may receive improved public support and create less resistance against controversial decisions.

1. Introduction

Technological innovations are proliferating and with them our opportunities to collect, communicate and compute information (van Knippenberg et al., 2015; George et al., 2014; Hilbert and López, 2011). Hence, in situations of decision-making, more information is available to decide upon. However, the flipside of this enriched information base is a phenomenon called "information overload" highlighting that individuals' attention in decision-making has not seen corresponding shifts (Knippenberg 2015). According to behavioural theories, individuals are endowed with bounded rationality. Having only limited cognitive capabilities, individuals who make politically relevant decisions, use simplification processes at the expense of complete information (Gigerenzer and Todd, 2001; Goldstein and Gigerenzer, 2002).

One fundamental manifestation of such a simplification process is described by the salience theory as proposed by Bordalo et al. (2012, 2013). The phenomenon of salience occurs if one or a few aspects in a decision situation draw an individual's limited attention more than other aspects. Hence, salient aspects are dominating decisions. Simplifying a decision situation by focusing primarily on salient aspects may distort preferences, which are often constructed spontaneously in the process of deciding (Bettman et al., 1998; Slovic, 1995). The distortion leads to decision outcomes that fail to represent true preferences.

Being able to decide in line with one's preferences is the essence of intelligent behaviour (Warren et al., 2011; Slovic, 1995). In situations when one cannot form preferences due to e.g., information overloads, the implications might affect all levels of society – especially in the context of politically relevant decisions. A concrete example thereof is the withdrawal of the United Kingdom from the European Union (EU), known as Brexit. Focusing on the salient aspect of leaving such as saving payments to the EU, which were estimated as £350m a week, British people might have forgotten to consider further implications such as trade, customs, or border implications for Northern Ireland. Hence, citizens voted for the Brexit with 53% in 2016. However, neither at the time of the vote, nor the recent years afterwards has been a clear understanding of how and when to withdraw from the EU. The implications thereof were serious: Parliament has rejected the negotiated plan to leave several times and the exit date has been postponed as well (Becker et al., 2017; Hobolt, 2016; Mueller, 2019).

Considering the serious consequences of information scaling faster than attention, fellow researchers have searched for a way to support individuals' processing of information in decision situations. In this context, particular attention has been brought to IS tools providing information visualisation functionalities. These range from common bar graphs to more sophisticated visualisations such as complete virtual environments (Lurie and Mason, 2007). Although a large variety of information visualisation tools are increasingly available to individuals in organizational and in consumer contexts (Lurie and Mason, 2007), little is known of such tools in the citizen context. Aiming to contribute to an inclusive world, within responsive, participatory, and representative decision-making at all levels, we formulate the following research question: *Does an IS tool influence individuals' decision-making in a citizen context?*

In response to this question, we develop an IS tool. The tool is considered IS-based, since it utilizes web-based information visualisation techniques to make the interaction with the tool more engaging. Thereby, we design the tool according to the gamification principles proposed by Liu et al. (2017). Gamification is an umbrella term referring to the utilization of elements from game design in a non-game application context with the aim of improving user engagement (Deterding et al., 2011). Thereby, gamification per definition can include many different elements i.a., also traditional interaction techniques such as filtering and zooming (Deterding et al., 2011; Figueiras, 2015).

Once built, we evaluate the performance of the gamified IS tool in the non-game application context of renewable energy i.e., onshore windfarm acceptance in Germany. We chose the context of renewable energy because it constitutes a major challenge of today's world (United Nations, 2019). Renewable energy is also considered as one of the 17 United Nations (UN) Sustainable Development Goals (SDGs). Within the context of renewable energy, we decided to focus on Germany, which has installed more wind turbines than any other European country (Wind Europe, 2019; NS Energy, 2019; Fleming, 2019).

In this applied context of German wind energy, there are of course many variables to consider. Given a plethora of interesting variables, including all of them simultaneously is challenging within one research project and with the aim of answering a clear-cut research question. Therefore, we make a deliberate decision to narrow the research focus to specific aspects for the sake of a clean research design and clear research question. More precisely, we focus on the variable land use by wind power, which is a current topic in Germany's wind context. Particularly, the German government is discussing new rules regulating the minimum distance for wind power from dwellings. The rule aims to keep new onshore wind turbines at least 1,000 meters away from residential areas. If released, the rules would have enormous implications on the availability of land areas for wind turbines (Bauchmüller, 2019; Witch, 2019). In this work, we develop an IS tool that visualizes the consequences (number and proximity of wind turbines) of the renewable energy portfolio selected by the users in an online survey. With this research, we contribute to an improved individual decision-making at the citizen level, which we believe is the first step towards enabling a participatory and representative decision-making at all levels of a society.

2. Theoretical Background

In the following, we provide details on preference construction, decision support tools, and the application domain: renewable energy acceptance at the citizen level.

2.1. Preference Construction and Salience

In decision literature, normative and behavioural theories describe how decisions are made: Normative theories provide prescriptions of how individuals should optimally make decisions, focusing on the idea of a rational homo oeconomicus maximizing utility by processing the complete information related to a decision situation (Wu et al., 2004; Starmer, 2000). Conversely, behavioural theories document deviations from normative theories (Gigerenzer and Todd, 2001; Goldstein and Gigerenzer, 2002). Specifically, Simon (1956) argues that decision-makers are frequently found to make sub-optimal and irrational decisions, a phenomenon resulting from limited cognitive resources to process information. More specifically, this phenomenon often results from a bounded working memory and bounded computational capabilities to anticipate decision consequences (Bettman et al., 1998; Simon, 1956; Slovic, 1995). This notion of bounded rationality affects decision-making and in particular the decisions' underlying preferences (Slovic, 1995). Decision-makers construct preferences spontaneously in a decision situation and thus preferences are a highly labile and malleable concept, reflecting the information processed by the bounded rational individual (Simonson, 1989, 1990; Nowlis and Simonson, 1997; Bettman et al., 1998; Warren et al., 2011; Slovic, 1995).

The aspects of information considered in preference construction can be explained by the psychological theory of *salience* (Bordalo et al., 2012, 2013). Salience captures that individuals' attention is differentially directed to one portion on the environment rather than to others. The information contained in that portion then receives disproportionate weighing in human cognition (Bordalo et al., 2012, 2015; Taylor and Thompson, 1982). Transferred to decision situations, salience suggests that the valuation of a choice option occurs not in isolation, but in a comparative context (Bordalo et al., 2015). Decision makers, as salient thinkers, contrast the features of the option in question to the features of alternatives or of “normal” situations that come to the decision makers’ mind. For instance, the valuation of a premium good may fall if the good’s high price (instead of the good’s quality) is salient, as when the good is presented together with cheaper alternatives or when the decision maker is accustomed to buying the same good at lower prices (Bordalo et al., 2015; Thaler, 1989, 1999; Bordalo et al., 2013; Tiefenbeck et al., 2016).

Considering individuals’ variant preference structures and the role of salient information in decision-making, decisions refer to a set of spontaneous goals individuals wish to accomplish, rather than a solid, knowledgeable choice (Slovic, 1995). Thus, we argue that in the context of complex policy decisions, citizens need adequate decision support to (1) base their decisions on a broad set of information, which (2) they are able to process. IS-based tools with information visualization (Card, 2009) may provide the means to fulfil both aspects and thus, to adequately support citizens in the construction of their preferences and in their decision-making.

2.2. Information Visualization for Decision Support

As stated above, individuals’ cognitive resources to process information are limited. As individuals acquire more information through vision than through all other senses combined, information visualisation (InfoVis) aids cognition (Heer et al., 2005; Dörk et al., 2013; Card, 2009). InfoVis refers to an IS-based, interactive visual representation of complex issues (Card, 2009; Yi et al., 2007; Hullman et al., 2011). Thereby, interactivity is key and aims at successively showing the data in manageable portions to reduce complexity. Doing so facilitates the user in information processing and uncovering insights (Figueiras, 2015; Hullman et al., 2011; Gelman and Unwin, 2013).

To enable interaction in InfoVis, different interactive techniques enable investigating the data (Figueiras, 2015; Ahmed and Mueller, 2014). A well-known interaction technique is *gamification*, which includes several elements, including traditional interaction techniques such as filtering or zooming of data (Figueiras, 2015). Gamification is defined as “using game design elements in non-gaming contexts” (Deterding et al., 2011, p. 1). This results in goal advancements e.g., supporting healthier lifestyles, greener consumption, or improved financial decision-making (Koivisto and Hamari, 2014). More broadly, the aim of gamification is fostering user motivation and engagement, which in turn increases user activity in a particular context (Hamari et al., 2014; Kwak et al., 2019). As increased user activity is promising in corporate and consumer contexts, respective gamified InfoVis approaches have gained significant attention among practitioners over the last couple of years and led to a panoply of respective tools in both contexts (Huotari and Hamari, 2012; Hamari et al., 2014; Osatuyi et al., 2018). Even though gamified approaches are prominent in corporate and consumer contexts, little is known about such tools in the citizen context. Two related tools refer to “Crime-Mapping” (crimemapping.com) visualizing urban crimes in respective cities on an interactive map, and the “Wahl-O-Mat” by the German Federal Agency for Civic Education (wahl-o-mat.de/europawahl2019), pairing voters with political parties. However, these two examples either primarily inform rather than providing decision support, or do not fulfil gamification standards (Liu et al., 2017). Thus, the examples do not address the pitfalls highlighted by preference construction and salience theory described above. Considering this, and responding to the call to arms of Dörk et al. (2013) to use InfoVis to engage citizens around social issues to support civic engagement, we develop a gamified InfoVis tool (henceforth IS-tool) and apply to a novel context that is currently widely debated in society: environmental sustainability, and in particular, renewable energies.

2.3. Application Context: Citizens’ Acceptance of Renewable Energy

Sustainability in general and replacing fossil fuels with renewable sources of energy in particular constitute a major challenge of today’s world (United Nations, 2019). As such, renewable energy is considered in the United Nations (UN) Sustainable Development Goals (SDGs), which were adopted by respective united member states in 2015 with the aim of achieving a sustainable development until 2030 (Sachs et al., 2019). The implication is clear: lacking sustainability is a rampant threat, which must be addressed with haste (Malhotra et al., 2013; Walsham, 2017). With the threat of climate change, sustainability has come to citizens’ forefront. Public support for sustainability runs high in all European countries, as the FridaysForFuture-movement strikes for climate (FridaysForFuture, 2019) or the increased number of votes for the Green party in the 2019 European elections (Der Bundeswahlleiter, 2019b) exemplarily indicate.

As real world events and research reveal, it is one of the most common mistakes to take citizen support for granted and to expect people to welcome developments they claim to support (e.g., Wolsink, 2000, 2007; Wolsink and Devilee, 2009; Hoen et al., 2019). One concrete example refers to the trade-off between individuals’ support for e-mobility and the resistance towards resulting consequences. In the case of Tesla, the construction of their Berlin factors was temporarily halted by demonstrations against the felling of trees, although Tesla’s non-fuel powered cars are popular (Reuters in Berlin, 2020; Marquart, 2019). Further, in the context of renewable energy such as wind energy, researchers consistently highlight the dynamic in citizens' preferences, along the phases of renewable energy planning. A typical opinion trajectory departs from a very positive public sentiment (that is when people are not confronted with respective consequences), to much more critical (when a project is announced and consequences start to unfold) (Wolsink, 2007; Devine-Wright, 2005; van der Horst, 2007). In view of the unstable and constructed preferences, Wolsink (2007) has already highlighted more than a decade ago that there is a need for quantitative and methodological tools to operationalize public perceptions of wind farms. By developing a respective IS-tool, we aim at addressing this challenge. Thereby, we focus on onshore wind turbines in Germany, since the country has installed more wind turbines than any other European country (Wind Europe, 2019; NS Energy, 2019; Fleming, 2019).

3. Research Model and Hypothesis

As discussed above, we base our research model and hypothesis on decision-making theory and acceptance of renewable energies. Figure 1 illustrates our research model, where we proceed in two steps: 1) we evaluate citizens' decisions before interacting with the IS-tool, this is before visualising the decisions consequences. This value serves as a baseline and reflects citizens' ex ante constructed preferences. 2) We evaluate citizens' decisions after interacting with the IS-tool, which visualises the consequences of citizens' decisions. We aim at testing if the IS-tool (gamified InfoVis approach) significantly changes decisions. Thus, we formulate the following hypothesis in line with the above mentioned literature on decision-making, InfoVis, and acceptance of renewable energy (i.a., Bettman et al., 1998; Lurie and Mason, 2007; Wolsink, 2007): *Citizens' decisions on renewable energy change when respective consequences become clear.*

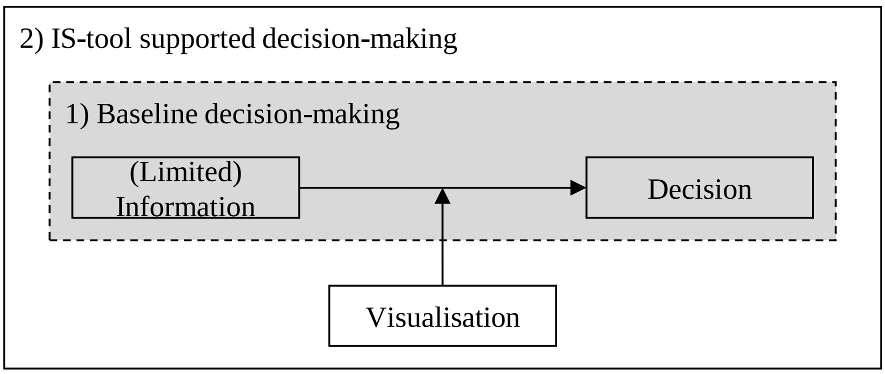

Figure 1. Research model

We include the control variables *gender*, *age*, *level of education*, *residence* (country or city and Northern- or Southern-Germany), and *ecological attitude*. While the interpretation of most potential effects is less obvious, we include them in our analysis in line with previous literature that identified heterogeneity in decision-making and/or renewable energy acceptance (e.g., Pierce and Sweeney, 2010; Venkatesh and Morris, 2000; Tiefenbeck et al., 2016; Thompson et al., 1993; Hoen et al., 2019; Koivisto and Hamari, 2014; Johnson, 1990).

4. Method

4.1. Designing the Decision Tool as a Gamified System

For designing the decision tool, we choose a gamified system. To this end, we follow the '*Framework for Design and Research of Gamified Systems*' of Liu et al. (2017). The framework is based on a synthesis of existing literature and grounded on the individual level of analysis. According to the framework, a gamified system is defined as a target system (i.e., users, task, technology) to which gamification design elements (i.e., objects and mechanics) are added, in order to secure desired user-system interactions as well as a meaningful engagement. For yielding meaningful engagement with the system, Liu et al. (2017) suggests the five gamification design principles. We summarize the operationalization of these principles in Figure 2 and describe them in detail in the following:

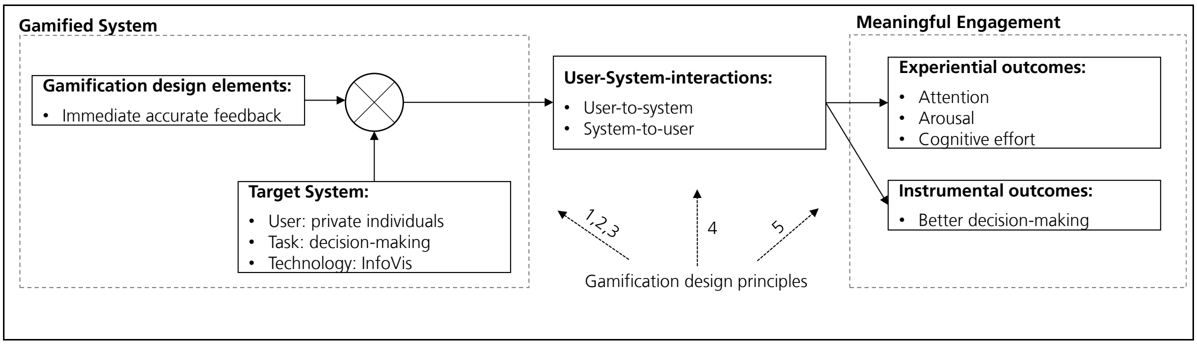

Figure 2. Design-principles of the IS-tool as suggested by Liu et al. (2017)

First, *task congruence* refers to the fit of the gamified system with the target task to perform. In particular, a gamified system needs to be congruent to task characteristics. If so, users' engagement and satisfaction are increased. To yield task congruence, gamification design elements can be used to give task feedback. The target task to perform in the decision tool is decision-making. We ensure the system's congruence with this task as we provide immediate and accurate feedback on the decisions made and, thus, enable users to adapt decisions. Including such immediate feedback is one of the most dominant uses of gamification (Liu et al., 2017). Since renewable energy originally lacks feedback (see Section *Theoretical Background*), providing such compensates for this deficiency in the task design.

Second, *personalization* refers to increasing the fit of the gamified system with the individual i.e., by focusing on the individual context. One way to comply with this principle is by analysing user-specific data for providing a tailored system design, for example (Liu et al., 2017). The users of the decision tool are individual citizens. To yield personalization, we tailor information and feedback provided by the decision tool to individual input provided at the start of interaction.

Third, *technology affordance* refers to the fit of the gamified system with the technology used. Specifically, this means that target system technologies should enable and facilitate gamification design features (Liu et al., 2017). The technology used by the decision tool to ensure this principle is an interactive map. This map visualizes existing and new wind turbines based on information provided by Open Street Map (www.openstreetmap.org) and the German weather service (Deutscher Wetterdienst, 2004) (see Section *Data Collection*).

Having addressed the fit of the system with task, individual, and technology in the first three principles, the fourth principle *dynamism* considers the production of desired user-system interactions. Thereby, interactions might be between user and system or, in the case of a multiuser system, also between users (Liu et al., 2017). The decision tool allows interactions between user-and-system only. Concerning the principle, we design those interactions in a way, which allows users to make aesthetic experiences. Specifically, we include dynamic feedback as well as different colours (white and blue wind turbines).

Fifth, according to Liu et al. (2017), *meaningful engagement* refers to integrating experiential and instrumental outcomes. Specifically, a design system should not only provide some kind of experience but should also enhance instrumental, context dependent task outcomes. Since the decision tool includes a decision-making task, the intended *experiential outcomes* are attention, arousal, and cognitive effort (Liu et al., 2017). The intended *instrumental outcome* is an improved decision-making, which is in line with ones' true preferences. To ensure that the decision tool relates to these outcomes, we on the one hand provide visualized information on different aggregation levels (i.e., zoom levels) and on the other enable participants to correct their decision until they fully agree with resulting consequences.

4.2. Data Collection

To test the tool, we ran independent pre-test modes: First, we used personal contacts and gathered data from 85 academic researchers with expertise in decision support systems, energy and critical infrastructures, sustainability, or individual behaviour in the IS context. About a quarter of them (i.e., 23) tested the tool in a face-to-face setting with one of the authors and directly provided their feedback. The remaining 62 participants tested the tool themselves in live mode and returned their feedback afterwards. All data gathered in pre-tests was excluded from analyses (Summers, 2001).

For the main survey, we recruited 353 German participants from the online panel Consumerfieldwork. 200 were female, 152 male, and 1 participant did not want to specify the gender as female or male. 20.40% were below 35 years, 68.56% between 35 and 64 years, and 11.05% above 64 years. Approximately 29.18% were college educated. Further, since more wind turbines are located in Northern- than in Southern-Germany (Bundesverband WindEnergie, 2018), we aimed at considering both regions and related participants' perspective and thus recruited participants in a half-half split from the regions – see Appendix A (Table A1) for details. At the start of the survey, participants entered their postal code. Then, we confronted them with the fact that in 2016, coal-fired plants covered about 40% of the German electricity consumption (AG Energiebilanzen e.V., 2016). We asked them how many of these existing coal-fired plants they would replace with renewable wind energy – assuming they had free choice. An adjustable slider ranged from 0 to 100 percent. Please note, that we are very well aware of the fact that the world is not quite as simple when it comes to replacing coal with wind power in the current electricity system and that many other factors play a role in this context. However, given a plethora of interesting variables, including all of them simultaneously is challenging within one research project and with the aim of answering a clear-cut research question. Given this challenge and also for the sake of investigating whether the mechanism on which the tool is based produces research-relevant results, we have deliberately reduced the focus in our study, which also served as an indicator of whether the tool can successfully create an impact on citizens' decision-making process. Particularly, we have focused on the variable land use by wind power, which is a current topic in Germany in this context (Bauchmüller, 2019; Witch, 2019) (also see Section *Introduction* for details).

After submitting an answer, we confronted participants with a map of Germany illustrating the selected proportion of renewable wind energy in form wind turbines emerging from the map. While white turbines illustrated existing turbines, blue turbines illustrated new turbines necessary for replacing coal-fired plants. Please note that if participants selected 0% in the previous question, only currently existing (i.e., white) wind turbines appeared. Further, participants could freely investigate the effects of their initial decision on the four different zoom levels *town*, *county*, *state*, *country (Germany)*. The initial zoom level at which the map of Germany appeared to the participant, was randomly determined with equal probability.

We again asked participants for deciding upon the percentage of renewable wind energy. Before deciding, participants could ‘play around’ with the slider and immediately received instant feedback on the consequences of their decision, as turbines were added or subtracted from the map on all zoom levels. Figures 3 illustrates this central part of the tool.

To determine the position of existing wind turbines, we used “OpenStreetMap” (www.openstreetmap.org). Therein, one can search for points of interest (nodes) and filter them by different attributes (tags). To locate the wind turbines, we focused nodes within Germany having the tags power = generator and generator:source = wind. To approximate plausible positions of new wind turbines, we used information on wind speeds provided by meteorological maps of the German weather service (Deutscher Wetterdienst, 2004). Additionally, we considered legal and economic factors, defining rules such as minimum distances of wind turbines to residential areas or necessary wind speeds. Appendix B provides details on the approximation.

In accordance with our research model and hypotheses, we measured the following variables: As dependent variable, we first measured the percentage of coal-fired plants participants decided to replace with renewable wind energy. At the start of the survey, this variable referred to the initial percentage decided upon when participants did not see any consequences of their decision (i.e., variable name “Percent_Wind_0”). At the end of the survey, this variable referred to the last value chosen after participants saw the consequences of their decision in form of white and blue turbines on the map (i.e., variable name “Percent_Wind_1”).

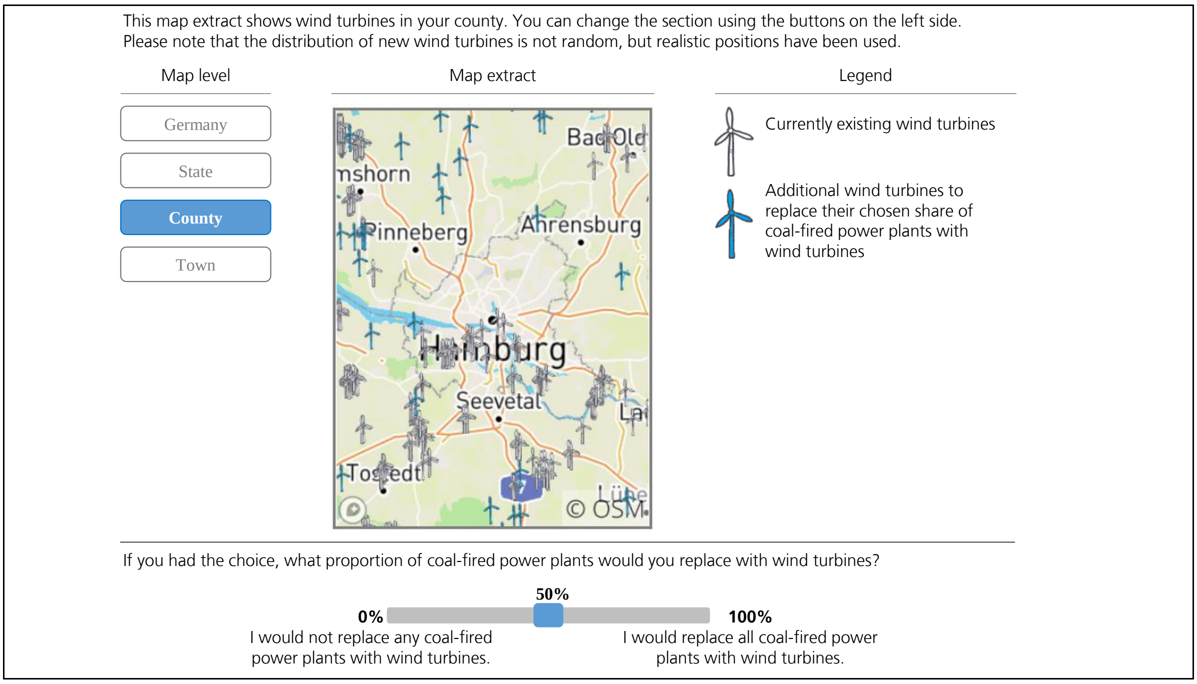

Figure 3. Illustration of the IS-Tool

As independent variables, we collected survey data on the participants' *gender*, *age*, and *education* as categorical (i.e., dummy) variables. Furthermore, we captured the participants' *ecological attitude* using a version of the New Ecological Paradigm scale (e.g., Bidwell, 2013), developed by Dunlap and his collaborators (Dunlap and van Liere, 1978; Dunlap et al., 2000). We used the scale as a single measure to capture participants' attitude regarding the balance of nature, limits to growth, and human domination of nature (Dunlap et al., 2000). Specifically, we calculated the average ecological attitude of all participants for this measure and classified citizens above this average as "*environmentally conscious*" and below this average as "*less environmentally conscious*." Further, we classified participants' location as (1) *Northern*- or *Southern-Germany* and (2) further a classified their location as *city* or *countryside* with a list (excel-karte.de) categorizing German postal codes accordingly. Details are stated in Appendix A (Tables A1 and A2). We analyse the variables via a regression model as quantitative method.

5. Analysis and Results

First, we calculated the average percentage of coal-fired plants the 353 citizens would replace with renewable wind energy. This resulted in 72.15% for the 'Baseline'. Second, we conducted the regression analysis. Table 1 states the results for the start of the survey (i.e., 'Baseline'), which indicate a significant influence of *Age* and *Country/City* and *Ecological Attitude* on participants' preference construction. In particular, participants between 35 and 64 years chose approximately 7 percentage (i.e., 5.91 percentage points) less renewable wind energy than younger citizens in our sample. Citizens living in cities chose an energy mix that included approximately 10 percentage (8.46 percentage points) more renewable wind energy. Further, less environmentally conscious citizens chose approximately 14 percentage (12 percentage points) less renewable energy than environmentally conscious citizens did.

Independent Variables	Description	Dependent Variable Percent_Wind_0 (in %)
Intercept		84.64 ***
Gender	Female	
	Male	-3.84
	Not specified	5.52
Age	<35	
	35-64	-5.91 +
	>64	-0.50
Education	College educated	
	Not College educated	-5.20
Country/City	Country side	
	City	8.46 **
Northern/Southern Germany	Northern-Germany	
	Southern-Germany	-2.96
Ecological Attitude	Environmentally conscious	
	Less environmentally conscious	-11.50 ***

*Notes: +p-value<0.10, *p-value <0.05, ***p-value<0.001*

Table 1. Regression Results at the Start of the Survey (i.e., 'Baseline')

At the end of the survey, we again calculated the average percentage of coal-fired plants the 353 citizens would replace with renewable wind energy. This resulted in 65.45% for the 'IS-tool supported decision-making'. Once more, we conducted a regression analysis. Table 2 states the results, which indicate a significant influence of *Education*, *Country/City* and *Ecological Attitude* on participants' preference for renewable energy. In particular, participants without college education ended the survey with approximately 9 percentage (i.e., 8.78 percentage points) less renewable wind energy than college educated citizens. Citizens living in cities chose an energy mix that included approximately 8 percentage (6.04 percentage points) more renewable wind energy. Further, less environmentally conscious citizens chose approximately 13 percentage (10.10 percentage points) less renewable energy than environmentally conscious citizens did.

Independent Variables	Description	Dependent Variable Percent_Wind_1 (in %)	
Intercept		77.73	***
Gender	*Female*		
	Male	-2.65	
	Not specified	10.26	
Age	*<35*		
	35-64	-3.34	
	>64	2.86	
Education	*College educated*		
	Not College educated	-8.78	*
Country/City	*Country side*		
	City	6.04	+
Northern/Southern Germany	*Northern-Germany*		
	Southern-Germany	-1.97	
Ecological Attitude	*Environmentally conscious*		
	Less environmentally conscious	-10.10	***

*Notes: +p-value<0.10, *p-value <0.05, ***p-value<0.001*

Table 2. Regression Results at the End of the Survey (i.e., 'IS-tool supported decision-making')

Additionally, we investigated the influence of the start value in the 'Baseline' (i.e., Percent_Wind_0) on the end value (i.e., Percent_Wind_1) in a regression analysis. Unsurprisingly, this initial relationship was strong and significant with an estimator of 0.87 and a p-value<0.001. This indicates that participants starting the survey with a higher percentage of renewable energy will end the survey with a high percentage of renewable energy. Although the preferred share of wind power at the start of the survey is a significant and strong predictor of the respective end value, we aimed at understanding participants' decision behaviour more precisely. Therefore, we tested whether differences between these two values changed significantly during the survey, indicating that participants have marginally revised their decision upwards or downwards. Given the small sample size in the sub samples and that respective data did not always meet requirements for normality, we conducted a Wilcoxon Signed-Ranks test. The Wilcoxon Signed-Ranks test is a non-parametric statistical hypothesis test that is used to compare repeated measures on a single sample and assess whether the population mean ranks differ before and after an intervention or treatment calculating the differences between their ranks.

In addition to this statistical significance testing, we estimate the effect sizes of the start values on the end value. According to Cohen (1992), each statistical test has its own effect size index. The effect size for the Wilcoxon Signed-Ranks test is a correlation coefficient (*r*) calculated by dividing the z statistic by the square root of N. Thereby, N equals the total number of observations (e.g., Pallant, 2007). The *r* value varies from 0 to close to 1. We evaluate the meaningfulness of this association by following Cohen (1992) who terms this effect size as small if $w \geq .10$, medium if $w \geq .20$, and large if $w \geq .40$.

Table 3 summarizes the mean and median of the variables Percent_Wind_0 and Percent_Wind_1 at the start (i.e, 'Baseline') and at the end of the survey (i.e., 'IS-tool supported decision-making') differentiated by employed independent variables. The table states the results of the Wilcoxon Signed-ranks test in form of significances and the effect sizes in the two last columns.

			Percent_ Wind_0		**Percent_ Wind_1**		**Results Wilcoxon test**	
Variables	**Description**	**N**	**Mean**	**Med.**	**Mean**	**Med.**	**Sign**	**|r|**
Gender	Female	200	73.87	80.00	66.51	70.00	***	.25
	Male	152	69.90	80.00	64.03	70.00	***	.25
Age	<35	72	76.53	85.50	68.03	72.50	***	.28
	35-64	242	68.92	76.50	63.23	70.00	***	.25
	>64	39	76.53	85.50	68.01	72.50	***	.20
Education	College educated	103	75.79	84.00	71.34	80.00	**	.22
	Not College educated	250	70.65	80.00	62.98	69.00	***	.26
Country/City	Country side	206	67.71	70.00	62.08	67.00	***	.24
	City	147	78.37	90.00	70.17	80.00	***	.22
Northern/ Southern Germany	Northern-Germany	185	75.08	76.50	63.23	70.00	**	.24
	Southern-Germany	168	68.92	80.00	62.98	69.00	***	.25
Ecological Attitude	Environmentally conscious	194	77.54	89.50	69.94	80.00	***	.26
	Less environmentally conscious	159	65.57	67.00	59.96	61.00	***	.23

*Notes: **p-value<0.01, ***p-value<0.001*

Table 3. Results of Wilcoxon Signed-Ranks test

As the results in Table 3 indicate, there is a consistent and significant difference between the end and start value across all sub-groups. In particular, the end value is significantly lower than the start value of citizens – across all sub-samples. Further, effect sizes indicate that this 'downward correction' in value is small to medium.

6. Discussion

Too much information often leads to information overload, which in turn degrades the quality of decision-making. Current examples illustrate that this particularly has serious implications for policy decisions taken by citizens. We believe that the use of IS has the potential to improve decision quality. Thus, this work sets out to design a gamified IS tool which interacts with the user by visualizing the consequences of decisions while guaranteeing meaningful engagement. The performance of the tool is exemplarily tested in context of renewable energy in Germany. Specifically, we ask a sample of 353 German citizens to select the percentage of coal-fired plants participants they wish to replace with renewable wind energy. Once selected, the tool immediately visualizes the selected percentage as wind turbines on a map of Germany. We apply regression analyses along with non-parametric tests to analyse gathered data. This yields the following three key findings:

First, the IS tool draws a realistic picture of citizens' preferences for renewable energy in Germany. Results indicate that young, urban, and environmentally aware citizens are willing to accept a high percentage of renewable wind energy. Specifically, we find the variables *Age*, *Country/City*, and *Ecological Attitude* to be significant predictors of the dependent variable *Percent_Wind_0* (i.e., 'Baseline'). This result reflects trends and socio-economic developments at the time when the survey was conducted. Examples include the #FridaysForFuture movement. The hashtag describes an international movement of young citizens (i.e., students) who strike for the climate instead of attending school. Another example are the 2019 European elections in Germany, during which the Green Party, which promotes renewable energies, received support from young citizens in particular (Der Bundeswahlleiter, 2019b, 2019a).

Second, and this is the main finding, results indicate that the tool influences citizens' decisions making. In particular, we find that all analysed cross-sections of citizens within our sample change the amount of renewable energy initially desired, after interacting with our tool. On average, the percentage of renewable energy is reduced by approximately 9 percent (72.15% average start value and 65.45% average end value). In fact, after interacting with the tool, citizens select less renewable energy than initially. Taking this further, this finding might imply that people agree less with something, as soon as they are able to see the implications of it. According to existing literature (e.g., Irvin and Stansbury, 2004), future political actions considering citizens' decision in terms of the revised preferences might then receive a higher level of support.

Third, the tool does not completely turn over decisions. In particular, results highlight the value of the variable *Percent_Wind_0* selected before interacting with the tool to be a strong and significant predictor of *Percent_Wind_1* end value. This indicates that individuals preferring high levels of renewable energy before interacting with our tool still do so afterwards and vice versa. There may be many scientific explanations for this: one refers to the scientific notion of the confirmation bias, making users to stick to their initial decision and hence, classify new information accordingly (Nickerson, 1998).

6.1. Implications

Considering the three key findings outlined, the implications of this work are both, theoretical and practical. Concerning the theoretical implications, it is to say that this research is positioned at the confluence of two fields of research, which are decision-making and IS. Linking these two research fields provides decision-theory researchers with an increased understanding and empirical evidence of the utility and suitability of IS tools for supporting human decision-making in a citizen context. IS researchers, however, get an understanding of how IS including InfoVis technologies influences decision-making, which enables them to support similar political decisions situations in the citizen context. Such similar decision-situations include elections of parties or political representatives, referendums of political independence and votes on legislative proposals or actions of any kind – not only restricted to the context of energy but also to the context of healthcare, taxation, or education, for example. In terms of practical implications, this work enables policy makers to formulate regulations, which are more realistically grounded in citizen's preferences, which are constructed on a broader set of information through tool interaction. What follows therefrom are future projects, which might receive improved support from the public and create less resistance - a calculation that underlies the involvement of citizens in political decisions (Irvin and Stansbury, 2004). We believe that the strengthening of the calculation will lead to an improved involvement of citizens in political decisions, even in countries where it was previously not customary. Hence, this research ultimately serves citizens by promoting an inclusive society where they get a voice in various decision-making.

6.2. Limitations

Like any study, the present study too has several limitations, referring to 1) the goal of this research paper, 2) the design procedure of the IS tool, 3) the chosen application context as well as the 4) validation procedure, which leaves room for further investigations by fellow researchers.

Concerning 1), the research goal is to develop an IS tool that directly confronts people with the consequences of their decisions in different citizen contexts. In the applied context of wind energy, there are of course many variables to consider. However, our research goal was not to design an IS tool that comprehensively informs German citizens about wind power and including all the complexity. Instead, we made a deliberate decision to narrow the focus to specific aspects for the sake of a clean research design and clear research question. More precisely, we focus on the variable land use by wind power, which is a current topic in

Germany's wind context. However, the findings reported in this paper should encourage further research to extend this work and explore additional aspects in more detail, such as local pollution, air-quality, health issues, grid development, storage, CO2, global warming, etc. Further, future research might also expanded the research by exciting related aspects, such as the dangers of a blackout that come with the coal exit (Wetzel, 2020).

Cornering 2) the design of our IS tool, it is to say, that we adhered to the design principles for gamified Information Systems suggested by Liu et al. (2017). Future research however, could also consider the inclusion of further principles such as e.g., principles of Green IS as proposed by, Seidel et al. (2013), Mustaquim and Nyström (2013, 2014), Recker (2016), or Seidel et al. (2018). Even though some of these principles refer to an organizational level instead to an individual one, future research could map them against the principles we have already considered. Besides including further principles, the design of the proposed IS tool could also be enhanced by changing the concrete implementation of those. For example, the implementation of the personalization principle could be intensified by further researcher demanding more input from individuals at the beginning of the survey, according to which feedback is then tailored. Finally, future studies could explore additional ways, beyond an IS tool, to support individuals on a citizen level with decision-making.

Concerning 3) the chosen application context, it is to say that the current study builds on data of *353* individuals living in Germany. We cannot guarantee the results to be stable in contexts or samples beyond the ones considered within this study. This is because, renewable energy decision-making might be influenced by different factors, such as e.g. contextual or cultural ones. Therefore, we suggest further research to investigate the evidence of our findings in other settings.

Concerning 4) the validation procedure, limitations derive from the survey conducted and the method of analysis applied. First, within the survey conducted, future research could apply further measures, enabling an improved understanding of the variables and their impact on the decision at hand. Finally, and beyond the limitations mentioned so far, this work is also limited by the assumptions associated with the use of such an IS tool. Thereby, the access to and the acceptance of the technology on which the tool is based upon should be mentioned as examples.

7. Conclusion

In times of technological revolution and associated information overload, citizens focus on salient aspects when making political decisions, rather than utilizing all information available.

Following therefrom are decisions, which fail to reflect true preferences. A situation that may be alleviated through decision support. Accordingly, this work designs an IS tool for decision support relying gamification principles for meaningful engagement as well as InfoVis as underlying technology. Once built, the IS tool is applied to the context of renewable energy in Germany. Three key findings are derived: First, the tool is able to replicate realistic preferences in terms of citizens' acceptance of renewable energy in Germany. Second, all citizens interacting with the tool reduce the preferred level of renewable energy. Third, we find that tool interaction changes initial decisions. The insights derived within this work increases the understanding of citizens' decision-making. Thereby, on a meta-level, this works contributes to an increasingly inclusive world, within responsive, participatory, and representative decision-making at all levels.

8. Appendices

8.1. Appendix A

Table A1: Classification of Participants' Residency as Northern-/Southern-Germany

Region	Sample size	Federal state	Sample Size
Northern-Germany	185	Northern Niedersachsen	39
		Schleswig-Holstein	35
		Hamburg	38
		Bremen	37
		Mecklenburg-Vorpommern	36
Southern-Germany	168	Baden-Württemberg	82
		Bayern	168

Table A2: Classification of Participants' Residency as Country/City

Region	Sample size	City or country	Sample Size
Northern-Germany	185	City	99
		Country side	86
Southern-Germany	168	City	48
		Country side	120

8.2. Appendix B: Details on the Calculating the Position and Number of New Wind Turbines

Details on calculating the position:

The calculation was primarily based on data and information from the German weather service (Deutscher Wetterdienst, 2004), which provides maps with average annual wind speed in 80-meter height. This height is close to the hub height of commonly used wind turbines like the Vestas V 90 (80m – 105m depending on the model). Whether a position is suited for wind turbines was based on information provided by Fachagentur Windenergie (2019b), which summarises and constantly updates legal and economic factors (e.g., minimum distance of wind turbines) for all federal states of Germany. We based our calculation on the 2017 version (slightly updated version of 2019 available, cf. Fachagentur Windenergie, 2019a). We averaged information (e.g., minimum distance affordances) across all federal states. On this information basis, we used OMS and Python to determine if a position fell into a restricted area. Wind speeds below 3 meters per second are not economically viable and therefore excluded. From the remaining positions, 17000 are randomly selected based on a linear distribution depending on the wind speed. This resulted in a list of random coordinates within Germany and the wind speed at their respective position.

Details on calculating the number of new wind turbines:

In 2016 coal-fired plants in Germany produced 250 terawatt-hours of electricity (AG Energiebilanzen e.V., 2016), which would need to be replaced by wind turbines in our survey. Thus, for estimating the number of wind necessary turbines, we estimated the yearly production of one wind turbine, considering the average annual wind speed in Germany.

9. References

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III The organizational level

III.1. Research paper 4: "When does it pay off to integrate sustainability in the business model? – A game-theoretic analysis"

Authors:	Henner Gimpel, Valerie Graf-Drasch
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Abstract

Acknowledging sustainability as a challenge of utmost importance, organizations face questions on dealing with different dimensions of sustainability. Respective actions include a fundamental shift in the purpose of business and almost every aspect of how it is conducted, or in short: an integration of sustainability in organizations' business model. However, as sustainability is no altruistic end in itself, respective transformation must resonate with organizations' economic conditions and their position in the market. But when does it pay off for organizations to integrate sustainability in their business model? Within this research paper we find answers by applying a game-theoretic framework and examining competition strategies for organizations integrating sustainability in their business model. Hereby we consider different market scenarios where symmetric and asymmetric, weak and strong, as well as a varying number of organizations interact. Our results suggest different strategies organizations can apply to gain competitive advantage.

1. Introduction

The "earth overshoot day" marks the date when we, all of humanity, have used more from nature in a single year than our planet is able to renew. In 2018, this day was as early as never before on August 1. As a consequence, we used 1.7 earths this year instead of the single one we inhabit (Earth Overshoot Day, 2018). This clearly illustrates the severity of today's environmental degradation, which is mostly man-made (Dunlap, van Liere, Mertig, & Jones, 2000; Fonseca, Domingues, Pereira, Martins, & Zimon, 2018; van Bommel, 2018). The consequences already manifest: a recent scientific report by 13 federal U.S. agencies predicts that if significant steps are not taken to combat global warming, the damage will lead to a ten percent decrease in the size of the American real economy by the end of the current century (Davenport & Pierre-Louis, 2018). But which actor is the most suitable one to take the steps demanded so urgently?

Associated with global warming is the emission of greenhouse gases. In 2016, the industrial sector accounted for 22% of America's greenhouse gas emissions (United States Environmental Protection Agency [EPA], 2017). Thus, as a considerable source of greenhouse gas production, business organizations (which we refer to as "organizations" from now on) hold a prominent position in achieving a higher level of sustainability (Abdelkafi & Täuscher, 2016; Brehmer, Podoynitsyna, & Langerak, 2018). Furthermore, customers are increasingly concerned about climate change, and are also fond of sustainable business models such as the sharing economy (Hamari, Sjöklint, & Ukkonen, 2016). To address this demand, transformation towards sustainability has been integrated in organizations for years, but mostly in singular business activities. For example, supply chain management focused on the integration of environmentally sound choices into supply chains (e.g., Srivastava, 2007), and marketing management focused on the promotion of sustainably produced products (e.g., Collins, Steg, & Koning, 2007). However, when facing today's challenges, a holistic and more strategic approach on the integration of sustainability not only in single business activities and processes, but in organizations' core business models, is necessary (Bini, Bellucci, & Giunta, 2018; Müller & Pfleger, 2014).

Such a sustainability integrated business model is called "business model for sustainability" (BMfS) and describes a fundamental shift in the purpose of business and almost every aspect of how it is conducted. The concept of BMfS is relatively new (Abdelkafi & Täuscher, 2016; Oghazi & Mostaghel, 2018). Thus, their functionality, their application in the real world, and the determinants for their success in the market, are not yet well understood (Piscicelli, Ludden, & Cooper, 2018). In fact, there is debate on how BMfS could translate environmental benefits into economic profit and in particular in competitive advantage for an organization (Bocken, Schuit, & Kraaijenhagen, 2018; Bryson & Lombardi, 2009; Lloret, 2016). The analysis of an organization's competitive advantage requires an analysis of the market and the behavior of other competitors. In academia, this has not happened so far. One reason might be that actual research in the field of BMfS and research on business model concepts in general take a single-actor or "egocentric" perspective of one focal organization (Breuer, Fichter, Lüdeke-Freund, & Tiemann, 2018). However, particularly in the context of sustainability, scholars point out the importance of a multi-actor approach (Breuer et al., 2018; Stubbs & Cocklin, 2008). This is where this work starts, as we analyze favorable competitive dynamics and market conditions of organizations innovating their business model towards sustainability. Particularly, we address the following research question:

When does it pay off for organizations to integrate sustainability in their business model?

To fill this knowledge gap, we contribute by using a game-theoretic framework where we consider different market scenarios with symmetric and asymmetric, weak and strong, as well as varying numbers of interacting organizations. Our results suggest different strategies organizations can apply to gain competitive advantage. The formal model can be applied by scholars and practitioners to specific industry settings or different natures of market settings with large degrees of freedom. The most important implication of our study is that organizations should consider the likely competitive effects, the market they are in as well as their market position, before revealing a sustainability business model innovation. To be more precise, in today's context of global economy and fierce competition, the "prize" will go to those organizations that will excel not only from a sustainability but also from a competition perspective.

The remainder of the paper is organized as follows: In the following section, we state the theoretical backgrounds of sustainability, sustainability business models, and related topics. We then postulate the assumptions our model is built upon, establish the market setting, define rules, and constitute the game. Further, we describe the implementation of our model and present respective results. We conclude by pointing out research contribution, managerial implications, and limitations.

2. Theoretical Background

2.1. Sustainability

Sustainability primarily received attention on the public agenda in the 1980s with the publication of the Brundtland Commission report (Brundtland, Khalid M, Agnelli S, Al-Athel S., & Chidzero B, 1987) . Since then, a vast stock of literature has formed to define the concept of sustainability and all of its aspects. Because of its general understanding, accessibility and meaning, we adhere to the original Brundtland version, which defines sustainability as "development which meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland et al., 1987, p. 43). The construct of sustainability focuses on planet, people, and profit. Those dimensions of environmental, social, and economic sustainability are referred to as triple bottom line (Elkington, 1998). Today, humanity has entered an era of complex and persistent environmental sustainability challenges that are threatening the viability of our globe (Fang, Heijungs, Duan, & Snoo, 2015; Lang et al., 2012; Lindberg, Markard, & Andersen, 2018). These challenges have called for perception of three different kinds of actors, who are turning their attention to the question of how we can make the world a better place and have sustainability on their agenda: nations, individuals and organizations.

First, nations are widespread determined to affect fundamental change in current political, social, and economic practices to achieve environmental sustainability (Elliot, 2011). Conferences, agreements and treaties dedicated to the combat of environmental downturns prove this determination (e.g., the yearly climate summit of the United Nations). Second, there is little dispute on the effects of degradation on human beings, which puts them in the center of concerns (Elliot, 2011). Additionally, by their demand, individuals influence the economic behavior of organizations. Understanding the effects of environmental degradation on everyday life, individuals demand more sustainable products, and therefore spur organization accordingly (Hamari et al., 2016; Jansson, Marell, & Nordlund, 2010). Third, organizations are broadly recognized as an essential contributor to combat environmental degradation (Dean & McMullen, 2007; Elliot, 2011). One reason for this salient role is that organizations have a total economic turnover greater than that of many nations (Elliot, 2011). With these possibilities, organizations can bring about far-reaching changes and improvements – locally, nationally, and globally (Brundtland et al., p. 16; Elliot, 2011; Melville, 2010).

2.2. Sustainability Business Research

Business researchers have studied the topic of environmental sustainability for decades (Malhotra, Melville, & Watson, 2013). Building upon and extending the literature overview provided by Melville (2010), different fields of research have been dedicated to this topic: operations researchers have examined the adoption of environmental quality standards (Isaksson & Steimle, 2009; Milne & Gray, 2013), lean production and environmental performance (Chiarini, 2014; King & Lenox, 2001), and sustainable supply chains (Brandenburg, Govindan, Sarkis, & Seuring, 2014; Seuring & Müller, 2008). Marketing researchers have examined consumer adoption of green products and the marketing of sustainable business initiatives (Collins et al., 2007; Gordon, Carrigan, & Hastings, 2011; Jansson et al., 2010; Nath, Kumar, Agrawal, Gautam, & Sharma, 2013). Business economists have analyzed regulatory mechanisms, such as voluntary programs that act as information diffusion programs (Lyon & Maxwell, 2007; Prakash & Potoski, 2012). Management researchers have examined antecedents of an organization's environmental management activities (Banerjee, Iyer, & Kashyap, 2003; Hofer, Cantor, & Dai, 2012) and have published research reviews and critiques (Dyllick & Muff, 2016; Salzmann, Ionescu-Somers, & Steger, 2005). Scholars of information technology (IT) have dedicated their work to the adoption of green IT in the business context (Marett, Otondo, & Taylor, 2013).

In addition to these established fields of research, another sustainability topic has gained momentum in the past few years: business model transformation towards sustainability and their interrelations with sustainability innovations (Bini et al., 2018; Boons & Lüdeke-Freund, 2013; Evans et al., 2017; Müller & Pfleger, 2014). First, the latter mentioned sustainability innovations describe an organization's ability to innovate in the domain of sustainability which can reach from small incremental steps to radical disruptive innovations (Evans et al., 2017). More specifically, respective innovations refer to a reconfiguration of specific business aspects envisaged to make real and substantial improvements, such as the integration of technology innovations, the development of superior production processes and operating procedures, or the exercising of strong market, social and political influence (Evans et al., 2017; Schaltegger & Wagner, 2011). Second, business models and their transformation towards sustainability are an emerging mechanism to integrate sustainability innovations into business (Antikainen, Lammi, Paloheimo, Rüppel, & Valkokari, 2015; Evans et al., 2017; Jolink & Niesten, 2015; Schaltegger, Lüdeke-Freund, & Hansen, 2012). In other words, business models are seen as the vehicle enabling sustainability innovations (Evans et al., 2017; Teece, 2010; Zott, Amit, & Massa, 2011). Thus, the aim of this underlying work is to advance research on sustainability innovations, by adopting a respective business model perspective. This requires a detailed understanding of the unit of analysis, which we provide in the following.

2.3. Business Models for Sustainability

Starting with the concept of business models in general, there is a lack of agreement on their definition in academia (Boons & Lüdeke-Freund, 2013; Evans et al., 2017). However, commonly accepted explanations consider that a business model refers to the logic of how an organization does business, and explain how the organization creates, delivers and captures value (Evans et al., 2017; Teece, 2010). On a generic level, Boons and Lüdeke-Freund (2013) distinguish the following four key elements describing a business model concept:

1) Value proposition: value embedded in products and services offered.
2) Supply chain: structure and management of upstream relationships with suppliers.
3) Customer interface: structure and management of downstream relationships with customers.
4) Financial model: costs & benefits from (1)-(3) and their distribution across business model stakeholders.

With respect to the concept of transforming business models for supporting sustainability innovations (see section "Sustainability Business Research" above), different labels such as "business models for sustainability (abbreviated with BMfS as introduced above)" or "sustainability business models" (Abdelkafi & Täuscher, 2016) are used in literature. Just like there is no general accepted definition of business models, there is a lack of consensus and established theoretical grounding in economics and business studies regarding BMfS too (Abdelkafi & Täuscher, 2016; Evans et al., 2017; Schaltegger, Hansen, & Lüdeke-Freund, 2016; Schoormann, Behrens, Kolek, & Knackstedt, 2016). Originally, BMfS refer to two classic articles (i.e., Hart & Milstein, 1999; Lovins, Lovins, & Hawken, 1999), which envision them as a way to reduce negative social and ecological impacts (Boons & Lüdeke-Freund, 2013). Similarly, Geissdoerfer, Vladimirova, and Evans (2018) describe BMfS as a modification of the conventional business model concept towards the incorporation of environmental principles and the integration of sustainability in a business value proposition. Within our work, we build upon literature and understand BMfS as models, where concepts of the triple bottom line (environmental, social, and economic sustainability) shape the driving force of an organization and its decision making. Hereby, environmental and social goals are coequal to the goal of creating economic success (Joyce & Paquin, 2016; Stubbs & Cocklin, 2008).

Within BMfS, various forms exist. A popular one is the concept of a circular business model (Bocken, Short, Rana, & Evans, 2014; Geissdoerfer et al., 2018). As traditional BMfS, also circular business models have reached increasing attention among academia and practitioners as a mean to promote sustainability (Bressanelli, Adrodegari, Perona, & Saccani, 2018). Abdelkafi and Täuscher (2016) describe them as the rationale of how an organization creates, delivers, and captures value with and within closed material loops. The general concept underlying a circular economy, is that it involves value creation by exploiting value retained in used products to generate new offerings. Thus, circular business models profit from the flow of materials and products over time. Further sub-categories of BMfS exemplarily include closed-loop business models, national capitalism, or product service systems (Bocken et al., 2014; Geissdoerfer et al., 2018)

Besides the popularity of circular business models and an increasing research trend in this field (Ghisellini, Cialani, & Ulgiati, 2015; Loorbach & Wijsman, 2013), there is a lack of theoretical grounding of BMfS, which is reflected in a scarce number of case studies and empirical analyses (Evans et al., 2017; Schoormann et al., 2016). For detailed and comprehensive literature reviews of BMfS, please refer to Abdelkafi and Täuscher (2016, pp. 76–77) or Schoormann et al. (2016), who inter alia state that literature on BMfS identifies archetypes (Bocken et al., 2014), ideal types (Stubbs & Cocklin, 2008), presents case studies (Lueg, Pedersen, & Clemmensen, 2015), or develops methodologies toward the innovation of BMfS (Bocken, Short, Rana, & Evans, 2013). Additionally, research scholars also discuss motivations, benefits as well as efforts of BMfS (Fellner, Lederer, Scharff, & Laner, 2017; Ritzén & Sandström, 2017; Rizos, Behrens, Kafyeke, Hirschnitz-Garbers, & Ioannou, 2015). In this context, scholars particularly postulate that assessing if and when benefits of business model transformation unfold, is complex to assess in advance and, thus, highlight the need for an integrated perspective before starting transformation. We discuss this issue in the following.

2.4. Motivations for BMfS and the need of an integrated perspective

Switching from a non-sustainable (i.e., “linear”) model of economy to a more sustainable one, has recently attracted attention from major global companies, such as Google, Unilever, Renault, or further key players attending the world economic forum, such as policy makers (Evans et al., 2017; Ghisellini et al., 2015; Lewandowski, 2016). According to related research, organizations’ motivation for transforming their business models towards a BMfS or respective sub-forms such as circular economy business models, can be classified as fourfold: huge environmental and societal benefits, changing customer demands, economic value potential, and the need to hold a pole position in the new sustainability market. In the following, we describe each motivation in detail.

First, there is a pressing need to transition to sustainability (Geissdoerfer, Savaget, Bocken, & Hultink, 2017). As already stated in the introduction above, environmental problems such as biodiversity loss, water, air, and soil pollution, resource depletion, or excessive land use highlight, that the natural environment is under immanent pressure to collapse (Geissdoerfer et al., 2017; Seidel et al., 2017). These problems are threatening the integrity of natural ecosystems that are essential for humanity's survival (Ghisellini et al., 2015). A study of seven European Nations found that a shift to a more sustainable (e.g., circular) economy would reduce each nation's greenhouse-gas emissions by up to 70% (Stahel, 2016; Wijkman & Skånberg, 2015). As the relationship between industry and environment is crucial for industrial performance, listed environmental impacts have pressure on industrial business and are threatening the stability of economies (Ghisellini et al., 2015; Lieder & Rashid, 2016). This effect can be mitigated by BMfS which are expected to lead to a more sustainable development and a harmonious society (Ghiselline 2015; Loorbach and Wijsman 2015). Adopting this rationale, the concept of BMfS has also gained momentum on the agendas of policy makers (Geissdoerfer et al., 2017; Zink & Geyer, 2017). The European Union for example, released a Circular Economy Action Plan that proposes measures for transitioning Europe towards a circular economy and sketches out future challenges to shaping the economy and paving the way towards a climate-neutral, circular economy (European Commission, 2019).

Second, from a strategic management perspective, a business model primarily serves customer needs (Schaltegger et al., 2012; Schaltegger et al., 2016). As already mentioned in the introduction above, customers are increasingly concerned about sustainability issues, seek sustainability in their consumption, and are fond of sustainability-oriented business models (Antikainen et al., 2015; Hamari et al., 2016; Moktadir, Rahman, Rahman, Ali, & Paul, 2018). Thus, there is also huge pressure to provide a more sustainable alternative to the current linear economic model from the customers' side (Moktadir et al., 2018). These changing customer habits come along with several benefits, such as attracting new customers and increasing market share in sustainability oriented customer segments, higher customer retention and customer value as a result of sustainability-oriented relationships, or reducing sustainability risks for customers which results in higher customer loyalty (Rizos et al., 2015; Schaltegger et al., 2012).

Third, organizations are increasingly aware of the opportunities and respective financial benefits coming along with sustainability-driven business models and have started to realize their value potential for themselves and their stakeholders (Lewandowski, 2016). Financial benefits are exemplarily derived from radically improved resource efficiency, waste reduction (waste is turned into secondary raw materials), cost savings such as net material costs and reduced demand for virgin materials which in turn mitigates price-volatility of raw-material markets (e.g., for iron ore) and supply risks, or increased employment potentials (Despeisse et al., 2017; Fellner et al., 2017; Ritzén & Sandström, 2017; Rizos et al., 2015).

Fourth, with respect to listed benefits coming along with BMfS, arguably, frontrunner organizations that orient themselves towards sustainability market decisions develop a competitive advantage. This competitive advantage is i.a. grounded in the co-creation of new sustainability markets and on the short term in the development renewed ambition and enthusiasm (Loorback and Wijsman 2012). Further, moving towards sustainability-driven business models requires fundamental changes in the whole organization and involves all stakeholders. Such a transition is certainly of disruptive nature. Thus, fostering the uptake of BMfS requires a comprehensive and detailed analysis of potential opportunities such a business model could yield and related costs (Ritzén & Sandström, 2017). Such an analysis is rather complex. The high complexity relates to how to preliminary assess the effort of business model transformation, the impact of subsequent sustainability innovations, and how to understand the effects on the whole business network (Evans et al., 2017; Ritzén & Sandström, 2017). Evans et al. (2017) therefore argues in this context that: "*A main source of complexity in business model innovation is given by the uncertainty of impacts and behaviors of network members regarding the three sustainability dimensions. A simulation model, therefore, should be built to support a focal firm to identify value flows and exchanges, which could reveal opportunities for business model innovations and de-risk experimentation*" (Evans et al., 2017, p. 605). Our research exactly addresses this rationale postulated by Evans et al. (2017) and we use game theory to study the market conditions and competitive dynamics that should be considered before innovating business models towards BMfS.

2.5. Game Theory and BMfS

Game theory has been recognized as indispensable to the understanding of environmental problems (Finus, 2002, 2008; Vrieze, 2012). Vrieze (2012) even states that game theory can help the world and its population to survive. Popular applications of game theory in the context of environmental sustainability are international environmental agreements (e.g., Chander & Tulkens, 2006; Finus, 2002), or the preservation of resources (e.g., Dolinsky, 2015).

Also in the business context, game theory is kindly regarded, as the essence of business success lies in making sure to play the right game (Brandenburger & Nalebuff, 1995; Seifi & Crowther, 2018). However, with reference to business models, Casadesus-Masanell and Zhu (2013) state, that their study offers the first formal model for business model innovation in a game-theoretic framework. The research paper focuses on sponsor-based business model innovations where an organization monetizes its products through sponsors rather than setting prices to its customer base. After an extensive literature review (also a cited reference search of Casadesus-Masanell and Zhu (2013)), we found little to no further research of the application of a game-theoretic framework in the context of business model innovation. Baniak and Dubina (2012) provide a comprehensive literature review on trends of game-theoretic applications in the context of business innovations but also miss out the field of business models. Thus, to the best of our knowledge, this study is a primer in using a game-theoretic framework to analyze business model innovation – in general and in particular in the context of sustainability.

In the following we propose the game-theoretic framework to examine when such radical change in business models in favor of sustainability pays off.

3. Research Model

For building an economic research model, we apply fundamental theoretical concepts of auction and game theory. While auction theory defines the market setting, the game-theoretic framework defines the game in terms of number of players, strategies, payoffs, information sets, and equilibria. The resulting model is implemented as a n-player and m-prize all-pay auction model and tested in different simulated market scenarios.

3.1. Model Assumptions

We implement our model in the game-theoretic framework that abstracts from reality, reflecting the most important characteristics from reality (Kreps, 1990). In general, the game-theoretic framework defines a game by three elements: i) players, ii) strategies and iii) payoffs (Gibbons, 1994). Applied on our research question, the game is characterized by i) the organizations which participate in the market, which have ii) different options to decide on strategies of sustainable behavior and iii) receive payoffs based on the interaction of the different market participants.

To sufficiently define the game, we establish a microeconomic model which considers market realities whilst capturing the three characterizing game elements players, strategies and outcomes (i.e., i), ii), and iii)). For this purpose, we follow the microeconomic theory which identifies the market in terms of size and structure, number of players (i.e., organizations), prices and production costs (for products), and demand preferences (of customers) as major influences on the market outcome (Mas-Colell, Whinston, & Green, 1995). Table 1-3 exemplify market structure and general market setting as well as scenario-specific parameters used in this work. Please note that the parametrization of these variables enables us to simulate real-world market situations and influences the possible outcome of an organization's decision, e.g. an organization's consequence of implementing a sustainable policy, given that other organizations in the market lack implementing such measures and the customers are modeled to not showing any preference to buy products from sustainable organizations.

Specifically, we make several assumptions on the market structure: we assume that at the beginning (t = 0), there is only one market which we refer to as "regular market" from this point on. In this market organizations have no level of sustainability[1] introduced in their business model yet. Further, we assume, that in this regular market a sustainability market potential (i.e., triggered by customers with preferences for sustainability) exists. If organizations decide to integrate sustainability in their business model, we assume a market split in t = 1 into a regular and a sustainability market. In this situation, total demand also splits and sustainability conscious customers shift their demand to the sustainability market. Hereby we assume no growth in the total demand between t = 0 and t = 1 and, thus, omit customers leaving or entering the market. The demand shift in the market happens once and instantly. We assume all market participants to have complete information about the sustainability levels integrated in the business model of organizations and observable exact outcomes. This implies that organizations are rewarded in terms of market share in the sustainability market on the basis of the implemented sustainability level in their business model.

Second, we apply the concept of "homo oeconomicus" and assume organizations are rational and risk-neutral players who aim at maximizing their overall payoffs. Further, we neglect capacity considerations by assuming organizations to perfectly adjust to demand. Referring to

[1] Please note: According to our description of BMfS, the "level of sustainability" either refers to a situation where organizations fully integrated sustainability (maximum level) in their business model or only did so in parts. Whereas in the first case, social and environmental goals are coequal to the goal of creating economic performance, they are subordinated to certain extents in the latter case.

the efforts made to integrate sustainability in the business model, we assign a sustainability cost factor, which depends on an organization's favored sustainability level.

Third, with reference to the products sold by organizations, we assume them to be homogenous within one industry. Hereby we specifically assume that an organization's integration of sustainability in its business model does not change the product itself, but has effects on the business level (e.g., supply chains) and positively influences customers' willingness to pay, allowing to charge higher prices for a still homogenous product. This assumption differentiates our model from a market in which investments in improved product quality directly influence product features and lead to heterogeneous products. In such a case, organizations would be able to offer two products simultaneously and allow customers to self-select the preferred product only based on price. Further, as we aim to capture the impact of an integration of sustainability in the business model imposes on organizations' economic performance, we assume the production cost per unit of a specific organization to remain constant.

3.2. Market Setting – All-Pay Auction

We use the economic idea of an all-pay auction and establish a market setting where organizations of the same industry (i.e., players) undertake efforts to integrate sustainability at a certain level in their business model (i.e., place their bets). After the auction, the market splits into a regular and a sustainability market and a share of customers with preferences for sustainability migrate to the sustainability market, which now represents the auction prize. Please note that the total market demand by assumption remains unchanged. However, the market volume changes due to the higher price for products from the sustainable organization(s). In the case of a single-prize auction, only one prize is allocated to the players and, thus, the organization with the highest bid gains market share in the sustainability market, whereas all other organizations do not get any compensation for their efforts made (i.e., all-pay). The single-prize all-pay auction establishes a hypothesis of a market in which customers solely reward the most sustainable organization, whereas the multi-prize auction serves as an alternative mechanism in which customers reward sustainability initiatives of multiple organizations (e.g., because they cannot identify the most sustainable but a number of most sustainable organizations).

As stated in our assumptions, organizations in the sustainability market will be able to charge a higher price for the still homogenous product. But as they are unable to charge higher prices from customers in the sustainability market than from customers in the regular market, organizations winning the auction exit the regular market and lose their former market share. The other players gain in market share in the regular market proportional to their previous market shares (pro rata assignment), i.e. the non-sustainable market demand is distributed among the remaining players.

Table 1 exemplifies this idea in a single-prize all-pay auction. Here we establish a market setting where different organizations (Organizations A, B, C, and D) of the same industry hold a certain market position in the regular market in t = 0. All organizations now decide to integrate sustainability in their business models and compete for the sustainability market in t = 1. The player with the highest bid (in this example Organization D) wins and gains total market share (i.e., acts as unique player) in the sustainability market to compensate for his efforts.

Besides the simple all-pay auction form with only one winner ("single-prize model"), we will also examine situations with multiple winners ("multi-prize model") and (for completion) technical limiting cases ("zero bidding") in this research paper.

t = 0

Regular Market Total Market Demand 100%	
Organization	Market Share
A	40%
B	10%
C	20%
D	30%

t = 1

Sustainability Market 30% of Total Market Demand	
Organization	Market Share
D	100%

Regular Market 70% of Total Market Demand	
Organization	Market Share
A	57%
B	14%
C	29%

Table 1. Market Setting in case of a single-prize all-pay auction

3.3. Single-Prize All-Pay Auction

Within this research paper, we examine different forms of an all-pay auction. However, each form has an equal starting point: in t=0 there is a sustainability market potential $\gamma \in [0,1]$ in in the regular market for which players can compete. As soon as the auction starts, organizations can place their bids and start implementing sustainability in their business model. Hereby, the costs for implementation depend on an organization's sustainability cost factor (α_i) and on the sustainability level (x_i) introduced.

At first, we examine a single-prize all-pay auction, which states that only one player wins the prize and is compensated for his sustainability investments. Please note that with reference to the link between business model transformation and sustainability innovations stated in section "Sustainability Business Research" above, we define sustainability investments as costs associated with sustainability innovations (e.g., costs for integrating technology innovations, or costs for developing and switching to superior production processes and operating procedures), which are in turn enabled by business model transformation. The players' payoffs depend on the sustainability level (x_i) integrated in the business model and are formulated by the function $\pi_i(x)$, $x = (x_1, \dots, x_n)$.

As organizations are per assumption risk-neutral, we use expected profits in the payoffs in case we are dealing with probabilistic payoffs. The pay-off function consists of two parts: first, the profit from operating in the assigned market after the all-pay auction, and second, the cost of integrating sustainability in the business model. First, the profit is calculated as follows: If organization i loses the auction and continues in the regular market (see equation 1.I in Figure 1), it obtains a market share proportional to its old market share i.e., $\frac{\delta_i}{1-\bar{\delta}} * (1-\gamma) * Q$. If organization i wins, its market share equals $\gamma * Q$ (see equation 1.II in Figure 1). The profit from operating in the assigned market is therefore the respective market share multiplied by the profit per product, $(p_i - c_i)$ in the regular market or $(\tilde{p}_i - c_i)$ in the sustainability market. Please note that we model prices and costs exogenously, and by assumption organizations make profits in both markets (i.e. $(p_i - c_i)$, $(\tilde{p}_i - c_i) > 0$), as otherwise organizations would leave the market. Further note, that depending on x_i, we may need to decide the winner of the auction by coin toss. When there is a tie among players, we determine the winner at random where every organization i has the same winning probability $P(i\ wins) = \frac{1}{m}$ for m tied players. In the case of organization i ties with another organization, we compute the expected payoff, which has the representation of equation 1.III in Figure 1. The organization receives an expected $\frac{Q}{k}[\gamma * (\tilde{p}_i - c_i)]$ in the case it wins the coin toss and an expected $\frac{Q}{k}\left[(1-\gamma) * (p_i - c_i) \sum_{j=1, j\neq i}^{k} \frac{\delta_i}{1-\delta_j}\right]$ in the case it remains in the regular market. Finally, if only other organizations tie – see equation 1.IV in Figure 1, it receives an expected $(1-\gamma) * Q * (p_i - c_i)\left(\frac{1}{k}\sum_{j=1}^{k} \frac{\delta_i}{1-\delta_j}\right)$. Finally, once the net profit is calculated for any case, costs of sustainability investment $\alpha_i x_i$ are deducted. Figure 1 illustrates respective formulas.

$$\pi_i(x) = \begin{cases} \frac{\delta_i}{1-\bar{\delta}}(1-\gamma) * Q * (p_i - c_i) - \alpha_i x_i, \quad \frac{\delta_i}{1-\delta_j} & \text{if organization } i \text{ loses (1.I)} \\ \gamma * Q * (\tilde{p}_i - c_i) - \alpha_i x_i, \quad \left(\frac{1}{k}\sum_{j=1}^{k} \frac{\delta_i}{1-\delta_j}\right) & \text{if organization } i \text{ wins (1.II)} \\ \frac{Q}{k}\left[\gamma * (\tilde{p}_i - c_i) + (1-\gamma) * (p_i - c_i) \sum_{j=1, j\neq i}^{k} \frac{\delta_i}{1-\delta_j}\right] - \alpha_i x_i, & \text{if organizations 1 to } k \text{ tie and } i \text{ is one of them (1.III)} \\ (1-\gamma) * Q * (p_i - c_i)\left(\frac{1}{k}\sum_{j=1}^{k} \frac{\delta_i}{1-\delta_j}\right) - \alpha_i x_i, & \text{if organizations 1 to } k \text{ tie and player } i \text{ not one of them (1.IV)} \end{cases}$$

Abbreviations:
$\pi_i(x)$: Organization i's payoff when all organizations invest levels x;
Q: Absolute demand in the regular market, which is also the aggregate demand of the later sustainability and regular markets, $Q \in \mathbb{N}$;
γ: Sustainability market potential in the regular market, $\gamma \in [0,1]$;
δ_i: Organization i's market share in the regular market before the all-pay auction, $\delta_i \in [0,1], \sum_{i=1}^{n} \delta_i = 1$;
p_i: Organization i's price per product in the regular market after the all-pay auction if it loses, $p_i \in \mathbb{R}_+$;
$\tilde{p}_i$: Organization i's price per product in the sustainability market after the all-pay auction if it wins, $\tilde{p}_i \in \mathbb{R}_+$;
c_i: Organization i's costs per product in all markets, $c_i \in \mathbb{R}_+$;
α_i: Organization i's sustainability cost factor, $\alpha_i \in \mathbb{R}_+$;
x_i: Organization i's level of investment in sustainability, $x_i \in [0,1]$.
$\bar{x} = x_1 + \cdots + x_m$: Aggregated sustainability levels of winners.
$\bar{\delta} = \delta_1 + \cdots + \delta_m$: Aggregated market share of winners.

Figure 1. Payoff function in single-prize all-pay auction model

3.4. Multi-Prize All-Pay Auction

The multi-prize all-pay auction states that multiple players win the prize and are compensated for their sustainability investments. In this case, multiple organizations migrate to the sustainability market. Respective payoffs $\pi_i(x)$ are formulated in Figure 2, Part A and are explained in this section.

In analogy to the single-prize model, players can be tied and a winner must be found. For two tied players, we toss a coin and for more than two players, we draw the number of remaining prizes out of the tied players, i.e., the organizations play a lottery. Thinking of this as a combinatorial problem, we need to find the probability for organization i that tied with players j to $m + k$ to be among the $m - j + 1$ winners drawn from all tied players. Equation 2.B1 and equation 2.B2 in Figure 2 are immediate results from the hypergeometric distribution. The probability distribution associated with this problem is a hypergeometric distribution, with equation 2.C1 in Figure 2 immediately resulting from this consideration. We note that for the expectation conditioned on organization i losing, we only draw from $m + k - j$ tied players since i cannot win in the lottery anymore.

The payoff function interpretations are generally similar to the one prize all-pay auction in Figure 1. In equation 2.AIV in Figure 2 the case of ties including organization i, its expected payoff is given by $P(i \text{ wins}) * \gamma * Q * \frac{x_i}{\bar{x}} * (\tilde{p}_i - c_i)$ in the case i wins the toss and $P(i\ loses) * (1-\gamma) * Q * E\left[\frac{\delta_i}{1-\bar{\delta}} \middle| i \text{ loses}\right] * (p_i - c_i) - \alpha_i x_i$ in the case i loses the coin toss. If organization i wins the auction and migrates to the sustainability market, it obtains the market share relative to its and the other winners' bids in the regular market, i.e., $\frac{x_i}{\overline{x}} * \gamma * Q$ (see equation 2.AIII in Figure 2).

When putting $\overline{x} = x_1 + \cdots + x_m$ and $\overline{\delta} = \delta_1 + \cdots + \delta_m$, we note that $\overline{x}$ and $\overline{\delta}$ may be random variables, depending on the outcome of the draw. Respective formula are stated in Figure 2, Part B and Part C.

With reference to the market share in the sustainability market, the winning organizations depend on the other winners' bids. Analogue to the single-prize auction, this market share is now multiplied by $\frac{x_i}{\overline{x}}$. Thus, if one organization integrates twice as much of sustainability in its business model than its counterpart, it is awarded twice as much market share in the sustainability market (pro rata assignment).

Part A: Payoff function

$$\pi_i(x) = \begin{cases} \frac{\delta_i}{1-\overline{\delta}}(1-\gamma) * Q * (p_i - c_i) - \alpha_i x_i, c_i) - -c_i) - -c_i) - \quad -c_i) - & \text{if i loses (2.AI)} \\ \gamma * \frac{x_i}{\overline{x}} * Q * (\tilde{p}_i - c_i) - \alpha_i x_i, * (\tilde{p}_i - c_i) * (\tilde{p}_i - c_i) -, & \text{if i wins (2.AII)} \\ \gamma * Q * \frac{x_i}{\overline{x}} * (\tilde{p}_i - c_i) - \alpha_i x_i, & \text{if } j \text{ to } m+k \text{ tie and } i \text{ wins anyway (2.AIII)} \\ P(i\ wins) * \gamma * Q * \frac{x_i}{\overline{x}} * (\tilde{p}_i - c_i) + P(i\ loses) * (1-\gamma) * Q * E\left[\frac{\delta_i}{1-\overline{\delta}} \middle| i \text{ loses}\right] * (p_i - c_i) - \alpha_i x_i, & \text{if } j \text{ to } m+k \text{ tie, } i \text{ one of them (2.AIV)} \\ (1-\gamma) * Q * E\left[\frac{\delta_i}{1-\overline{\delta}}\right] * (p_i - c_i) - \alpha_i x_i, c_i) - c_i) - c_i) c_i) - \quad) \quad) & \text{if } j \text{ to } m+k \text{ tie, } i \text{ not one of them (2.AIV)} \end{cases}$$

Part B: Definition of the term $E\left[\frac{1}{1-\overline{\delta}}\right]$ in the payoff function (see Part A of this table)

$$E\left[\frac{1}{1-\overline{\delta}}\right] = \sum_{\sigma \in m-j+1-\text{tuple } of \ \{j,\ldots,m\}} \frac{1}{\binom{m+k-j+1}{m-j+1}} \frac{1}{1-(\delta_1 + \cdots + \delta_{j-1} + \delta_{\sigma(j)} + \cdots + \delta_{\sigma(m)})} \quad \text{(2.BI)}$$

$$E\left[\frac{\delta_i}{1-\overline{\delta}} \middle| i \text{ loses}\right] = \sum_{\sigma \in m-j+1-\text{tuple } of \ \{j,\ldots,m\}\setminus\{i\}} \frac{1}{\binom{m+k-j}{m-j+1}} \frac{1}{1-(\delta_1 + \cdots + \delta_{j-1} + \delta_{\sigma(j)} + \cdots + \delta_{\sigma(m)})} \quad \text{(2.BII)}$$

Part C: Probability that organization i wins

$$P(i \text{ wins}) = P(i \text{ is among the } m-j+1 \text{ winners drawn from } m+k-j \text{ tied players})$$

$$= HyperGeom_{m+k-j+1,1,m-j+1} = \frac{\binom{m+k-j+1}{1}}{\binom{m+k-j+1}{m-j+1}} = 1 - P(i\ loses) \quad \text{(2.CI)}$$

Abbreviations:
$\pi_i(x)$*: Organization i's payoff when all organizations invest levels* x*;*
Q*: Absolute demand in the regular market, which is also the aggregate demand of the later sustainability and regular markets,* $Q \in \mathbb{N}$ *;*
γ*: Sustainability market potential in the regular market,* $\gamma \in [0,1]$*;*
δ_i*: Organization i's market share in the regular market before the all-pay auction,* $\delta_i \in [0,1], \sum_{i=1}^{n} \delta_i = 1$*;*
p_i*: Organization i's price per product in the regular market after the all-pay auction if it loses,* $p_i \in \mathbb{R}_+$*;*
$\tilde{p}_i$*: Organization i's price per product in the sustainability market after the all-pay auction if it wins,* $\tilde{p}_i \in \mathbb{R}_+$*;*
c_i*: Organization i's costs per product in all markets,* $c_i \in \mathbb{R}_+$*;*
α_i*: Organization i's sustainability cost factor,* $\alpha_i \in \mathbb{R}_+$*;*
x_i*: Organization i's level of investment in sustainability,* $x_i \in [0,1]$.
$\overline{x} = x_1 + \cdots + x_m$*: Aggregated sustainability levels of winners.*
$\overline{\delta} = \delta_1 + \cdots + \delta_m$*: Aggregated market share of winners.*

Figure 2. Formula in multi-prize all-pay auction model

3.5. Limiting Cases

The above stated single- and multi-prize all-pay auctions omit the following limiting cases, which we introduce for reasons of completion:

a. In a single- and multi-prize auction no organization transforms its business model towards sustainability and bid $x_i = 0$.

b. In a multi-prize auction an organization with a bid of $x_i = 0$ may be awarded for its sustainability efforts but gains no market share due to $x_i = 0$.

Referring to the first special situation (a.), this resembles the market in its regular state (t = 0), where no player places a bid and, thus, in t = 1 we fall back to an identical market situation and calculate the players' payoffs with no change in the market.

Referring to the second special situation (b.), we assume at least one player with $x_i \neq 0$ and players $x_j = \cdots = x_{m+k} = 0$. In this case, prizes would be given to players who did not place a bid. Therefore, we reduce the number of prizes in a way that only players with a bid of $x_i > 0$ can be rewarded. Without doubt, one could think of different ways to address the zero-bidding problem in the payoffs, however our analyses indicated that results are robust to other allocation methods.

3.6. Discretization of the model

In the theoretical model, players can set continuous levels of sustainability x_i, whereas in our implementation players are limited to a fixed number of sustainability strategies. Therefore, we set levels discretely between 0 and 1 with a step size of 0.1. The step interval of 0.1 is chosen to limit computational complexity.

When simulating the outcome of a game, we start by filling the payoff matrix $\Pi \in R^{l^n xn}$ for the specific situation, in which every dimension represents an organization and the number of rows represents its number of strategies. The last dimension represents the payoffs associated with the organizations' strategies, i.e., sustainability levels.

3.7. Model Implementation

We implement the model as n-player and m-prize all-pay auction in Python and define the game as follows:

1. Set of players in the game: Our model incorporates n (finite) competing organizations.

2. Strategy for each player: The decision variable x_i represents the level of sustainability integrated in the business model of an organization and is a standardized value between 0 (no sustainability is integrated, i.e., linear economy) and 1 (maximum level of sustainability is integrated).

3. Payoffs: Payoffs result from organizations' profits which depend on the integrated level of sustainability in their business model and the above payoff functions for the corresponding setting.

4. Rules of the game: The model assumes complete information, simultaneous moves of all players and a one-stage game (i.e., the game is only played once).

We make use of the normal form, an illustrative representation of games, allowing us to identify Nash equilibria. We limit the analysis to pure strategies. The Nash equilibrium concept is characterized by every player choosing its best responses for every player given the other players behavior in all possible situations, i.e., in all possible states of the world given all players choices of behavior. Hence, we automatically calculate all payoffs and optimal behaviors given every possible state of the world, implementing functions in Python calculating payoffs and Nash equilibria for varying γ-levels, number of players, and prizes. Please note that the high dimensionality of the normal form of the payoff matrix, i.e. $\Pi \in R^{l^n x n}$, does not allow for a proper visualization of the normal form if more than two players interact with each other (Gibbons, 1994).

3.8. Identification of Nash Equilibria in Pure Strategies in a Payoff Matrix

We calculate best response matrices for every player. Therefore, we mark the best response in a $\{0, 1\}^{l^n}$ matrix and reduce these n matrices we found for the players to one by applying a logical "and"-operation. The identified 1's in the equilibrium matrix are the resulting Nash equilibria in pure strategies. Although from the position of the 1's in the matrix one can determine the corresponding strategies, one still needs to reason for the identified equilibria.

When considering the size of the involved payoff matrix Π, we observe that it grows exponentially with the number of players or the number of strategies involved. The computational complexity for finding these equilibria in pure strategies is $\mathcal{O}(n^2 l^n)$. A simple profiling of the associated Python code indicated that calculating the involved payoff matrix is the extensive part. As there is in general no linearity or regularity to be found in the payoff matrix, we need to calculate every tuple of payoffs individually for every strategy combination. This makes our calculations for player numbers greater than seven or strategy numbers greater than ten very extensive, having to write every field of the matrix for itself.

Nevertheless, for reasonable player and strategy numbers, our algorithm for calculating Nash equilibria in pure strategies performs very well.

3.9. Simulation Scenarios

We apply our theoretical model in the following four simulated market scenarios:

1. Five symmetric players compete for one and two prizes.
2. The number of symmetric players in scenario (1) in the one-prize setting is varied (i.e., n ϵ {3,4,6,7}).
3. The symmetry assumption is dissolved, and a more generalized asymmetric market scenario is created: A “strong player” (high market share, low costs for integrating sustainability to the business model) competes with four symmetric players (“weak players”) for one and two prizes.
4. As scenarios (1) – (3) indicate multiple market outcomes within the friction interval (see below), we provide guidelines on how to handle such friction intervals. One player with no sustainability costs (otherwise symmetric) competes with two symmetric players. We denote the player without implementation costs zero-bid organization.

Scenario (1) serves as the reference scenario in which we investigate similar (symmetric) organizations that compete for a single prize, i.e. a setting in which customers reward only the most sustainable organization with the market entry as well as in a two-prize setting, in which customers award two sustainable organizations. (2) is examined to investigate the robustness of results if the number of players is varied. This scenario also represents the fundamental microeconomic question of market effects of atomistic vs. oligopolistic markets. We investigate a non-symmetric market setting in scenario (3) to allow a more realistic market setting and include the dimension of market leadership, such that one can study the interactions between larger and smaller players. The final scenario examines a frequently observed market in which one player has a strategic advantage over the other players and has zero implementation costs (i.e. due to a superior business model or sustainable business culture). We aim to study under which circumstances this advantage of zero bidding costs constitutes the corresponding player as sustainability leader and how stable this result is.

When simulating these scenarios, comparability of the results is of considerable importance. Therefore, all four scenarios derive their parameters from one basic setting stated in Table 2. In this basic setting, every organization has the profit margin of 17.6% in the regular and 35.0% sustainability market. Originally, each of them earns $Q * \delta_i * (p_i - c_i) = 3$ in a five-player setting, which means that efforts on sustainability may cost them as much as 2/3 of their profits. Please note that the basic parameter choices can be varied w.l.o.g. as long as organizations make profits in the regular market (and hence, also in the sustainable market).

Parameter	Value
Price (regular market)	$p_i = 1$
Price (sustainability market)	$\tilde{p}_i = 1.15$
Costs	$c_i = 0.85$
Sustainability Cost Factor	$\alpha_i = 2$
Market Share (for five players)	$\delta_i = 0.2$
Total Demand	$Q = 100$
Sustainability Levels	$\in \{0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1\}$

Table 2. Basic parameters

Now, depending on the scenario, we change the parameters as stated in Table 3. This change aims at enhancing visibility of occurring effects. We employ a higher sustainability cost factor in scenario (4) to clearly carve out the contrast between the organizations.

<table>
<tr><th>Scenario</th><th>Organization 1</th><th>Organization 2</th><th>Organization 3</th><th>Organization 4</th><th>Organization 5</th></tr>
<tr><td>(1)</td><td colspan="5">Scenario equals basic parameters stated in Table 2</td></tr>
<tr><td>(2)</td><td colspan="5">The number of players is varied for Scenario (1) in the one-prize setting</td></tr>
<tr><td>(3)</td><td>$\tilde{p}_i = 1.3$
$c_i = 0.65$
$\alpha_i = 0.5$
$\delta_i = 0.6$</td><td>$\alpha_i = 4$
$\delta_i = 0.1$</td><td>$\alpha_i = 4$
$\delta_i = 0.1$</td><td>$\alpha_i = 4$
$\delta_i = 0.1$</td><td>$\alpha_i = 4$
$\delta_i = 0.1$</td></tr>
<tr><td>(4)</td><td>$\delta_i = 1/3$
$\alpha_i = 0$</td><td>$\delta_i = 1/3$
$\alpha_i = 10$</td><td>$\delta_i = 1/3$
$\alpha_i = 10$</td><td colspan="2">$n = 3$ is sufficient in this scenario</td></tr>
</table>

Table 3. Scenario-specific parameters

4. Results

For each scenario, stated results refer to the level of sustainability implemented in organizations' business models and payoffs (i.e., profits).

4.1. Scenario (1)

Simulation results for five symmetric players competing for one prize are stated in Figure 3. Results for sustainability levels indicate, that players symmetrically start to integrate sustainability in their business model, if the sustainability market potential in the regular market γ is ≥ 0.1. However, a Nash equilibrium in pure strategies only occurs, if γ reaches a critical value. Within this scenario this critical mass in sustainability demand γ is 0.3. From this point on, the number of equilibria spike, which we refer to as friction interval (grey-shaded area in Figure 1). If $\gamma \geq 0.5$, the model predicts that all organizations symmetrically play a maximum sustainability strategy in the resulting unique Nash equilibrium ($x_i^{0.5} = 1 \; \forall i \in \{1, \ldots, 5\}$), yielding a maximum market sustainability.

Results for organizations' profits indicate that if the sustainability market potential is low (e.g., $\gamma \in [0.2, 0.4]$), organizations lose profits compared to the regular market scenario, but are (over)compensated when $\gamma > 0.7$. From $\gamma > 0.7$ on, organizations increase the total market profit compared to t = 0.

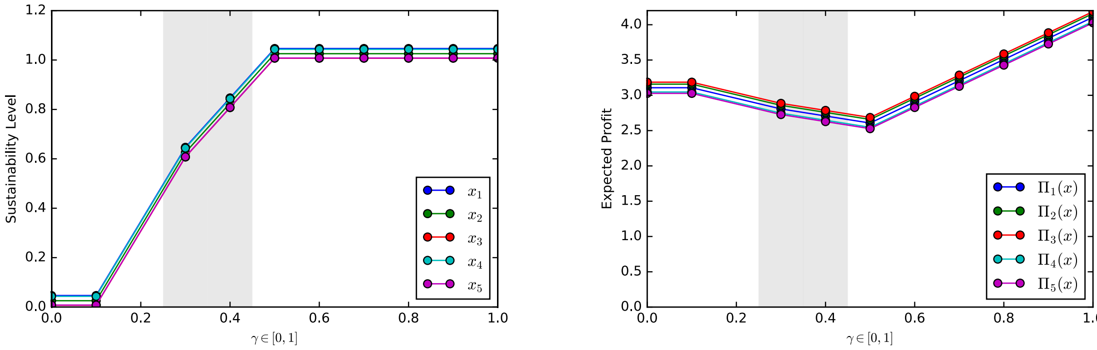

Figure 3. Sustainability level and expected profit for Scenario (1) in the one-prize setting

Simulation results for five symmetric players competing for two prizes are stated in Figure 4. Results for sustainability levels indicate, that although two winners share the sustainability market, the critical value of γ remains unchanged. However, the simulation yields a larger number of situations where no Nash equilibrium in pure strategies can be found. This effect can be linked to the synthetic setting in which players are perfectly symmetric and, thus, play a coordination game in which only one player implements a maximum sustainability strategy $x_i = 1$ while others implement $x_j = 0$.

Results for organizations' profits indicate that when comparing this two-prize to the one-prize setting, individual players' aggregated payoff (due to the symmetry of the equilibrium) is robust against an increasing number of prizes for scenarios for $\gamma > 0.5$.

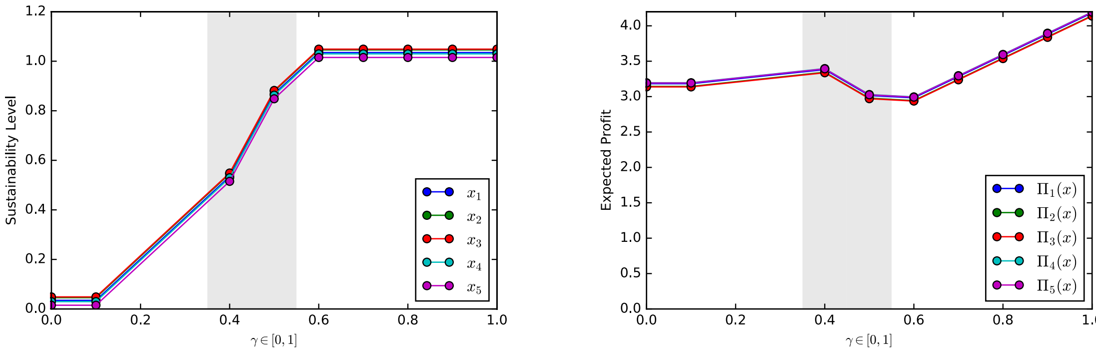

Figure 4: Sustainability level and expected profit for Scenario (1) in the two-prize setting

4.2. Scenario (2)

Simulation results for a varying number of symmetric players of Scenario (1) with one prize are interpreted via the mean of all players and are stated in Figure 5. Results for sustainability levels indicate that if $\gamma \geq 0.4$, at least one player plays a maximum sustainability strategy. Analogue to Scenario (1), we find that the number of equilibria spikes within the friction interval. Further, we identify the number of equilibria to increase in tendency with an increasing number of players, such that a larger number of players calls in tendency for coordination game market settings, which we interpret as the potential need for governmental guidance in transforming more atomistic industries towards more sustainability.

Additionally, we examine that the location and size of the friction interval changes with the number of players. With reference to the interval's location, organizations start to invest in sustainability at a lower γ, when the number of players grows. This effect can be linked to the smaller market share of each organization in the regular market for which it becomes more profitable to compete for the prize, even if multiple others also compete. With reference to the interval's size, the friction interval grows symmetrically in both directions with an increasing number of players. However, we examine that averagely implemented sustainability levels are robust against an increase in the number of players, which implies that the implemented strategy does not systematically vary upon the number of players and that the amount of organizations sharing a market does not strongly influence the resulting sustainability under symmetrical players.

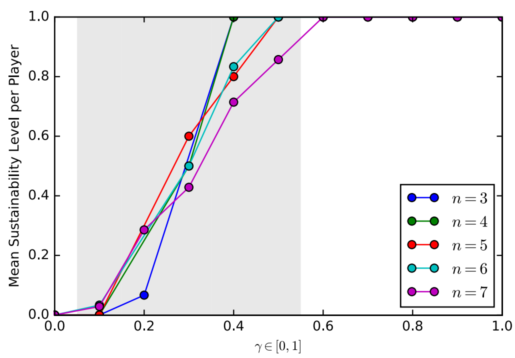

Figure 5: Mean Sustainability level for Scenario (1) in the one-prize setting

Results for organizations' profits indicate a slight decrease with an increasing number of players. This effect can be linked to the modelling of expected profits in the case of identical bids: as an increasing number of players compete in the auction and implement maximum sustainability levels, an increasing amount of industry profits is invested into the sustainability competition.

4.3. Scenario (3)

Simulation results for one strong (x_1) and four weak players (x_2-x_5) competing for one prize are stated in Figure 6. Results for sustainability levels indicate that no Nash equilibrium in pure strategies occurs for small sustainability levels. Further, we examine that the strong player only invests in sustainability, if γ is large enough. The larger the share of a strong player in the regular market, the later he will invest in sustainability. If $\gamma \geq 0.4$, the strong player's expected profit of winning – even if weak players participate in the auction – exceeds the costs of sustainability investments in the strong players' response function. Thus, the strong player invests $x_i^{\gamma} = 1$ if the critical value $\gamma_{critical}^{strong} = 0.4$. (the average implementation in multiple Nash equilibria in the friction intervals is 1, i.e., in each equilibrium the strong player implements $x_{strong} = 1$). Nevertheless, when looking at the Nash equilibria within the friction interval, each weak player i would invest either $x_{weak}^{\gamma} = 0$ or $x_{weak}^{\gamma} = 1$ in our model setting for potentially competing against the strong leader in the coin toss. Hereby, the weak players play coordination games to compromise on one player to compete in the auction, since the market within the friction interval is too small and unprofitable if all weak players compete.

Results for organizations' profits indicate, that the strong players' total expected profit function is strictly decreasing with increasing γ, whereas profit functions of weak players are non-monotonous in γ. This effect can be linked to the opportunity of weaker organizations to challenge the market leader. However, as both observations are immediate consequences of the assumed allocation of the sustainability market in a tie case, this result illustrates a sensitivity of the outcomes with respect to its underlying allocation rules.

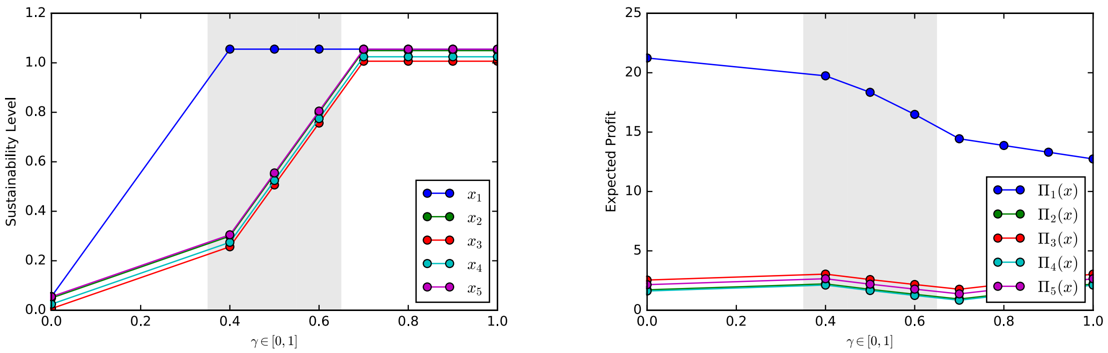

Figure 6: Sustainability level and expected profit for Scenario (3)

We additionally examine the extent to which sustainability strategies depend on our exogenously-modelled profit margins. Therefore, we perform a sensitivity analysis: we can change the margins by varying the price in the sustainability market $\tilde{p}_i$ or by decreasing the cost for sustainability investments α_i. Results of this analysis indicate that for low margins ($<$ 25%), no sustainability strategies are played. Results of a varying profit in the sustainability market are stated in Figure 7.

With reference to the weak players, increasing margins shift the critical point of sustainability investment to the left. This intuitive result indicates that a lower sustainability level γ is sufficient for weak organizations to participate in the auction.

In contrast, with reference to strong players, even at margins of 65%, they will not invest if $\gamma = 0.2$, although intuitively, it should become profitable. This is because a situation can occur where strong organizations must compete with the weak ones in the coin toss. Hence, the scenario indicates that even strong market participants can be deterred in implementing sustainability by the sheer existence of competitors even if the profitability is very high. This result complements the analysis of (2), in which the number of players in a symmetric game has little influence in the implemented sustainability level by suggesting that asymmetric market structure have different market dynamics than symmetric ones.

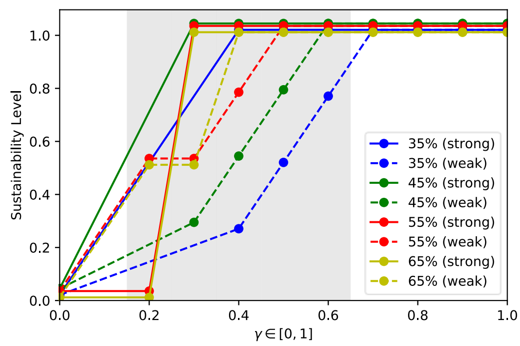

Figure 7: Sustainability levels for Scenario (3) with varying profitability in the sustainability market

4.4. Scenario (4)

Simulation results for one player with no costs of implementing sustainability (x_1) and two symmetric players with sustainability cost (x_2-x_3) compete for one prize are stated in Figure 8. Results indicate that if $\gamma \leq 0.8$, there is only one plausible equilibrium in the friction interval where the no-cost player implements sustainability, whereas the other two symmetric players do not. This is plausible, as weaker players, given the no-cost player plays $x_{no\ cost} >$

0, make a sure profit when staying in the regular market while they otherwise must play a coordination game in the other equilibria and risk to make a smaller profit.

The results indicate that a strategic (sustainability cost) advantage in implementing corporate sustainability can mean a strategic competition advantage and effectively prevent the market entry of players without such capabilities. In addition, our results indicate that the market entry of weaker organization is prevented until a very high sustainability demand (in our case $\gamma > 0.7$), and their profits are further decreased, such that sustainability leadership can pay off well for a zero-bid player. Moreover, the results indicate that even if the sustainability demand is very high and the weaker candidates finally enter the auction to get access to the sustainability market, the expected profit for the zero-cost player is larger than when γ is very low (in our case $\gamma < 0.4$).

Finally, scenario 4 complements previous the results of previous scenarios such that asymmetric markets can lead to higher sustainability implementation if there is a player with superior capabilities (i.e. cost advantages regarding sustainability.

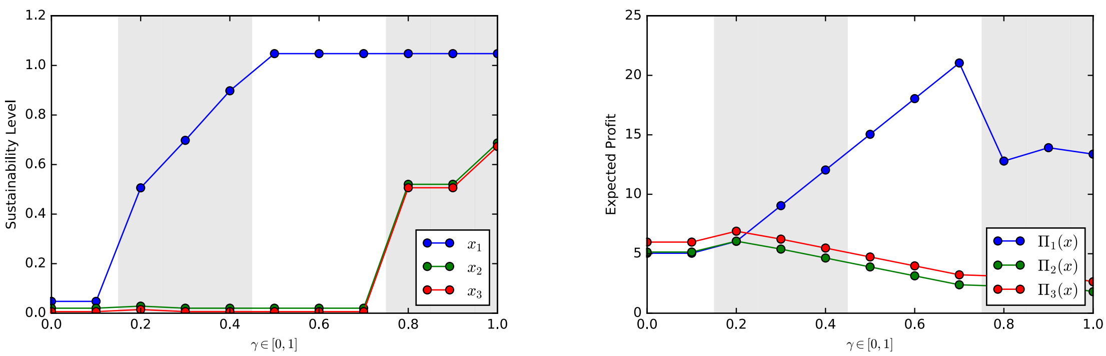

Figure 8: Sustainability levels and expected profit for Scenario (4)

5. Discussion

This research sets out to establish a research model for examining the conditions under which an integration of sustainability in an organization's business model pays off. We introduce a game-theoretic model of an all-pay auction setting which captures the competition for a market share in a sustainability market. We test the model in different market scenarios where we examine symmetric and asymmetric, weak and strong, as well as scenarios with a varying number of players.

This research offers four major theoretical contributions. First, we examine that organizations willingness to integrate sustainability in their business models increases with the sustainability market potential γ in the regular market. However, γ must reach a critical value before investments are started. Therefore, a preference for sustainability in a market is the main driver of business model transformation in our model. Additionally, we observe symmetric players to not on average start investing in sustainability much earlier in a more atomistic market. This result is not intuitive, especially in the one-prize setting in which the small organization could exclusively enter the sustainability market, translating to higher profits.

Second, we examine balancing effects of γ: Strong players only invest in sustainability, if γ is large enough. Otherwise, strong players are worse off if implemented sustainability efforts are compensated by a smaller sustainability market. However, the higher γ, the more likely it is that the strong player gets challenged by one weak player. In contrast, the introduction of insecurity about competitors' sustainability efforts tends to let the strong player get deterred from sustainability efforts. This shows that the larger the sustainable market is, the larger the relative benefit of even weak organizations to implement sustainable policies. However, this ecologically beneficial behavior of the weak can deter the strong player (with more market share) from sustainability.

Third, we perform a sensitivity analysis examining the effect of profit margins. By varying the margins, we examine that additional margins – even if substantial – play a negligible role for sustainability investments of large players but trigger weak players to start sustainability investments earlier. Again, we argue that the reason for this observation is the relative attractiveness of leaving the regular market, which increases if the margin difference between regular and sustainable market grows. These observations suggest that customers who increasingly motivate sustainable actions especially influence the decisions of weak players.

Fourth, our model suggests that if an organization can achieve very low (or zero) relative sustainability implementation costs (e.g. through superior operations or a sustainable business culture), becoming a zero bidding cost player, it can establish systematic market entry barriers to its competitors and increase its own profits. Although the simulation result implies negative effects resulting from the economic regulation and welfare loss perspective, this incentive may lead to higher sustainability.

5.1. Managerial implementations

Apart from the above-mentioned theoretical contributions, our work also has clear managerial implications: First and foremost, to have the option to enter a sustainability market and satisfy needs of sustainability conscious customers, organizations need to actively communicate introduced levels of sustainability e.g., via marketing and communication measures.

Further, results imply that organizations should undertake market research to examine the sustainability market potential e.g., in form of customers' preference for sustainability.

Especially in an asymmetric market setting (i.e., existence of one/a little number of strong market players), weak players should consider starting sustainability investments at an early sustainability demand level, potentially resulting in deterring the larger competitors from entering the sustainable market. This result holds especially the larger the number of players and the smaller the number of prizes.

Finally, our model suggests that organizations which manage to become zero bidding cost players, could set up market barriers and improve their economic performance by implementing cheap / costless sustainability measures and secure a strategic competitive advantage. Hence, transforming the business to more sustainability not only has positive effects on societies but also improve performance metrics within the organization.

5.2. Limitations

The limitations of our study are fivefold:

First, our analysis of the all-pay auction generally fits into previous literature regarding all-pay auction which predicts bidders to either bid very low or very high (Klose & Kovenock, 2015). Although we can confirm that an extreme bidding behavior explains parts of the previous literature, our results indicate that there is no such simple answer especially in situations where competition for sustainability is not very profitable for the market participants, as observed within the friction interval. Thus, the applied game-theoretic solution concept of Nash equilibria in pure strategies can explain only parts of such competition behavior. To further examine the friction interval, more advanced equilibrium concepts need to be applied to better predict organizational strategy. We indicate one such plausibility approach in scenario (4).

Second, although we also see our contribution in building a basic model and research framework as foundation for future research and that it can be enhanced through the implementation of more advanced equilibrium concepts, we are aware of the shortcoming that despite careful considerations, we feed the model with microeconomic data which remain theoretical and are difficult to empirically observe. We have performed sensitivity and scenario analyses to account for the shortcomings induced by the theoretical research method.

Third, all observed results are subject to the very strong assumption of modelling a static game. As the world is dynamic and sustainability is not a one-time decision-making process, we cannot include considerations of time in our model, e.g., punishment effects in the market when an implicit hygiene requirement of sustainability in the market is not met. In consequence, the suggested results are to be considered carefully especially due to the lack of the time dimension. In particular, the results are indicating that a strong player would tend to invest late in sustainability because it’s more profitable for him to serve the conventional market are probably not robust when one includes multi-period competitions. It would become less profitable to disregard sustainability in the long-term corporate strategy.

Fourth, we observe that the number of prizes in the game does not strongly influence the behavior of the customers. This is due to the expected value assumption for the payoffs. Since the number of prizes serve as a distribution indication on the market and a larger number indicates that the reward for investment splits more evenly, the indicated results should be evaluated in the further examination. Thus, the assumption of the organizations to include expectations of profits is crucial to this outcome. Although this assumption is uncritical for organizations that are active in multiple product markets and therefore are diversified, for organizations only active in one or a small number of product markets this assumption would not be met.

Fifth, comparing and contrasting our findings with insights from existing studies might be insightful. However, this is difficult to implement: first, as stated above, to the best of our knowledge, our study is a primer in using a game-theoretic framework to analyze business model innovation – in general and in particular in the context of sustainability. Second, related studies vary in employed concepts of auction and game theory. In particular, they choose different market settings, number of players, strategies, payoff functions, information sets or equilibria, and of course: contexts. Thus, we propose a systematic review of the literature on auction and game theory in a general context of competing for new markets, which may result in the identification of adequate existing studies, for future research.

6. Conclusion

We establish a research model for examining under which conditions an integration of sustainability in an organization’s business model pays off. To this end, we apply auction- and game-theoretic approaches and develop a n-player and m-prize all-pay auction model. The model is tested in different simulation scenarios, which bring fourth three key findings: First, the sustainability potential in a regular market must reach a critical value before organizations start investing into sustainability. Second, the structure of the market plays a significant role, as players with a low market share can deter high-market share players from investing into sustainability, reducing the overall sustainability efforts. Also, additional margins gained from a sustainability market, play a negligible role for strong players, while triggering weak players to start investments earlier especially in atomistic markets. Third, the transformation towards a truly sustainable organization can help gaining and defending strategic market leadership and foster economic performance. Aiming at applying our research to various contexts, we establish a model that not only describes and interprets the outcomes in our proposed theoretical framework, but is also applicable to extended cases, more advanced game-theoretic concepts or empirical data for further research.

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III.2. Research paper 5: "Facilitating like Darwin: Supporting Cross-Fertilisation in Crowdsourcing"

Authors:	Henner Gimpel, Valerie Graf-Drasch, Robert J. Laubacher, Moritz Wöhl
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Abstract:

Humankind faces many "wicked" decision-making problems, which must be solved. One promising approach refers to crowdsourcing systems that hold the potential to solve any kind of problem – notably wicked ones. Crowdsourced solutions work well because crowds exchange knowledge from different domains – a concept known as "cross-fertilisation." Thereby, the "facilitator" of a crowdsourcing system is the primary decision maker when it comes to specifying and managing the crowd. The facilitator's role includes actively managing cross-fertilisation. However, in the light of technological advancements and large-scale data, facilitation proves difficult – especially in one particular type of crowdsourcing – crowdsolving. Thus, academia recently called for relieving some burden of facilitators and started developing tools for supporting or automated facilitation. Yet, the focus of existing tools is not on fostering the innermost core of crowdsolving endeavours – cross-fertilisation. By taking a design science perspective, we propose design principles and design guidelines for a decision-support tool aiding facilitators to (a) set the boundary conditions for, (b) measure, and (c) facilitate cross-fertilisation. We evaluate feasibility and value added of the abstract design by applying it to different crowdsolving platforms including a prototypical implementation and qualitative evaluation by facilitators.

1. Introduction

Our global society faces many important decision-making problems of “wicked” kind [1,2]. These are highly complex problems for which no single computational formulation is sufficient, and for which involved stakeholders even disagree on what the problem actually is [2–5]. One of these wicked problems is global climate change: it clearly is universal, it must be addressed with haste, and there is a lack of central authority pushing towards a solution [2,3,6,7].

To solve wicked problems in general, and climate change in particular, crowdsourcing as a promising approach has received much attention over the past years in research and practice [1,2,8,9]. Howe [10] already asserted over a decade ago that crowdsourcing holds the potential to solve any kind of problem. The rationale making crowdsourced solutions so valuable originates from diversity, often coming along with crowds: diverse crowd members are able to intellectually cross-fertilise one another, providing solutions superior to those offered by lone individuals [11–14]. Thus, heterogeneous crowds may provide significant insight and wisdom, and cross-fertilisation enhances their ability to develop solutions to so-called “wicked problems” [13–17].

Thereby, “facilitators” in crowdsourcing systems take on a central role, as they are primarily responsible for avoiding homogeneous knowledge creation in the crowd and managing associated processes accordingly [9,18,19]. Particularly, a facilitator must decide upon procedural and/or content-related actions to efficiently coordinate, lead, integrate, classify, and summarise the discussion so that the crowd can achieve effective results [9]. Thus, the facilitator greatly affects crowd behaviour and quality of associated contributions [9,18].

As information and insights do not automatically emerge out or raw crowdsourced data, the facilitator must make active decisions [19,20]. Thereby, in current times of greater scope and large-scale crowdsourcing systems, facilitators are forced to acquire systematic methodologies to maintain a high degree of information and knowledge accessibility. Otherwise, they could not establish options and select adequate courses of action to guide the crowdsourcing process [8,18,19].

Only recently, academia acknowledged that facilitators must be supported in managing such crowdsourcing systems [8,9,18,19]. In relieving some burden of facilitators, scholars have proposed advancements in machine learning algorithms for supporting automated facilitation [8,9,18,21]. While this research stream has already made great strides, the focus of existing tools primarily is on supporting the facilitator in achieving consensus within crowd discussions efficiently [8,9]. However, tools supporting the facilitator in measuring and fostering cross-fertilisation especially in a particular type of crowdsourcing – crowdsolving – are currently missing (see section *2.2* for details on crowdsolving). In this work, we address this gap and follow scholars' current call to action in this regard [8,9]. Particularly, the objective of our study is to:

Develop design principles and design guidelines for intelligent decision-making support tools aiding facilitators of crowdsolving for wicked problems in fostering and managing cross-fertilisation in their crowds.

Taking an information systems design science perspective, we propose four generic design principles leading to 15 detailed design guidelines for a decision-support tool aiding the facilitator of a crowdsolving system, to (a) set the boundary conditions for, (b) measure, and (c) facilitate cross-fertilisation. For brevity, we use the term "the tool" as reference to the abstract design principles and guidelines for the respective decision-support tool. To demonstrate the tool's value added and feasibility, we instantiate a respective prototype in the real-world crowdsourcing system "Futures CoLab," henceforth referred to as the "FCL." The FCL is a crowdsolving system, jointly operated by the Center for Collective Intelligence of the Massachusetts Institute of Technology (MIT CCI) and Future Earth. The goal of the FCL is to enable diverse experts to collectively explore solutions to global systemic challenges, referencing wicked problems [22]. Additionally, we discuss the tool's feasibility in the surrounding space of further crowdsourcing systems. With this study, we contribute to both research and practice on crowdsourcing. For research on crowdsourcing, we outline how to design information systems and in particular evolving decision-support tools to provide adequate support for facilitators. For practice on crowdsourcing, our research is triggered by the needs of practitioners, and resulting design principles and guidelines primarily aim at supporting and advancing their daily operations.

The remainder of this paper is structured as follows. We present the theoretical background of our work and review related literature on crowdsourcing and existing support tools for facilitators. In section *3* we describe the paper's underlying methodology. We develop design principles and guidelines in section *4* and evaluate them in section *5*. We conclude by discussing the implications for theory and practice.

2. Theoretical Background

2.1. Wicked Problems

Academia defines two overarching problem categories: *hard* and *soft*. Hard problems are mostly mathematic or algorithmic, such as stock-price prediction or proposals for the exploration of new raw material occurrences. Solutions to hard problems must comply with well-defined evaluation criteria and preserve objectivity [23,24].

By contrast, soft problems lack clear solutions and objectivity [23,24]. Extremely complex and vague soft problems, which involve divergent viewpoints and the interests of multiple stakeholders, reference *wicked* problems. Global climate change, social injustice, or affordable, high-quality healthcare are just a few examples of wicked problems [2,3,6,7]. Solving wicked problems is not easy. Their subjective nature means that definitions of these problems – and potential solutions – are often highly contentious. Consequently, intervention, rather than a solution, is usually the goal [24–26]. To measure the success of an intervention is difficult for three reasons: (1) the future development of a problem is often hard to predict; (2) the effects often take a very long time to become apparent; (3) it is a delicate analysis to isolate the impact of a single intervention given the vast number of interventions taking place [27–30]. Most promising approaches to identifying a reasonable intervention are collaborative, utilising tech-enabled approaches to bring together stakeholders and combine the abilities of humans and machines [13–15,17,31]. Collaborative strategies base on the rationale that individuals achieve better results working together than they do working alone. Ultimately, wicked problems are social issues and, as such, demand responses which are fundamentally social in their nature [15–17,32,33]. One approach falling within this paradigm and additionally asserted to be particularly suitable for solving wicked problems is crowdsourcing [1,2,10,34].

2.2. Crowdsourcing as a Solution Approach for Wicked Problems

Crowdsourcing is often used as an umbrella term for a variety of approaches, which harness the potential of the human collective by issuing open calls for contributions to a particular task [11,23,35]. In organisational contexts, crowdsourcing is often linked to open innovation [36]. Particularly, when the sourcing serves a corporate goal, open innovation is consistent with crowdsourcing and can be effectively done in the crowdsourcing mode [37,38]. However, it is worth noting that although the two concepts share the assumptions that knowledge is distributed and the crowd wisdom and the collective intelligence can be a source of competitive advantage, crowdsourcing and open innovation have some differences [39]: On the one hand, open innovation exclusively focuses on innovation processes while crowdsourcing is much broader in perspective [37,39]. On the other hand, open innovation mainly describes knowledge flows between firms, or when applied to a very large degree, also with stakeholders (mainly customers) [38,40]. By contrast, crowdsourcing refers to links between an organisation and an (rather) undefined, anonymous crowd [39].

We follow an established stream of literature and define crowdsourcing as a sourcing approach for information, which supports decision makers in their decision making through wisdom generated by an anonymous crowd [19,41,42]. This wisdom is the result of improvements made by one person providing the foundation for the additional improvements made by the next in the crowd [43–47].

Surowiecki [34] found that a *diverse*, *decentralised*, and *independent* crowd tends to lead to successful crowdsourcing. Thereby, particularly diversity is key in yielding solutions from crowdsourced tasks for reasonably complex tasks [48]. This link between diversity and superior performance is originally rooted in biology and known as *cross-fertilisation*. Historically, the natural scientist Charles Darwin examined the self- and cross-fertilisation of plants and found that self-fertilised progeny had weaker characteristics than cross-fertilised progeny [49,50]. Recently, this concept has found its way from biology to social science where it serves as performance accelerator since scholars emphasised that diverse groups outperform homogenous ones [33,51–54]. Although a widely accepted definition of cross-fertilisation in this social context is not yet established, current explanations focus on the interaction of diverse individuals with regards to either knowledge, specialisations, or domains [18,55–57]. And while exchanges between people from different domains of knowledge do not always result in superior ideas (e.g., because of too little exchange or conflicts among diverse participants), the probability of high-quality ideas being generated is higher than in an exchange between people from the same knowledge domain [55].

Darwin not only observed but also facilitated cross-fertilisation by, firstly, planting various species and creating a diverse set of plants and, secondly, actively managing pollination to accelerate reproduction [49]. Likewise, the cross-fertilisation of human ideas can also be facilitated by, firstly, creating an environment in which cross-fertilisation can easily occur – i.e., by bringing together diverse, open-minded, and motivated people as a crowd – and, secondly, purposefully influencing interaction therein [55]. A crowdsourcing system for which such cross-fertilisation may be particularly valuable, is one that seeks *heterogeneous* contributions which are appraised individually in accordance with their quality, and which unfold their value in an *emergent* way (i.e., the value emerges from a subset of contributions which are considered in combination). Such crowdsourcing systems are considered as "crowdsolving" systems, which are in the focus of this work [23,42]. Thus, we henceforth use the term "crowdsolving" to reference this focus.

A crowdsolving system considers three categories of actors [19,42]:

1) the (diverse) individuals forming the crowd,
2) stakeholder(s) (e.g., organisations) benefitting from the crowd's contributions,
3) an intermediation platform and facilitator, linking the crowd and the stakeholder(s) and thus, serving as crowdsourcing enabler.

Those actors are involved in crowdsourcing respectively crowdsolving throughout the whole process, which typically consists of five phases, namely *sourcing, validating, consolidating, evaluating,* and *choosing*. During these phases, content is generated, verified, aggregated, rated among relevant criteria, and relevant contributions are selected. These phases usually build upon each, however, it is possible to jump back to previous phases [19]. A central and boundary-spanning role at this interface is taken on by the "facilitator" as primary decision maker when it comes to specifying and managing the crowd and associated crowd data [19,58,59].

2.3. Facilitator as Central Decision-Maker in Crowdsolving

A facilitator has various actions to influence crowd work. We follow Ito [9] and assume that a facilitator thereby selects the action that maximises the expected utility corresponding to his/her intention. Literature on the matter distinguishes two overarching categories of actions that facilitators can take: process and content facilitation [60,61].

In process facilitation, the focus is on the crowd's processes and relationships. In this sense, a facilitator equals a process guide who simplifies processes and increases convenience in this regard [9,60]. Exemplary actions include the monitoring of postings in subject threads, observing replies or voting behaviour, motivating participants for productive and fruitful discussions, or identifying participants who are engaging in anti-social behaviour [9,58–60]. In content facilitation, a facilitator's action directly influences the (further) content of crowd work [60,61]. Exemplary actions refer to facilitator comments to crowd members' contributions to make them aware of connections with other contributions and knowledge domains for avoiding homogenous knowledge creation. Strategies like fostering remixing or divergent thinking have emerged in this context [62,63]. Accordingly, content facilitation supports the recombination potential of the focal knowledge nodes and therefore its inventive potential [18]. This work focuses more on content-facilitation, which arguably dominates the results of crowdsolving systems [8,18].

For facilitating crowdsourcing systems, facilitators are required to have a high degree of information and knowledge accessibility, which allows them to support knowledge aggregation and integration across contributions [9,18]. However, since crowdsourcing is characterised by dispersive, multi-threaded, and asynchronous work, human facilitators need systematic methodologies to perform associated actions [8,55]. Thus, research recently started supporting automated facilitation via developing associated tools: particularly, Ito [9] developed and implemented an intelligent crowd decision-making support system that has facilitator support functions to lead crowd discussions to better results. Similarly, Yang et al. [8] proposed a novel case-based reasoning approach to facilitate online discussions for crowd-scale deliberation. Additionally, Rhyn and Blohm [21] recently constructed a design theory for semi-automated information processing and decision support in crowdsourcing, yielding more efficient and effective decision-making. Although there has recently been some technical progress, scholars call for further investigation and advanced technical solutions [8,9,18]. In this work, we follow this call and aid facilitators by providing design principles and guidelines that coalesce in a tool supporting them in deciding on cross-fertilisation.

3. Method

We apply an information systems (IS) design science research (DSR) approach. Design is a search process [64]. Following the classification of types of theories in IS suggested by Gregor [65], our research contributes to a theory for design and action (type V). Our contribution can be classified as “improvement”, a “level 2 nascent design theory” that produces knowledge in the form of operational principles [66]. We follow the DSR methodology by Peffers et al. [67] which aims for applicable solutions for organisational problems and broadly usable artefacts [68]. Our design involves design principles (DPs) and design guidelines (DGs) for a tool to support facilitators of crowdsolving systems, enabling them to create, assess, and facilitate an environment for cross-fertilisation. DPs are generic descriptions of functionalities of an instantiation while DGs are more detailed recommendations on how to implement the DPs. Instantiations of this abstract design should hold the potential to advance crowdsolving endeavours and, thus, contribute to addressing wicked problems. Importantly, we do not claim to provide a well-developed level 3 mid-range or even grand design theory [66] – this is yet to emerge from maturing and generalising design knowledge. Rather our contribution is prescriptive knowledge captured in DPs and DGs. Design knowledge is prescriptive knowledge that is considered to have no truth value in itself [69]. Thus, the validity of DSR results can only be assessed by means of descriptive knowledge obtained in the DSR process. In the search for a satisficing design, evaluation against descriptive knowledge plays a particularly important role. For evaluation of our design artefact, we take the design objective (section *1*) as overarching objective and evaluate from an outcome-oriented, practical view [68].

We build on the six-step process of Peffers et al. [67]: (step I) Identify problem and motivate, (step II) define objectives of a solution, (step III) design and development, (step IV) demonstration, (step V) evaluation, and (step VI) communication. As our research is triggered by the needs of practitioners, the entry point of our approach is an "objective-centred solution" [67].

In section *1 Introduction*, we detail the motivations behind our research and identify a research gap (step I) and our design objective (step II). The resultant DPs and DGs were defined via a search process [64] and gradually improve in the course of our project (step III). The search process includes literature review enriched by interviews with experienced facilitators to create an initial design, which then is enriched with insights from prototyping and use of the prototype in a real-world case.

In addition to fulfilling the design objective, the tool must fulfil a meta-requirement (MR) [66]. We derived the MR from interviews with facilitators of the FCL (see section *1* for explanation of FCL), which enabled us to identify the facilitators' mission: to extract as much value as possible from the participants' experiences and perspectives while minimising the time the participants spend on non-value-creating activities (e.g., reading duplicates, rereading ambiguous instructions, etc.). Most of the facilitators' actions, therefore, involve communication (i.e., providing clear instructions and guidance, summarising content), although they are also responsible for other tasks such as deleting redundancies and synthesising results. However, facilitators' primary goal is to enable valuable contributions from the crowd [70]. Because cross-fertilisation is likely to improve the quality of these contributions, it needs to be assessed. Consequently, in order to reach our design objective our meta-requirement is:

MR: Enable the facilitator to assess the level of cross-fertilisation.

The DPs and DGs for a tool to facilitate cross-fertilisation on crowdsourcing platforms were based on justificatory knowledge [71] presented in section *2*. We instantiate a prototype of this tool for testing its design in a real-world crowdsolving system (step IV). The DPs and

DGs are evaluated with regards to the ease of use, efficiency, generality, and operationality. With regards to the prototype, that demonstrates the design is feasible, effective, efficient, and has an impact on the user's environment as suggested by Sonnenberg and vom Brocke [69]. These criteria ensure added value for the facilitator, applicability across various platforms, and the fulfilment of our meta-requirement (step V). Lastly, we communicate the final design of the tool (step VI).

4. Artefact Design

Our design objective is the development of DPs and DGs for intelligent decision-making support tools that, when instantiated, aid facilitators of crowdsolving for wicked problems in fostering and managing cross-fertilisation in their crowds. To understand how and where a tool could support facilitators, we needed to gain insight into the tasks and challenges they face during a crowdsourcing process. Access to the records of previous crowdsolving endeavours provided such insights, as did our interviews with facilitators. The semi-structured expert interviews we conducted provided insights in facilitators' needs. Overall, we interviewed two facilitators and three additional stakeholders in the surrounding field of the facilitators up to ten times each. We took field notes of the interviews and analysed them subsequently [72,73]. The interviewees had already run several projects and realised that an awareness of the ways in which participants interact and contribute on the platform is of central importance when attempting to effectively facilitate the exercise. Facilitators are very interested in honing the decisions they make during the crowdsolving endeavour. They agree that there is a need for support of their facilitation decisions, which would help them to facilitate the exercise and eventually improve the quality of contributions [70].

Facilitators aim at gaining meaningful and diverse insights from experts on a given topic [70]. These insights will inform proposals for interventions on a wicked problem (see section *2.1*). We divide this goal into four sub-goals achieved via facilitation: 1) encourage participants to contribute, 2) ensure they are focused on the task, 3) keep them up to date, and 4) encourage broad thinking. Depending on the sub-goal the facilitator is trying to achieve, s/he can take facilitation actions. The columns in Figure indicate the matching between the sub-goal and possible facilitation actions. In terms of fostering cross-fertilisation, a facilitator will become most active in the *validation* and *consolidation* phase of a crowdsourcing process [19].

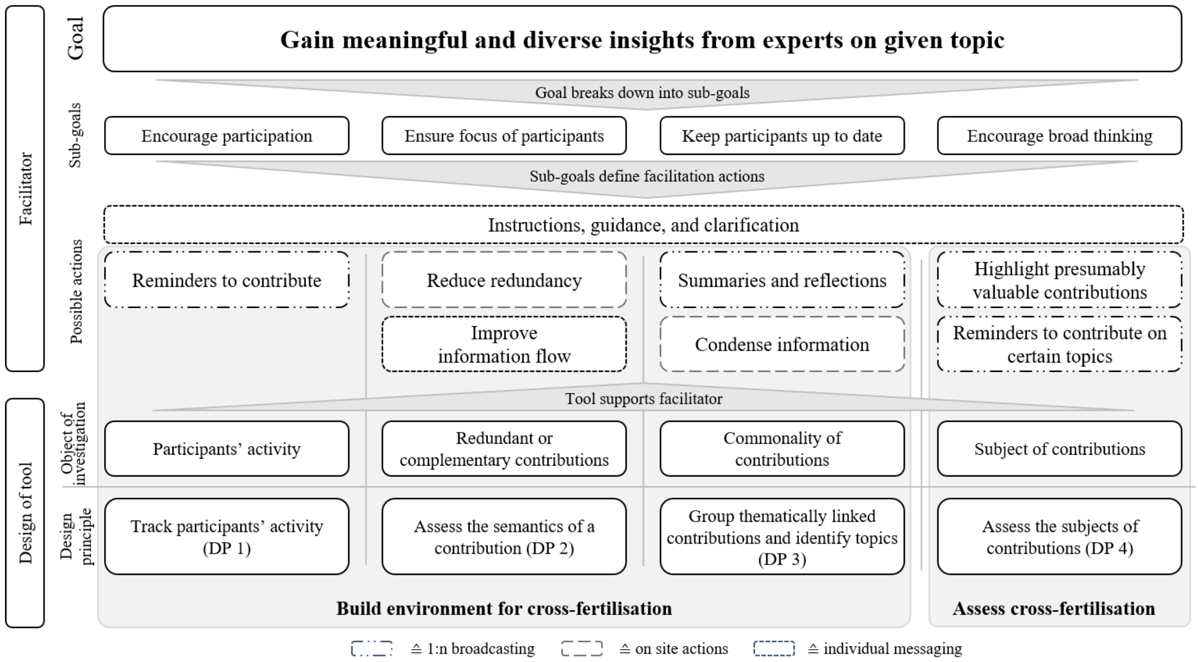

Figure 1. Facilitation actions in a crowdsolving endeavour

In the following, we elaborate on each of these four sub-goals and discuss possible actions the facilitator may take to achieve her/his (sub-)goal. Based on the facilitator's sub-goal we derive DPs, which are supported by literature. The DPs aim at both, building an environment for cross-fertilisation by creating the appropriate preconditions (DP1-3), and assessing cross-fertilisation (DP4). Building an environment for cross-fertilisation mostly centres around knowing what is being contributed and who is contributing so if a perspective is missing the facilitator can reach out and try to bring it to the table. The DGs are more detailed; either based on insights from literature or previous crowdsolving endeavours (identified via the interviews) and guide the implementation of the DPs.

4.1. Encourage participation

Inactive participants do not contribute to solving problems. Without interaction between participants, cross-fertilisation cannot take place [55,74]. Thus, active participants are crucial to any crowdsolving endeavour, however, encouraging participation is a challenge [70,75,76]. Information about activity is essential for the facilitator, who can monitor and manage the participants' activity and, potentially, intervene (i.e., send a reminder) if, for example, not enough participants are actively contributing [41,70]. Measuring activity also makes it possible to observe patterns of exchange [77] and identify lead users [78], which may provide further valuable insights for improving the crowdsolving endeavour. Furthermore, with knowledge of the participants' professional backgrounds, the facilitator can assess whether participants have contributed perspectives from all relevant areas based on their knowledge of their professional background. When this is the case, a prerequisite for cross-fertilisation is fulfilled. We define *activity* as posting, commenting, liking, or voting for contributions, which are typical functionalities on crowdsolving platforms (e.g., Climate CoLab, OpenIDEO, etc.). In short, the tool should assess the participants' activity, which is important information for the facilitator. Thus:

DP 1: Track participants' activity.

Crowdsolving activities usually have multiple phases and types of activity [19], which are of interest for the facilitator both on a detailed and aggregated level. Assessing detailed data on activity per phase later enables Drill-Up operations (DG1.1). In addition, activity data can be condensed by calculating KPIs like active participants, comments per participants, etc. to get an impression of the activity level within the crowd (DG1.2). Activity might not always be tracked on crowdsolving platforms. In this case, the facilitator would need to manually collect information about activity, which would be a time-consuming process, prone to errors, and not scalable – consequently a tool ideally automatically extracts and processes the activity data (DG1.3). Although activity tracking itself does not provide the facilitator with novel information, enriching the report with background information about the participants (e.g., profession, country, etc.) enables OLAP-like operations to extract insights and thus enables targeted facilitation actions for sub-groups (DG1.4) [70].

Design Principle	**Supporting Literature**	**Design Guidelines**
DP 1: Track participants' activity	[41,75,76]	DG1.1: Record activity data and calculate statistics by phase and type of activity per participant
		DG1.2: Aggregate activity into relevant KPIs
		DG1.3: Automatically extract activity data
		DG1.4: Enrich activity statistics with background information

Table 1. Design guidelines for tracking participants' activity

4.2. Ensure focus of participants

In contrast to numerous advantages of crowdsolving, a few challenges need to be tackled to make crowdsolving, respectively crowdsourcing in general, successful. In particular, the vast amount of heterogeneous content creates a problem of attention, both on the facilitator's and on the participants' side [70,79]. In order to properly contribute, participants need to be up-to-date on existing content on a crowdsolving platform and remain focused, which falls under the facilitator's responsibility [70,76,80]. Redundancy can be a problem, particularly towards the end of multi-stage processes when participants use content generated in earlier phases [21,70]. If there is too much content, the participants may experience cognitive overload, feel overwhelmed, and have difficulty contributing. As a result, the quality of the process and the potential for cross-fertilisation can suffer in later phases [30]. In a similar vein, the facilitator is eager to receive the "right" amount of contributions. The facilitator will later synthesise the contributions to provide a collective opinion. While a minimum amount of valuable contributions is necessary to provide a certain level of insight, gathering too many contributions may be counterproductive, as the effort needed to manage the heterogeneous content increases [70,79,81]. To ensure that both parties (i.e., the facilitator and the crowd) bring their limited resources to bear in the most value-adding way, it is important to reduce the redundancy of contributions [19,21]. One aspect of idea quality is rarity (i.e., non-redundancy) and, thus, reducing redundant contributions promotes the quality of the whole crowdsolving endeavour [82]. Redundancy can be tackled by applying appropriate filter mechanisms and ensuring that redundant contributions are identified and removed or consolidated as early as possible [81]. Filters include, for example, clear instructions provided to the participants [30,83], and manual monitoring and intervention by the facilitator, e.g., deleting or merging existing contributions [70]. However, a more (resource) efficient way to operationalise filtering is via automatically identifying redundancies before they are put into the system, comparing the (entered) contribution to the existing content before it is submitted [81]. Thus:

DP 2: Assess the similarity between contributions.

Detecting duplicates via the use of keywords may not be effective because, thanks to the richness of natural language, the same can be said using different words, and different messages can be conveyed using similar phrasing. We suggest addressing this problem by comparing the semantics of contributions, for example, via natural language processing (NLP). The outcome of this assessment should be a machine-readable output, which allows comparing two contributions with each other to assess their semantic relatedness (DG2.1). Depending on the task and the aim of a crowdsolving endeavour, a threshold should be defined, which allows to manage whether nuances of a topic are desired or rather misleading [21,70]. From a practical perspective, it will be of interest to create a way to display all matches of potentially redundant contributions, as it is more efficient to screen a list of potential duplicates rather than screening the full content on the site. So the facilitator is able to easily identify and delete or merge those contributions, which rather cost valuable time without giving new insights (DG2.2) [21,30,70]. In a similar vein, a facilitator could use the same functionality to compare contributions, which are non-redundant but appear to be related by semantics (as those contributions were contributed in different content categories potentially existing and/or emerging in crowdsolving endeavours) (DG2.3). This builds upon the concept of remixing, bringing up new connections between topics. Ideally, deletion of redundant contributions is not the task of the facilitator but a presumably intelligent technical artefact, which identifies and deletes irrelevant or duplicate contributions [21]. Alternatively, the crowdsolving platform implements filter mechanisms which involve the participants into the process of avoiding redundant contributions, so there is not *ex-post* assessment, but redundant contributions are not even entered into the system (DG2.4) [81].

Design Principle	Supporting Literature	Design Guidelines
DP 2: Assess the similarity between contributions	[19,21,30,79,81,82]	DG2.1: Assess the semantic similarity of pairs or larger sets of contributions (and define similarity threshold)
		DG2.2: Provide a list of pairs/sets of potentially redundant contributions (i.e., similar contributions from the same category)
		DG2.3: Provide a list of similar contributions (i.e., from different categories)
		DG2.4: Help participants to avoid redundancy when submitting their contributions

Table 2. Design guidelines for the assessment of semantics

4.3. Keep participants up to date

Time is a constraint for both facilitators and participants. Section *4.2* outlines that irrelevant contributions do cost time. Getting an overview of the topics being discussed costs time, too [70,79]. It is in the facilitator’s interest to summarise the content and guide the process, so the participants are able to bring their perspectives to bear [70,76,80,84]. One way to summarise is by aggregating content so it can be accessed and prioritised more easily [19,21,70]. Another is linking or merging of contributions, which are thematically similar (but not redundant). This type of summarising is an important means of assessing the wisdom [34,85] and intelligence [44–47] of the crowd. Keeping participants up-to-date on the main discussion streams enables them to join the discussion at any point, introducing other/new perspectives and increasing the potential for cross-fertilisation [76,80]. Aggregation is also important for the facilitator, as it allows to handle many contributions and identify the topics participants are talking about [70,81]. The facilitator is then able to intervene if a particular (a-priori known) topic is absent from the discussion and to otherwise enrich the process. Aggregation can be operationalised in two ways. One method is to link all the contributions which belong together and then process them as a whole (e.g., all of the individual contributions in a group are either eliminated or promoted) [30]. The other method is to merge similar contributions to produce one that represents them all. However, great manual effort is needed to group contributions and identify commonalities between them [70]. Depending on the use-case, different levels of granularity are required [21], which of course impacts the extent to which contributions will be aggregated. This can involve anything from the selective combination of specific contributions to the assignment of contributions to a few main topics. Thus:

DP 3: Group thematically linked contributions and identify the topics of the resultant groups.

In analogy to redundancy detection, grouping might be necessary at different levels of granularity. Hence, the facilitator seeks for ways to be flexible in creating groups of related contributions. A tool should support this end by making multiple suggestions (DG3.1) [21,70]. From a practical point of view, the facilitator might still want to overrule the tool's suggestion. Thus, it could be reasonable to allow manual intervention with regards to the grouping outcome (DG3.2) [21,70]. Finally, to grasp the gist of what is being discussed, it is not enough to simply group together contributions, but the facilitator will be interested in the topic(s) presented in one group of contributions, which then again helps to guide the endeavour and to encourage other perspectives (DG3.3) [70,76,80,84].

Design Principle	**Supporting Literature**	**Design Guidelines**
DP 3: Group contributions which are thematically linked and identify the topics of these groups	[21,30,76,79–81]	DG3.1: Provide suggestions of clusters, accounting for multiple levels of detail
		DG3.2: Provide suggestions for groups of contributions, which are easily rearrangeable
		DG3.3: Identify topic(s) in content groups

Table 3. Design guidelines for grouping of contributions

4.4. Encourage broad thinking

In terms of enabling and fostering cross-fertilisation the most important task of the facilitator is to encourage and support multiple perspectives and divergent thinking [70,76,86,87]. Hence, an indicator of cross-fertilisation is the diversity and number of perspectives accounted for by a single contribution or within one stream of discussion. With increasing heterogeneity of participants with respect to, for example, their disciplinary background the barriers to collaboration increase, yet so do the potential benefits of cross-fertilisation [55]. The result is that, for cross-fertilisation to take place, cross-disciplinary community building is necessary [56]. To assess whether cross-disciplinary communities are forming, the facilitator needs to assess which knowledge domains respectively perspectives are represented in the contribution. Thus:

DP 4: Assess the knowledge domains captured by contributions

Section *4.3* highlights that extracting the topics from the contributions is important. On a broader scale, topics are potentially too narrow. The facilitator is interested in around which knowledge domains a discussion is turning (e.g., sustainability, information technology, etc.). Consequently, instead of assessing such information manually, the facilitator seeks for an automated way to assess from which perspectives a topic is being discussed (DG4.1) [70]. In order to automatically assess such information, the perspectives, which will be covered, need to be anticipated respectively predefined. Two sets of knowledge domains are relevant. First, the set of domains, which are relevant for the given task respectively the wicked problem (e.g., for climate change; sustainability, policy, etc.) (DG4.2). Second, the set of domains, which participants bring into the discussion, i.e., their (professional) backgrounds (DG4.3). Finally, as one of the main goals of the facilitator is to foster cross-fertilisation, the facilitator will observe how the knowledge domains covered over time will develop (DG4.4).

Design Principle	Supporting Literature	Design Guidelines
DP 4: Assess the knowledge domains captured by contributions	[56,80]	DG4.1: Indicate the extent to which knowledge domains are represented per contribution
		DG4.2: Define a set of knowledge domains relevant to the given task
		DG4.3: Define a set of knowledge domains based on participants' backgrounds
		DG4.4: Assess knowledge domains covered over time

Table 4. Design guidelines for the assessment of knowledge domains

5. Artefact Evaluation

Evaluation is an important step of DSR. We present the criteria relevant for the evaluation in section *3*. In particular, we will outline that the presented DPs and DGs support facilitators in fostering cross-fertilisation and to emphasise the broad applicability of our design, we exemplarily discuss three use cases of crowdsolving platforms, the Climate CoLab, OpenIDEO and the FCL. For all three cases, we argue from a qualitative perspective that the proposed design would be applicable and of value to the facilitator of these platforms. In addition, we developed a prototypical instantiation that helped to demonstrate the feasibility of the design and supported an in-depth analysis of our design for the case of the FCL from a quantitative and a qualitative perspective. Details on the implementation of the prototype and its evaluation are available upon request.

5.1. Use case #1: Climate CoLab

The Climate CoLab (CCL) [1,2,88] has a community of more than 120,000 people from all around the world participating in online contests that seek proposals about actions that might be taken to address specific aspects of the problem of global climate change (e.g., increasing building efficiency or decarbonising electricity production). Participants can comment or like the proposals submitted by others. After submission, a recruited panel of experts reviews the proposals and selects semi-finalists. The semi-finalists then may revise their submissions and the judges select the finalists. Afterwards, the judges select the winner of the Judges' Choice Award and the community votes to select the winner of the Popular Choice Award. In addition to running contests in specific domains, the Climate CoLab has also used contest webs, in which integrated proposals are sought that combine entries from earlier contests [1]. In that particular case, cross-fertilisation is essential as the quality of contributions emerges when multiple perspectives are considered in an integrated way [88].

An instantiation of our DGs would help the facilitators of the Climate CoLab to foster cross-fertilisation. First, a functionality to track activity (DP1) would be, regardless of whether cross-fertilisation is a major goal or not, a baseline functionality. Facilitators could use it to check how actively participants contribute to the CCL. Second, as anyone is able to contribute to the CCL and the first phase is usually a "sourcing" phase, the entries need to be validated among others in the sense that redundancies need to be removed (DP2) [19,89]. By design of most contests, value is generated by one single best solution; consequently, a matching of contributions (DG2.3) might not be relevant in terms of processing contributions [89]. But because participants are able to join forces by forming teams, such functionality could help them to find the right partner to create a powerful team [70]. Third, clustering of contributions (DP3) seems not to be relevant in the "consolidation" phase, since in the CCL single contributions are being judged [19,70]. However, the facilitation team might have a need to keep track of all topics and potentially promote contributions from certain tracks. In such a case, the judges' selection of (semi-) finalists could be supported by a thematic clustering (DG3.2) of the contributions, or at least a list of topics (DG3.3), to address various tracks more equally [2]. Finally, although the evaluation criteria for the contests differ with regards to what the winning contribution should outline, generally the purpose of the CCL is to harness the collective intelligence from people all over the world [88]. In this realm, cross-fertilisation plays an important role, so regardless of the winning contribution in the current contest, the CCL has an interest in participants that cross-fertilise and create better ideas even though it might only affect future contributions [70,88]. As a result, the facilitation team of the CCL should also monitor the addressed knowledge domains over time (DP4).

Altogether, our DPs could create value in running the CCL by creating an environment for cross-fertilisation and the assessment of it. Although cross-fertilisation might only be a secondary goal in the CCL, it does not contradict the primary goal of eliciting good ideas from people from all around the world. Rather, cross-fertilisation supports the primary goal, as participants in the CCL are refining their contributions over the course of the contest and, thus, incorporating further perspectives from others (via discussions, collaboration, etc.) helps to mature the contributions so they become better. In particular, when contests build upon each other [1,70].

In addition, the functionalities that result from the DPs and DGs could not only help facilitators but also participants. Finding a related comment on a different contribution or grouping contributions on related topics could help picking up relevant perspectives to connect participants, which hopefully sparks cross-fertilisation [70].

5.2. Use case #2: OpenIDEO

The collaborative design network OpenIDEO is another web platform that relies on a contest model. Participants aim to solve an outlined challenge, usually via a five-phase process, which involves initial research, the contribution of ideas, the refinement of ideas, the provision of feedback, and the evaluation of top ideas. During the process, participants can post and respond to comments on the submitted concepts, which fosters interaction [90,91]. Overall, the default process on OpenIDEO is comparable to the one on the CCL. Consequently, the arguments we brought up for the CCL are also valid in the context of OpenIDEO, and an instantiation of our DPs and DGs could help to create an environment for cross-fertilisation and help to assess it on OpenIDEO.

OpenIDEO does not host contest webs as the CCL does. Nevertheless, some of the hosted contests encompass an inspiration phase in which the participants primarily research, question, and explore a topic without generating ideas [92,93]. This initial step of the process aims at cross-fertilisation in the sense that participants become aware of the facets of a topic. They get a feeling for where to bring in their perspective and have the chance to discuss with others [92]. Especially in this scenario, a tool implementing our design could help to create an environment for cross-fertilisation.

5.3. Use case #3: Futures CoLab

The FCL hosts a process for asynchronous and facilitated dialogue among a network of diverse international experts on a crowdsolving platform. The goal of Futures CoLab is to enable subject matter experts to collectively explore solutions to global systemic challenges. The crowdsolving platform is developed by MIT CCI and run in cooperation with Future Earth (an international non-profit organisation whose mission is to accelerate transformations to global sustainability through research an innovation [93]). In contrast to the CCL or OpenIDEO, Future Earth is seeking numerous insights concerning their research, not just one top contribution. In the case we use here as an example, the FCL invited 181 participants to contribute ideas about potential systemlevel changes which might enhance global sustainability. In addition to encouraging innovative contributions, the secondary goal was to encourage collective learning among the participants, who were recruited via Future Earth's network and were professionally and geographically diverse. They contributed during a three-phase process of the type commonly used in crowdsolving platforms, depicted in Figure 2 [19]. The overall process took three weeks. For screenshots of the platform, please refer to the Appendix (Figure 3-5). Throughout, the facilitator stayed in touch with the participants via e-mail, sending updates, summaries, etc. several times each week. In the aftermath of the process, an advisory board of selected senior researchers evaluated the innovative potential and impact of the top contributions, which served as input for workshops aiming to define a research agenda to accelerate the transformation towards global sustainability.

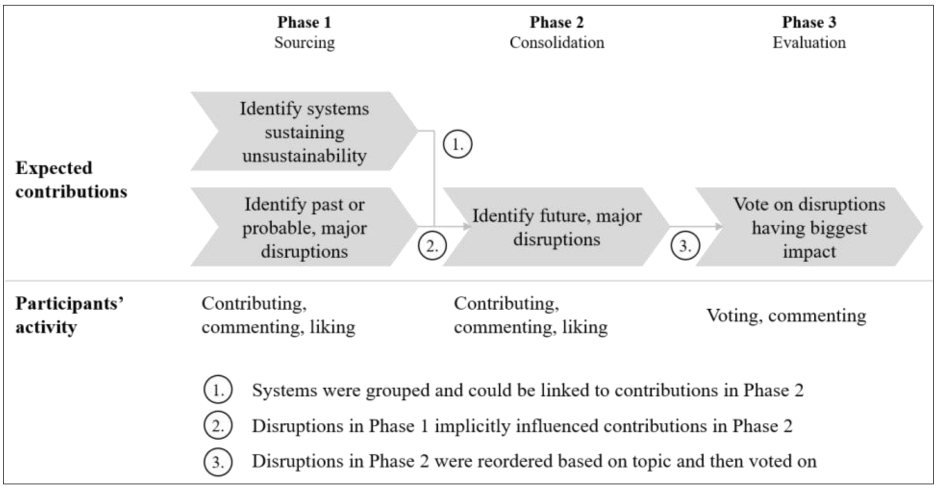

Figure 2. Process Description of FCL

Phase 1 involved brainstorming: Participants were asked to identify (a) systems which prevent society from shifting to a sustainable and equitable path (three categories: *political-economic*, *technology and infrastructure*, and *cognitive socio-cultural*) and (b) disruptions which have occurred in the past or are on the horizon (three categories: *political-economic*, *technological*, and *other*). Participants' contributions consisted of a compulsory title, a tweet-length description of the idea, and an optional full description. Participants could also comment on or "like" contributions. In this phase, participants identified 92 systems (which collectively solicited 175 comments and 256 likes; example: "air transportation systems", for details see Appendix Table A.2) and 80 disruptions (81 comments and 171 likes; example: "direct democracy", for details see Appendix Table A.2). At the end of this phase, the facilitation team, with the help of our prototype, sorted the 92 systems into 13 groups, which reflected the gist of the contributions therein.

Phase 2 involved refining and developing the contributed content. Participants were asked to suggest disruptions, which might resolve the inertia that maintains unsustainable systems. This resulted in 71 contributions (with 142 comments and 205 likes; example: “real accounting of environmental externalities”, for details see Appendix Table A.2). Participants were invited to connect their contributions to – and thus enrich – one of the 13 groups from Phase 1. This step, however, was optional.

In Phase 3, participants were asked to identify promising contributions from Phase 2. Participants voted for the disruptions most likely to enable transformations toward sustainability (each participant had up to 15 votes, with a maximum of 5 per contribution), and were also invited to further discuss their opinions in the comments (total of 141 comments and 903 votes, for details see Appendix Table A.2).

Generally, similar arguments as for the CCL and OpenIDEO apply to the FCL. The biggest difference between the FCL and the other two platforms is the fact that the FCL does not seek for a single best contribution, rather for a set of interesting and novel thoughts. Consequently, the focus is less on refining single contributions to a mature state, rather considering a subset of contributions as a whole and discussing thoughts. Therefore, the FCL is predestined for fostering cross-fertilisation. In contrast to the CCL and OpenIDEO, especially DP2 is of interest as it enables to further develop and connect ideas of participants, besides the aforementioned arguments with regards to content aggregation, etc.

In addition to a qualitative evaluation how our DPs and DGs would also help the facilitators of the FCL, we exemplarily instantiated our DPs and DGs and apply our prototype in a real-world setting. In particular, we evaluate whether the instantiation of the DP’s is suitable for use in a live crowdsolving endeavour, rather than merely *ex-post*. The problem-solving process on the FCL was supported by a five-person facilitation team consisting of one experienced main facilitator, two assistants and two authors of this paper, of which one had led several former crowdsolving endeavours. The prototype regularly processed the input from the FCL. The tool’s output was collated by one of the authors and presented in a comprehensive report to the other members of the facilitation team. In future applications, this process could also be fully automated [21]. During a daily call with all members of the facilitation team overseeing the process, the insights from the reports were discussed and conclusions about the facilitation actions were drawn. In the aftermath of the 3-week process, we interviewed the head of the facilitation team, who is not an author of this paper, to ensure our evaluation reflected the facilitator's point of view. In order to gather more feedback, a survey evaluating the overall process was sent out to the participants. In addition to qualitative judgements, we analysed quantitative metrics.

When cross-fertilisation occurs, the results should be apparent. It should be evident in the development of their contributions that participants have incorporated other perspectives into their thoughts (DG4.4). Consequently, we expect that, over time, contributions will relate to more knowledge domains. In our case, we defined seven knowledge domains we anticipated to be discussed (for detailed list refer to appendix A.1) and ran during the process a classifier trained to assess the prevalence of a knowledge domain in each contribution and return a value between 0 % (not at all represented) and 100 % (fully represented). All of the label values can be added up to represent the Overall Fit (OF) of the contribution to the entire set of labels (in our case, adding up to a possible maximum of 700 %, indicating full representation of all seven knowledge domains, for details see Appendix Table A.2). Two examples make the OF measure more tangible: A contribution from Phase 1 at the lower end of the OF (~ 120 %) was very specific and exclusively addressed the IT domain "Artificial intelligence and advances in machine learning". In contrast, a contribution from Phase 2 covered a broader scope (OF ~ 310 %), addressing earth science, IT, and sustainability "multi-scale, transparent, streaming ecosystem and biodiversity monitoring." In the survey sent out at the end of the process, a question included a 5-point Likert scale to rate the seven contributions which drew the most votes. These were evaluated according to four criteria: impact, novelty, feasibility, and scope. The latter reflects the extent of a contribution's disruptive potential, which may be limited to a particular niche (narrow scope) or wide-ranging (broad scope). The OF of the entire set of labels should reflect this dimension. When we compared the OF of the contributions with the survey's appraisal of the scope, we observed a correlation of 91 % between the two measurements. As the labels were the foundation for the following analytical evaluation, this gives credibility to the assigned labels.

As we expect that over time people cross-fertilise, they incorporate more perspectives into their thoughts and thus the OF should increase over time. To test for this, we ran a simple linear regression. We modelled the day of the process (i.e., the first day of the process as "day 1") as the independent variable and the OF as the dependent variable. We observed an increase in the OF over time. The estimate for the time is 1.4 % (p-value 0.031, intercept 204 %). This means that the average OF of contributions increased day by day, indicating that the participants were thinking in broader terms. Near the beginning of the process, the average

OF of a contribution was around 200 %, whereas, towards the end, the average exceeded 230 %. This makes sense, as later contributions were presumably informed by more discussions, which would have encouraged cross-fertilisation.

We found further evidence to support this claim. Comparing the labelling from the authors' original text with their final text in the contribution (including comments), we also observed significant differences, as a Wilcoxon-signed rank test reveals (p-value <0.001). For example, in a contribution concerning the development of improved data and analytical tools as a means to better understand systems (labelled as IT), a participant added his thoughts on policy implications, which enriched the discussion and brought more perspectives to the table. Further investigation of the entire text of a contribution, including the comments, using another linear regression revealed that the comments did significantly increase the OF (estimate of 3.6 % and p-value of 0.002). In this case, the OF of the final contribution was the dependent variable, and the number of comments was the independent variable. The OF increased over time, and the comments contributed to this increase. While, at a single point in time, the OF does not necessarily convey information about the level of cross-fertilisation, the development of the OF over time does. Hence, it is this development that the facilitator should monitor (DG4.4).

In the aftermath of the process, participants reported in an online survey that they had learned something from other participants, engaged with persons they would not normally have engaged with, and benefited from the variety of perspectives. Together with the quantitative indications, these statements suggest that cross-fertilisation occurred. Our DP's provide guidance to facilitators how to foster and measure cross-fertilisation and we fulfil our meta-requirement.

6. Discussion

6.1. Contribution

Our research proposes a design for a facilitation support tool that helps in fostering cross-fertilisation in a crowdsourcing (and particularly crowdsolving) context. By applying DSR, we identified four design principles (DPs) and 15 more detailed design guidelines (DGs) for a tool to support the facilitator of a crowdsolving system to (a) set the boundary conditions for, (b) measure, and (c) facilitate cross-fertilisation. For evaluation, we first assessed the design's applicability and value for two crowdsolving platforms on an argumentative basis from the outside. Then, we developed a prototypical instantiation of our design. The prototype used Natural Language Processing (NLP) for purposes such as redundancy detection, content clustering, and topic identification (DP2-4). We applied this prototype in the facilitation of a three-week real-world crowdsolving task with 181 participants. Feedback from the facilitation team (two of five members of that team at authors of the present paper), ex-post survey data from the crowd members, and quantitative analyses of the digital trace data that emerged on the crowdsolving platform support effectiveness, efficiency, and impact on the user's environment of the prototype. We found ways to encourage cross-fertilisation between diverse participants. Further, we demonstrated that cross-fertilisation can be observed over time and is of interest to the facilitator of a crowdsourcing endeavour as it improves the quality of results. Specifically, we developed a metric that allows the facilitator to monitor the scope of the online dialogue, indicating whether participants are able to anticipate other/more perspectives. As Charles Darwin earlier revealed, cross-fertilisation occurs naturally but facilitating enables us to reach a "desired" state sooner. In our context, the gradient of the OF over time indicates whether, and to what extent, cross-fertilisation is taking place. In the aftermath of the process, the head of the facilitation team outlined the "advantage of combining human and machine learning" [95] with regards to the prototype which incorporated our design. Cumulatively, these evaluation steps suggest that the design is easy to use, efficient, generalisable, and operationalisable.

Gregor and Jones [71] suggest that a design theory should consist of eight components. In Table 5, we list specific components relating to knowledge about design originating from this study. This design knowledge is the core theoretical contribution if the present paper.

Component	Description
Purpose and scope	Support intelligent decision-making aiding facilitators of crowdsolving for wicked problems in fostering and managing cross-fertilisation in their crowds.
Constructs	*Relating to purpose and scope:* Facilitation, cross-fertilisation, crowdsolving, wicked problems. *Relating to the design principles:* Semantic embedding, platform activity, NLP. *Relating to the tool's functionalities:* Redundancy detection, content clustering, topic identification, text labelling, activity tracking.
Principle of form and function	We provide four design principles (DPs) and 15 design guidelines (DGs) for a tool, which enables and enriches facilitation actions during a crowdsolving endeavour thus fostering cross-fertilisation among participants.
Artefact mutability	Depending on how a platform runs the problem-solving process, the functionality of the tool needs to be tailored, which has implications on the instantiation.
Testable propositions	Implementing the DPs leads to increased efficiency and effectiveness in facilitating cross-fertilisation in crowdsolving.
Justificatory knowledge	Extant knowledge of facilitation, cross-fertilisation, crowdsourcing, collective intelligence, and wicked problems.
Principles of implementation	IT systems implementing the DPs and DGs can be build based on statistical, machine learning and Natural Language Processing (NLP) techniques that operate on digital trace data from the IT platform supporting a crowdsolving exercise.
Expository instantiation	A prototypical instantiation of the abstract design has been applied in facilitating crowdsolving and achieving cross-fertilisation.

Table 5. Eight Components of an Information Systems Design Theory [71] and their specific manifestations in this study

Beyond this, the facilitator of the FCL process mentioned that now that she is used to the tool and familiar with its capabilities she could imagine that, rather than simply using the tool as additional support for her facilitation actions, she could design further problem-solving processes around the tool in order to fully leverage its potential. Yet, our tool is not only of practical use in research focused on finding solutions to wicked problems. It will also assist organisations that employ crowdsourcing in ideation competitions or open innovation, wherein cross-fertilisation is desirable. In terms of filter design, the instantiation of DP3 which allows processing several contributions as a whole is of particular interest. The prototypical implementation of the NLP capabilities we present (namely redundancy detection, content clustering, topic identification, and text labelling) may also hold value in contexts where practitioners need to monitor and process vast amounts of heterogeneous context. Examples include monitoring reviews of, or complaints about, products via online social networks.

6.2. Limitations and further research

Our study involves some limitations, which we hope will stimulate further research. Firstly, as we did not run A/B or comparable tests, we were unable to disentangle the effects of the tool's individual components including the process itself, which was predefined. What is more, as cross-fertilisation between participants also occurs without facilitation, we are unable to make any claims about the extent to which the tool or the facilitator is responsible for the cross-fertilisation we observed. Nonetheless, qualitative feedback from facilitators suggests that the support provided by the tool was of great value to them and, as the tool fulfils the MR, it also fulfils our design objective. Future research might analyse the effectiveness of single DPs and DGs, or the design as a whole, by running multiple comparable crowdsolving processes (in parallel). Secondly, our assessment of cross-fertilisation is not suitable for comparing processes with one another due to the variability of participants, goals, knowledge domains and the time horizon, which will presumably require different labels and produce different OF gradients over time. Thirdly, in terms of cross-fertilisation, we expect the OF will meet its upper limit when the process exceeds a certain duration, so a facilitator will not always observe an increase in the OF even though cross-fertilisation continues. In this case, a more sophisticated measure of cross-fertilisation is necessary. Since we did not have any information on how often participants logged in or which discussion thread they followed, we had to assume cross-fertilisation happened over time. Future research might address this issue, identifying whether certain participants, which e.g. login more often, cross-fertilise more than others do and which other factors are involved. Fourthly, our prototypical way of identifying different knowledge domains cannot detect the extent to which ideas and concepts from different knowledge domains are discussed in parallel or synthesised to form comprehensive concepts. To this end, we assume that, at least in the FCL, either the facilitator or other participants would ask for or provide further explanation when concepts are insufficiently integrated, which would then lead to actual cross-fertilisation. Finally, we only evaluated a prototypical instantiation of the design in a single crowdsolving exercise.

7. Conclusion

Cross-fertilisation is a crucial mechanism, which increases the probability of high-quality ideas emerging in problem-solving or idea-generating exercises. This paper establishes four design principles and 15 design guidelines for a decision-support tool for facilitators of crowdsolving endeavours, who must make decisions about facilitation actions intended to foster cross-fertilisation among participants. Our design principles and guidelines are prototypically operationalised by NLP, which lets the facilitator handle the vast amount of input they receive. In order to evaluate our design, we analysed three crowdsolving platforms and applied an instantiation of the design in the context of the FCL and demonstrated the tool’s ability to derive meaningful insights and actionable input which support the facilitator and indirectly contribute to solving wicked problems.

8. Appendix

Knowledge Domain	Business/ Economics	Earth Sciences / Energy	IT	Natural Sciences	Policy	Society	Sustainability
Keywords	Business	Earth Sciences	Artificial Intelligence	Biology	Legislation	Culture	Climate Change
	Economics	Earth systems	Computer Science	Chemistry	Policy	Philosophy	Ecology
	Finance	Energy	Data	Engineering	Politics	Social Sciences	Global Warming
	Management	Geography	Distributed Ledger Technology	Nanotechnology		Society	Sustainability
		Geology	Information Technology	Physics		Sociology	
		Resources	Technology				
		Water					

Table A1. Identified knowledge domains from participants and corresponding keywords used to obtain training data

These keywords were used to extract texts from Wikipedia articles, which were then used to train the classifier that assessed the prevalence of knowledge domains in the contributions (see Section 5.3).

	Overall	Phase 1	Phase 2	Phase 3
Contribution length (in words)				
Max	477	401	477	-
Min	17	19	17	-
SD	86	83	97	-
Average	100	98	105	-
Overall Fit (OF) of contributions				
Max	341 %	318 %	341 %	-
Min	113 %	113 %	120 %	-
SD	45 %	45 %	44 %	-
Average	211 %	207 %	219 %	-
Comment length (in words)				
Max	505	383	505	421
Min	2	3	2	5
SD	69	60	63	83
Average	78	70	69	102
Participation				
Contributions	243	172	71	-
Comments	539	256	142	141
Likes	632	427	205	-
Votes	903	-	-	903
Active participants	103	83	70	70

Table A.2 Descriptive statistics of participation in the FCL

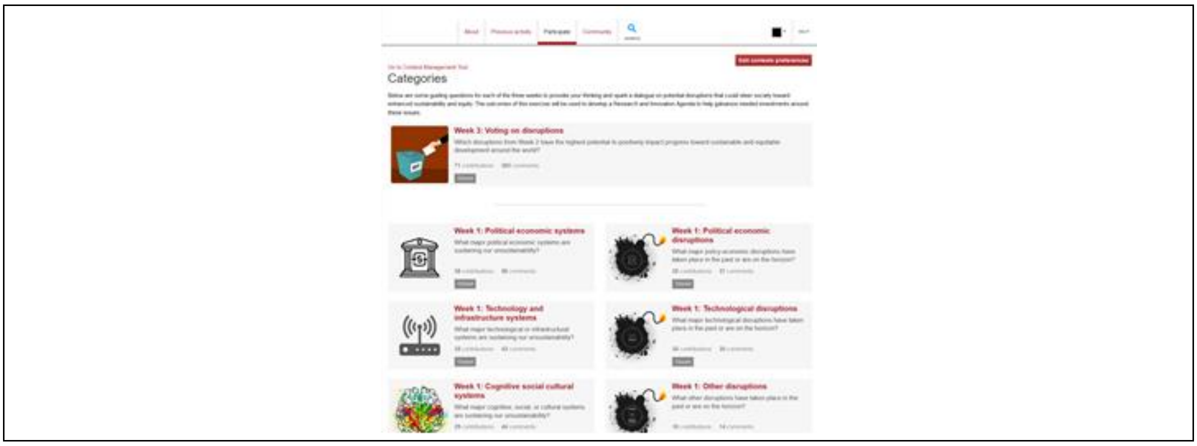

Figure 3. Landing page of the FCL

Figure 4. Contribution overview after opening category on landing page in the FCL

Figure 5. Contribution in FCL including comment

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IV The societal level

IV.1. Research paper 6: "Health is wealth – But what about digital technologies? A comparative mixed-methods study"

Authors:	Valerie Graf-Drasch
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Keywords:	Sustainability; Sustainable Development Goals; ICT4D, Comparative Research, Mixed-Methods.

Abstract

IS research on global sustainable development primarily focuses on developing countries and the materially less advantaged members therein. Acknowledging this, associated scholars are now calling for broadening the perspective in the hope of uncovering synergies and unearthing universal solutions. This research thus sets out to provide a more global consideration of sustainable development issues. We investigate the link between the sustainable development goal "good health and well-being" and digital technologies which hold significant potential to address this goal. This link is analyzed quantitatively and qualitatively in the context of India and the USA, which act as representative developing and developed countries. Results reveal the digital technologies that stand to address the most health targets in each country. In many instances, the technologies will differ between countries, but this is not the case for all health targets. For some targets, a universal multi-country solution may be applicable. We also reflect on contextual factors moderating core results and provide a brief outlook on how digital technologies could be implemented to achieve specific health targets India and the USA.

1. Introduction

“Transforming the world” is the vision under which the United Nations (UN) released the 2030 Agenda on global development (United Nations, 2015b). The Agenda comprises 17 Global Sustainable Development Goals (GSDGs) forming a plan of action for people, planet, and prosperity. All UN member states should collaborate to achieve the GSDGs (Sachs et al., 2019; United Nations, 2018). The collaboration of the G20 countries is of utmost importance as these nations represent two-thirds of the world’s population, 84% of global GDP, and over 75% of global trade. Stated differently, it is expected that, when the G20 countries are “on board,” the world will follow (Sachs et al., 2019).

Although the 17 GSDGs are equally important, the goal “good health and well-being” particularly given the current COVID-19 pandemic, which has caused a global health crisis and revealed the vulnerability of societies’ abilities to protect the good health and well-being of their citizens (World Health Organization 2020). Not only does a lack of good health – i.e. the presence of disease and/or death – affect the existence and well-being of individuals, it also burdens families, takes up public resources, weakens societies, and squanders potential (Sachs et al., 2019). The significance of this goal led Walsham (2017) to promote it to a prominent position on his agenda for developmental research in upcoming years. He highlighted that, although the topic of health has already received substantial attention (e.g., Braa et al., 2004), a whole range of further issues could be addressed (Walsham, 2017). Walsham is not alone in his observation that the Information Systems (IS) discipline holds significant potential to support countries’ efforts to achieve the GSDGs (Walsham, 2017; Venkatesh et al., 2019b). In particular, IS and associated digital technologies are crucial to health care systems in that they improve patient safety and treatment outcomes while improving economic efficiency (Bertelsmann Group 2019, Winkler et al. 2020).

Research at the intersection of the GSDGs and IS falls under the strand “ICT4D,” an acronym referencing “Information and Communication Technology for Development” (Venkatesh et al., 2019a; Venkatesh et al., 2019b). To date, ICT4D research has primarily focused on the contribution that particular kinds of ICTs have made in developing countries and their materially less-advantaged populations (Walsham 2017). Although highly valuable, such contextual research grapples with the trade-off between particularism and generalizability. This tension primarily concerns the transfer of findings in context-specific research to other contexts, such as from developing to developed countries (Avgerou 2019). Thus, IS scholars recently called for an understanding that looks beyond the current division between research on developing and developed countries (e.g., Information Systems Journal, 2019; ECIS 2020 in partnership with HEM Business School, 2019; Scandinavian Journal of Information Systems, 2020). One appropriate approach involves comparative methods (Avgerou, 2019), which consider contextual specifics – examining details of the practices that bring about an IS phenomenon – but also take a broader view to study the dynamics of the emergence of practices across contexts (Avgerou, 2019; Cecez-Kecmanovic et al., 2014).

This paper sets out to investigate the link between the key GSGD “good health and well-being” and digital technologies. To this end, it provides a comparative study of India and the USA, examining perceptions of the ways in which digital technologies contribute to “good health and well-being”. We selected India and the USA as representative developing and developed countries that are also G20 members, meaning both are considered to be key players in efforts to achieve the GSDGs. As a theoretical framework guiding our research, we use Sen’s (1999) concepts of “means to achieve” – referencing digital technologies – and “freedom to achieve” – representing health targets of GSDG3 – and map these to the context. As the results show differences between perceptions in the USA and India (which may be expected as the countries have different development statuses), we also explore the interesting questions of why and how. We summarize this endeavor in the following three dependent research questions:

RQ1: Does the potential of digital technologies to contribute to “good health and well-being” differ between developed and developing countries?

RQ2: If so, what are the contextual conditions moderating results between countries?

RQ3: Considering these contextual factors, how can digital technologies contribute to “good health and well-being” in a developed or a developing country?

To answer our research questions, we follow other comparativists and use a mixed-methods design that combines quantitative and qualitative approaches (Bernardi et al., 2007; Lieberman, 2005). Via the quantitative (*RQ1, RQ2*) and qualitative (*RQ3*) nature of our research questions, we hope to obtain a complete and meaningful picture of the phenomenon that cannot be achieved using only one approach (Venkatesh et al., 2013; Venkatesh et al., 2016). In this research, we online survey citizens from the USA and India. Results of *RQ1* indicate that the potential specific digital technologies hold to contribute to “good health and well-being” differs between countries. However, there are some health targets where certain digital technologies have equal potential in both countries. For those targets, a universal solution – in the form of a digital technology that supports goal attainment, regardless of the country – might be applicable. For the results of *RQ2* and *RQ3*, we narrow the focus to two health targets to which the potential contribution of digital technologies varies greatly between India and the USA. We discuss which contextual factors moderate this link and list examples of how digital technologies could be implemented to achieve specific goals.

2. Theoretical Background

2.1. GSDG "Good Health and Well-Being"

In September 2015, world leaders ratified the 2030 Agenda for Sustainable Development at a historic UN Summit (United Nations, 2015b). Although not legally binding, the GSDGs apply to all countries – poor, rich, and middle-income. In the years ahead, they will encourage efforts to end all forms of poverty, fight inequalities, and tackle climate change. The implementation and success of the GSDGs will rely on countries' own policies, plans, and programs. Working under the auspices of the Economic and Social Council, the High-Level Political Forum on Social Development reviews the progress made by each country towards achieving the GSDGs (Sachs et al., 2019).

In the global context of sustainable development, health and access to health are considered to be fundamental human rights and key development indicators. Poor health standards threaten other human rights, such as children's access to education and economic opportunities for men and women, and increase poverty at a local and national level (SDG Compass, 2015). Diseases resulting from poor health – such as cardiovascular diseases, cancer, chronic respiratory disease, and diabetes – also impose a significant burden on human health worldwide. It is predicted that, by 2025, such diseases will have led to cumulative economic losses surpassing U$ 7 trillion in low- and middle-income countries (United Nations, 2015a). In recognition of these challenges, "good health and well-being" is among the GSDGs, referred to as "GSDG3" (Sachs et al., 2019).

The aim of GSDG3 is to foster and promote life-long health and well-being for all. In its 1946 constitution, the World Health Organization defined health as "a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity" (World Health Organization, 1946, p.2). Table 1 states nine targets underpinning GSDG3:

Nr.	Description
1.	Reduce maternal mortality.
2.	End all preventable deaths under 5 years of age.
3.	Fight communicable diseases.
4.	Reduce mortality from non-communicable diseases and promote mental health.
5.	Prevent and treat substance abuse.
6.	Reduce road injuries and deaths.
7.	Universal access to sexual and reproductive care, family planning, and education.
8.	Achieve universal health coverage.
9.	Reduce illnesses and death from hazardous chemicals and pollution.

Table 1. Targets of GSDG3 "good health and well-being" (Sachs et al., 2019)

When it comes to achieving the GSDGs and respective targets, the G20 countries account for most of the current achievement gaps and are, thus, central stakeholders (Sachs et al., 2019). In this work, we focus on the examples of two G20 countries – the USA and India – which occupy positions 35 and 115, respectively, in the global GSDG ranking (Sachs et al., 2019). Both countries are among the top three countries in the world in terms of their population size (World Population Review, 2019), yet, in the context of GSDG3, the two countries differ significantly. India alone represents 23.9% of the total achievement gap on GSDG 3, while the USA only represent 1.5%. In terms of well-being, a UN survey which asks citizens to self-evaluated their status between "worst possible life" (0) and "best possible life" (10), resulted in an average score of 4 for India and a 6.9 for the USA (Sachs et al., 2019) – a difference which can may associated with health-related indicators for the two countries (Wendt et al., 2009; Rechel et al., 2016; Thiel et al., 2019). In the course of providing countries with guidance on achieving the GSDGs, the UN has recognized the potential of IS: in 2019's World Summit on Information Society (WSIS), the UN, in particular, stressed the role of ICTs as catalysts for achieving the GSDGs (World Summit on the Information Society, 2019). In this regard, the IS community also found a means to help achieve the GSDGs.

2.2. The Role of IS in Achieving the GSDGs

The discipline of IS holds enormous potential to accelerate sustainable development (Venkatesh et al., 2019a; Venkatesh et al., 2019b). In this discipline, an established research stream – ICT4D – links the potential of ICT to international and societal development initiatives, such as the GSDGs (Walsham, 2017). As stated above, the history of ICT4D research spans some 30 years, during which time it has been known by different acronyms, such as "ICTD" and "ITD" (Walsham, 2017). For seminal works structuring the field, we point to recent literature reviews, such as those by Gomez et al. (2012), Gallivan and Tao (2013), Thapa and Saebø (2014). More recently Walsham (2017) categorized existing ICT4D research into three waves, the first of which began in 1988.

In contrast to ICT4D, the term e-health, which was coined in the 1990s, focuses on the development of applications to deliver health services for the individual (Wilson et al., 2014; Eysenbach, 2001). Eysenbach (2001, p. e20) defined e-health as “an emerging field in the intersection of medical informatics, public health and business, referring to health services and information delivered or enhanced through the Internet and related technologies.” However, this research paper primarily focuses on macro-economic perspectives, and consequently is in line with the ICT4D, which focuses on goal attainment (such as delivering health services) on societal- or global levels.

Today, ICT4D has become a key focus for governments and non-governmental organizations, and, of course, for IS researchers, all of whom seek to improve the lives, health, and well-being of citizens (Venkatesh et al., 2019a; Venkatesh et al., 2019b). While a plethora of existing ICT4D research focuses on the contributions made by particular kinds of ICTs in developing contexts (e.g., Venkatesh et al., 2019b; Venkatesh et al., 2019a; Jha et al., 2016), current calls demand a broader perspective and ask the IS community how else researchers might contribute (e.g., Information Systems Journal, 2019; ECIS 2020 in partnership with HEM Business School, 2019).

Taking a broader perspective, ICTs are digital technologies (Legner et al., 2017). The category ‘digital technologies’ includes emerging technologies (e.g., Internet of Things, blockchain) and established technologies (e.g., cloud computing, social media) (Berger et al., 2018; Gimpel and Röglinger). The enormous scale of the opportunities brought about by digital technologies has become apparent in the current wave of digitalization (Legner et al., 2017). In this work, we evaluate which digital technologies have the potential to contribute substantially to the achievement of GSDG3. To this end, a detailed understanding of types of digital technologies is necessary.

2.3. Types of Digital Technologies

The need to structure the field of digital technologies has been discussed from various perspectives (Bharadwaj et al., 2013). One popular high-level perspective refers to the SMAC acronym and provides guidance structured in terms of the four technology groups; social, mobile, analytics, and cloud (Frank, 2012). Although high-level approaches such as this consider various technologies, they do not enable a detailed classification of digital technologies (Berger et al., 2018). Subsequently, Berger et al. (2018) recently reviewed existing classification approaches, developed a set of seven archetypes, and classified 45 real-life objects from the Gartner Hype Cycles between 2015 and 2017 (Gartner Inc., 2015, 2016, 2017). The seven archetypes and exemplary digital technologies are:

I) *connectivity* (e.g., 5G, 802.11ax),

II) *actor-based products* (e.g., 4D Printing),

III) *sensor-based data collection* (e.g., Bioacoustic Sensing, Smart Dust),

IV) *analytical insight generation* (e.g., Citizen Data Science, Machine Learning),

V) *analytical interaction* (e.g., Virtual Assistant, Smart Advisor),

VI) *augmented interaction* (e.g., Gesture Control, NLQA*), and*

VII) *platforms* (e.g., cloud services, serverless platform as a service).

Please refer to Berger et al. (2018) for a detailed description of each archetype. In the following, we adhere to these archetypes of digital technologies (henceforth, digital archetypes). Specifically, we evaluate their potential to contribute to development in terms of achieving GSDG3. Thereby, in terms of theory, we draw on the Capability Approach (Sen, 1999).

2.4. Capability Approach

Much of the existent ICT4D research is descriptive and participatory, and, as such, informed by action research (Heeks, 2006; Hayes et al., 2013). Recently, however, scholars have argued the need for more theory-based evidence on the impact ICTs have on development. They noted that theory-based research is crucial when comparing disparate phenomena – e.g., across countries – in order to identify unseen commonalities (Walsham, 2017; Heeks, 2006). With respect to theory, there are many approaches linking human development to IT artefacts. And, while there is a significant body of research linking concepts of IS, the potential of Sen’s (1999) Capability Approach (CA) has recently attracted increased attention.

The CA contrasts with typical welfare economic models that focus on monetary aspects, such as income, expenditure, and growth models (Heeks, 2006; Walsham, 2017; Smith et al., 2011; Gigler, 2015). Instead, the CA has a non-monetary focus and refers to a normative framework for evaluating human development (Smith et al., 2011). In particular, it interprets development as “the process of expanding the real freedom people enjoy” (Sen, 1999, p. 1). Sen argues that the evaluation space for human development should be individuals’ capabilities: that is, the freedom people have to be and to do those things that they have reason to value (Sen, 1999). The CA is primarily a framework of thought; a mode of thinking. As such, the CA is not easily accessible to researchers from different domains (Zheng, 2009; Robeyns, 2000, 2005). Thus, we build on core aspects of a simplified version of the CA, developed by Robeyns (2005).

Figure 1 captures these core aspects in a stylized representation including the constructs "*means to achieve*" and "*freedom to achieve*" (Zheng, 2009; Robeyns, 2005). As discussed, our study focuses on "*means to achieve*", which includes digital archetypes with characteristics that provide people with the freedom to achieve good health and well-being.

Further, scholars suggest that the link between *means* and *freedom to achieve* is influenced by contextual variables, termed "moderators". Such moderators represent conversion factors, which can be personal (e.g., physical condition, sex, reading skills, intelligence), social (e.g., public policies, social norms societal hierarchies, power relations), or environmental (climate, geographic location). Thus, a person's freedom to achieve is defined by the capabilities with which she is endowed, including those that her individual contextual conversion factors allow her to generate (Zheng, 2009; Robeyns, 2005; Sen, 1999).

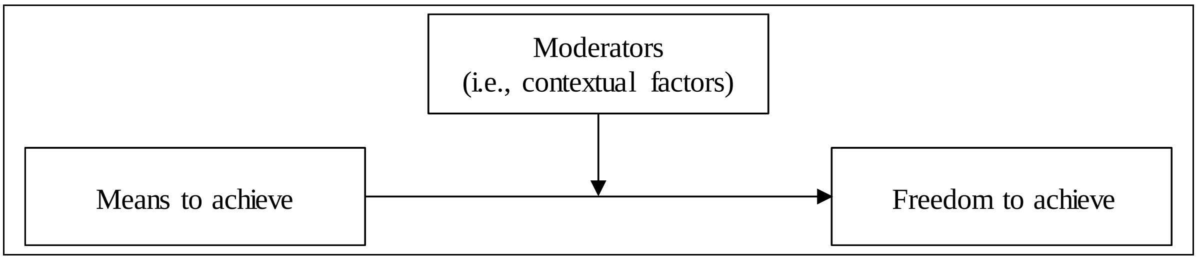

Figure. 1 Stylized representation of selected core aspects of the CA (adapted from Robeyns 2005)

3. Study Design and Research Model

A mixed-method approach suitable for conducting comparative research is central to the design of our study (Bernardi et al., 2007; Lieberman, 2005). Mixed-methods research integrates quantitative and qualitative approaches (Tashakkori and Teddlie, 1998; Johnson et al., 2007; Venkatesh et al., 2016) enabling researchers to explore confirmatory and exploratory research questions. More specifically, we use quantitative approaches to answer our confirmatory research questions RQ1 and RQ2 and a qualitative approach to answer our exploratory research question RQ3 (Venkatesh et al., 2013) We anticipate that this method will yield insights beyond those available via the lone use of either of the two approaches (Venkatesh et al., 2013).

Our mixed-methods design is based on the guidelines provided by Venkatesh et al. (2016) and Venkatesh et al. (2016). In this regard, we chose "developmental" and "completeness" purposes, meaning we first conducted a quantitative study, then uses the results from this "strand" to inform the qualitative "strand" of research and provide a more complete picture of the phenomenon under study. The quantitative approach was therefore dominant, with the qualitative approach providing an additional view to strengthen the research. Our design can, therefore, be classified as a "partially mixed sequential dominant status design" (Venkatesh et al., 2013; Venkatesh et al., 2016). Appendix A lists all the steps in our decisions about the mixed-methods design we used, following Venkatesh et al. (2016). Figure 2 summarizes our resultant study phases.

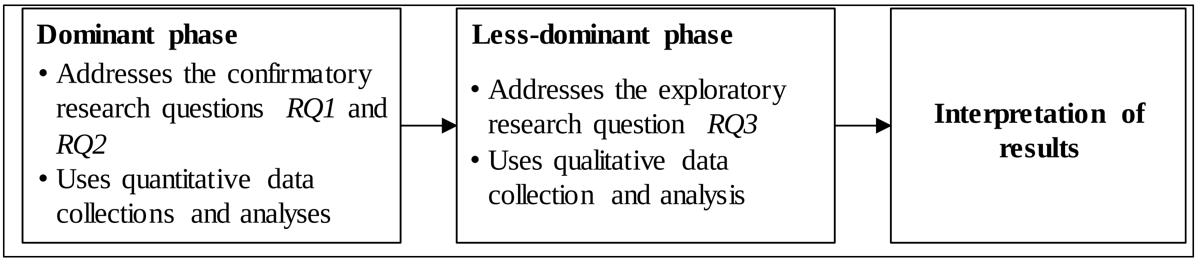

Figure 2. Summary of our study phases

Quantitative research approaches (as a feature of our dominant study phase; see Figure 2), usually test a theory and hypotheses. To this end, we built upon the CA and developed our research model depicted in Figure 3 which illustrates digital archetypes as "*means to achieve*," and the 9 health targets of GSDG3 as "*freedom to achieve*."

Concerning the literature supporting this research model, we have noted in the theoretical background section that a relationship between IT and development artefacts is at the innermost core of ICT4D research (e.g., Venkatesh et al., 2019b; Venkatesh et al., 2019a; Walsham, 2017). In keeping with previous research and the aims of this work, we postulate the following hypothesis, which reflects *RQ1*:

> *Hypothesis 1: The potential of digital archetypes to contribute to health targets differs between the USA and India.*

Further, we include contextual variables moderating the relationship between "means to achieve" and "freedom to achieve." The influence of contextual factors on this relationship has also been highlighted by ICT4D scholars (e.g., Walsham, 2017; Hayes et al., 2013; Venkatesh et al., 2019b) and in Sen's (1999) CA model. Attention to contextual variables is crucial when considering the likely reasons for similarities and differences. That is, different contextual conditions may explain different outcomes for the USA and India, while similar contextual conditions may explain similar outcomes between the two countries (Brislin, 1976; van de Vijver and Leung, 1998; Esser and Vliegenthart, 2017; Avgerou, 2019) & Avgerou 2019). We derived our contextual variables from a recent international report on 17 countries, which investigated the relationship between contextual variables and the extent to which countries can exploit the potential of digital technologies in the service of health care systems (Thiel et al., 2019). In brief, the report considers contextual factors relevant to the two broad categories "Political and Social System" and "Digital Health Governance." Table 2 lists the contextual variables considered in our study. Please note that these refer to those 12 variables which were theorizes to have a strong effect, as discussed in the report of Thiel et al. (2019, p. 42). For each of the 12 variables, we also postulate a hypothesis that reflects *RQ2*:

Hypothesis 2a-l: [Insert specific contextual factor] moderates the applicability of a certain digital archetype in the USA and India.

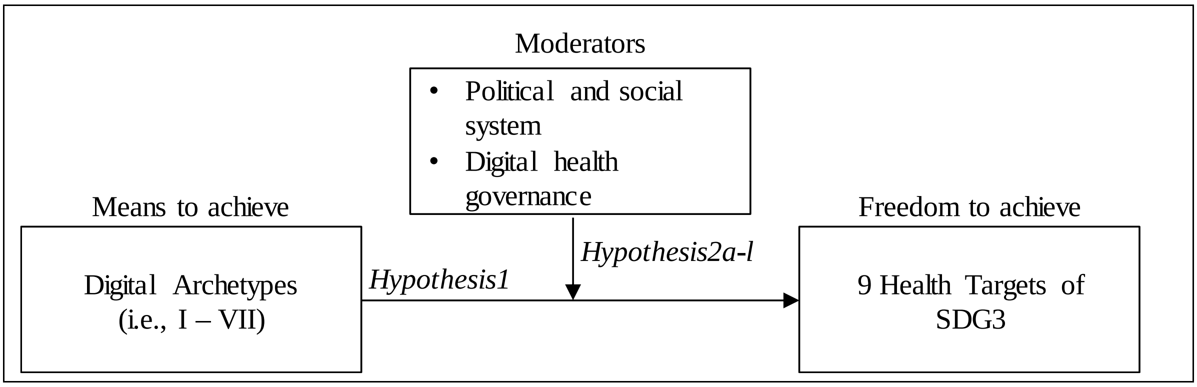

Figure 3. Research model for confirmation in our dominant study phase

Dimension	Category	Contextual conditions	Hypotheses
Political and Social System	Country Characteristics	Country size and population	*H2a*
		Corporatism (degree of self-government)	*H2b*
	Political culture	Role and cultural embeddedness of data-privacy protections	*H2c*
	Healthcare system type	Financing system	*H2d*
		Organizational structure	*H2e*
	Actors and institutions	Constellations of actors and advocacy coalitions: Number and role of veto actors	*H2f*
Digital health governance	Strategies and laws	Mandated use of standards and interoperability solutions	*H2g*
		Role of digital health strategies	*H2h*
	Institutional embedding	Secured financing for national / regional digital health competence centers (e. g., for staffing purposes)	*H2i*
		Centralized political management structure in place	*H2j*
	Political leadership	Commitment and involvement	*H2k*
		Coordination	*H2l*

Table 2. Moderators considered in research model

4. Method

4.1. Quantitative methods of dominant phase

In the dominant phase, we quantitatively investigated 1) the potential of digital archetypes to substantially contribute to the nine targets of GSDG3 across countries (*RQ1*) and 2) contextual factors moderating this link (*RQ2*).

Starting with *RQ1*, a survey sample consisting of USA and Indian citizens is used to conduct a single-round mapping process, in which the seven digital archetypes are mapped to the nine GSDG3 targets. To this end, we chose a purposive sampling scheme featuring criterion sampling (Venkatesh et al., 2016): specifically, participating citizens were members of the crowdsourcing platform Amazon's Mechanical Turk (MTurk) and employed in either the health care sector or the software and IT service industry. Although the use of MTurk is popular as a means to source empirical data, it is also subject to criticism regarding sample quality. However, many scholars involved in testing the quality of samples argue that the quality of MTurk samples is good and often better than the quality from regular internet panels or more traditional methods of data collection (Buhrmester et al., 2011; Hauser and Schwarz, 2016). We ensured a high sample quality by employing crowd workers who had either been rewarded by MTurk for their high-quality performance (i.e., "master qualification") or had accomplished at least 5,000 tasks with an approval rate of at least 97% from previous requesters (Earth Overshoot Day, 2020; Turkrequesters Blogspot, 2012). Additionally, we checked for citizens' conscious survey participation via control questions.

Following Berger et al. (2018), we provided a description and examples of each digital archetype in the survey. We asked the participating citizens to honestly state whether they understood each digital archetype after reading the descriptions and examples. If not, there were no consequences for them (e.g., in terms of lower payment), but we excluded the respective data sets from our analysis. The participants were then mapped up to 3 digital archetypes according to their potential to substantially contribute to each of the nine targets.

We used Pearson's contingency coefficient (C) to assess differences between the two countries. C is a measure of association between two (categorical) variables and uses the chi-square statistic to compare data summarized in a contingency table (Sheskin, 2011). The rows of each contingency table indicate whether a digital archetype has the potential to contribute to a certain health target (i.e., "yes" or "no") while the columns present the countries USA and India. Data in each cell represent the number of observations (i.e., frequencies): how often did participants in the USA and India rate a digital archetype in terms of its potential to substantially contribute to a certain target. We used the adjusted contingency coefficient of Ott et al. (1992), which allows for comparisons across differently sized contingency tables.

We evaluated the significance of association (i.e., C) via the chi-square test (Agresti, 2007; Sheskin, 2011) with Monte Carlo simulation, as suggested by Hope (1968). We evaluated the meaningfulness by following Cohen (1988, 1977) who translates C in an effect size (w), which he terms large if $w \geq .5$; medium if $w \geq .3$; and small if $w \geq .1$.

For *RQ2*, we built upon previous results and narrowed the focus to significant associations with considerable effect sizes. Such associations point to contextual conditions moderating the results in the USA and India. To identify such contextual conditions, we employed another survey sample consisting of American and Indian citizens and asked them for their opinions. In particular, we asked about the impact that certain contextual variables (as listed in Table 2) might have on the ability of frequently stated digital archetypes to address a specific health target in their country. The data collected was analyzed using a binomial logistic regression. In the analysis, we controlled for the country (USA or India).

4.2. Qualitative method of less-dominant phase

In the less-dominant phase, we aimed to gain additional data to support previous quantitative deep dive results (Venkatesh et al., 2016). In particular, we sought qualitative survey insights as to *how* digital archetypes might contribute to GSDG3 targets in practice. To this end, another survey sample consisting of American and Indian citizens asked for examples of how particular archetypes might substantially contribute to particular targets in their countries.

5. Results

5.1. Results of dominant phase

In total, they two surveys in the dominant phase resulted in 230 valid survey responses. Specifically, the first survey involved 84 citizens (41 American and 43 Indian), 33% of survey participants were female and 65% had a higher level of education (i.e., Bachelor, Master or Doctoral Degree). The second survey involved 146 citizens (99 American and 47 Indian), 25% of survey participants were female and 73% had a higher level of education (i.e., Bachelor, Master or Doctoral Degree).

Firstly, we provide descriptive statistics: digital archetypes stated with the *most* and *least* frequency were *III) sensor-based products* and *VII) platforms* in the Indian sample and *IV) analytical insight generation* and *VI) augmented interaction* in the American sample. Table 3 summarizes the three (or, in case of an equal number of ratings, four) most frequently rated digital archetypes per GSDG3 target for the USA and India, and summarizes the number and percentage of health targets each digital archetype is perceived to address in each country. The two most frequently rated archetypes per country are listed in bold type.

Secondly, Table 4 summarizes the contingency tables for each of the nine targets of GSGD3, and states the results of the Pearson's C analyses at the bottom of the table. The numbers in the table's cells indicate how frequently each answer was given by survey participants. Firstly, the results indicate non-significant differences in the potential of digital technologies to contribute to health targets 4 and 5 in each of the two countries. Secondly, for the remaining seven health targets (1-3, and 6-9), results indicate significant differences in opinions about which digital archetypes might be most able to address these targets in the USA and India. In the context of health target 2 "*end all preventable deaths under 5 years of age*" and 7 "*universal access to sexual and reproductive care, family planning and education*," in particular, country differences are not only highly significant but also of medium effect size and, thus, were analyzed via binomial logistic regression analysis in the following.

Table 5 states the results of the regression analyses. The coefficients are in logits and thus reference log odds ratios. From the signs and significances of the predictors, we summarize regression results as follows:

The first regression analysis focused on health target 2 "*end all preventable deaths under 5 years of age*" where the digital archetypes *II) Actor-based products* in India and *IV) Analytical insight generation* in the USA were perceived to have high contribution potential. To analyze the difference in the archetypes' perceived potential, we examined the contextual conditions of Table 2. The regression results indicate that particularly the contextual variable '*organizational structure of the health care system*' explain the selection of archetype *II) Actor-based products* in India. This result is only partially confirming *H2e,* as it does not apply for the USA.

The second regression analysis focuses on health target 7 "*universal access to sexual and reproductive care, family planning and education*" where the digital archetypes *III) Sensor-based data collection* in the USA and *VII) Platforms* in India were perceived to have high contribution potential. Again, to analyze the difference in the archetypes' perceived potential, we examined the contextual conditions of Table 2. The regression results indicate that the contextual variables '*financing system*', '*Role* of *digital health strategies'*, and '*Secured financing for national / regional digital health competence centers'*, are significantly favorable contextual conditions for the application of archetypes *III)* in this target context. The contextual condition '*centralized political management structure in place*' explains the application of archetype IV) *Platforms*. These results confirm *H2d, H2h, H2i, H2j*.

Health Targets		**1.**		**2.**		**3.**		**4.**		**5.**		**6.**		**7.**		**8.**		**9.**		**Descriptive Summary**	
		Maternal Mortality		**Deaths < 5**		**Comm. diseases**		**Mental health**		**Substance abuse**		**Road injuries**		**Sexual care**		**Health coverage**		**Hazardous chemicals**		**Nr. (and %) of targets digital archetype addresses**	
Country		USA	India	USA	India	USA	India	USA	India	USA	India	USA	India	USA	India	USA	India	USA	India	USA	India
Digital Arche-types	I) Connectivity		✓		✓				✓		✓		✓	✓			✓			1 (11%)	6 (67%)
	II) Actor-based products	✓		✓	✓				✓			✓	✓		✓			✓	✓	3 (33%)	4 (44%)
	III) Sensor-based data collection	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓		✓		✓	✓	✓	7 (78%)	**8 (89%)**
	IV) Analytical insight generation	✓		✓	✓	✓	✓	✓		✓		✓		✓		✓		✓	✓	**9 (100%)**	3 (33%)
	V) Analytical interaction		✓			✓		✓		✓	✓		✓			✓	✓	✓		4 (44%)	4 (44%)
	VI) Augmented inter-action		✓				✓		✓						✓				✓	0 (–)	5 (56%)
	VII) Platforms													✓		✓				2 (22%)	0 (–)

Table 3. Descriptive statistics: most rated digital archetypes to address GSDG3 targets in the USA and India

Health Targets		**1. Maternal Mortality**		**2. Deaths < 5**		**3. Comm. diseases**		**4. Mental health**		**5. Substance abuse**		**6. Road injuries**		**7. Sexual care**		**8. Health coverage**		**9. Hazardous chemicals**	
Country		USA	India	USA	India	USA	India	USA	India	USA	India	USA	India	USA	India	USA	India	USA	India
Digital Archetypes	I) Connectivity	9	19	7	19	9	17	11	17	11	22	10	19	25	20	17	23	10	18
	II) Actor-based products	19	17	25	**25**	18	16	13	23	15	15	15	22	12	22	14	15	16	22
	III) Sensor-based data collection	27	19	28	14	28	19	20	17	22	21	34	19	7	**21**	8	29	33	19
	IV) Analytical insight generation	26	16	**33**	20	26	23	21	14	20	12	27	17	18	14	21	17	23	21
	V) Analytical interaction	17	19	10	17	19	15	22	14	23	24	13	23	16	14	19	20	16	14
	VI) Augmented inter-action	13	24	8	16	4	18	14	24	13	18	10	12	9	21	8	8	10	21
	VII) Platforms	4	8	4	13	7	14	11	14	9	15	7	11	**27**	10	25	13	5	11
	∑ of ratings	115	122	115	124	111	122	112	123	113	127	116	123	114	122	112	125	113	126
Pearson's C:	Adjusted C	. 310		**.431**		.355		.285		.242		.336		**.426**		.360		.318	
	p-Value	.061		**.001**		.014		.126		.305		.025		**.001**		.010		.047	
	Effect size	Weak		**Medium**		Weak		Weak		Weak		Weak		**Medium**		Weak		Weak	

Table 4. Summary of contingency tables: frequency statements on the potential of digital technologies to contribute to health targets

			Dependent Variables			
			Choice of archetype II) or IV) to contribute to target #2		Choice of archetype III) or VII) to contribute to target #7	
Independent Variables			β	p-value	β	p-value
Intercept			3,884	.016 *	12,311	.000 ***
Control variable country for interaction effects (0=USA, 1=India)			-.129	.940	.683	.768
Dimension	Category	Contextual conditions				
Political and social System	Country Characteristics	Country size and population	-.264 (-.136)	.170 (.669)	-.326 (.291)	.188 (.549)
		Corporatism (degree of self-government)	-.209 (-.399)	.440 (.309)	-.429 (.404)	.167 (.457)
	Political culture	Role and cultural embeddedness of data-privacy protections	-.157 (.036)	.389 (.911)	-.254 (-.063)	.248 (.890)
	Healthcare system type	Financing system	-.285 (.028)	.302 (.933)	-.791 (.059)	.015 * (.901)
		Organizational structure	-.222 (.902)	.442 (.029) *	.064 (.325)	.816 (.486)
	Actors and institutions	Constellations of actors and advocacy coalitions: Number and role of veto actors	.166 (.114)	.504 (.727)	.010 (.113)	.975 (.821)
Digital health governance	Strategies and laws	Mandated use of standards and interoperability solutions	-.175 (.042)	.473 (.900)	-.095 (.095)	.755 (.855)
		Role of digital health strategies	-.088 (.139)	.721 (.654)	-.593 (.343)	.096 + (.470)
	Institutional embedding	Secured financing for national / regional digital health competence centers (e. g., for staffing purposes)	.002 (-.326)	.994 (.382)	-.685 (.033)	.049 * (.946)
		Centralized political management structure in place	.471 (-.145)	.147 (.689)	.656 (-.793)	.085 + (.167)
	Political leadership	Commitment and involvement	-.023 (-.136)	.933 (.699)	-.468 (-.092)	.107 (.833)
		Coordination	-.190 (.311)	.484 (.356)	-.202 (-.057)	.528 (.915)

Table 5. Results of regression analysis

In the following less-dominant survey phase, we elaborated on these quantitative results. In particular, we sought qualitative insights on how the operationalizations of digital archetypes might contribute to health targets 2 "*end all preventable deaths under 5 years of age*" and 7 "*universal access to sexual and reproductive care, family planning and education*," and what these interventions may look like.

5.2. Results of less-dominant phase

To gain qualitative insights, we investigated *how* the archetypes *II) actor-based products* and *III) sensor-based data collection* in India, and *IV) analytical insight generation* and *VII) platforms* in the USA, might substantially contribute to the targets 2 *"End all preventable* *deaths under 5 years of age"* and 7 *"Universal access to sexual and reproductive care, family planning and education."* The selected archetypes appear frequently in Table 5 thanks to their perceived potential to substantially contribute to these targets. To gain insights, we reach out to 26 citizens (16 Indian, 10 American) for detailed qualitative survey statements. Table 6 displays frequently stated exemplary specifications of how digital archetypes might contribute to targets. Appendix B links to *Supplementary Material* where we state all qualitative data collected.

Target	**Digital Archetype**	**Country**	**Examples**
2. End all preventable deaths under 5 years of age	II) actor-based products	India	Improve physical environment that directly affects health conditions, or physically involve products in medical care (e.g., transplantations, prostheses), or arranging space which also has substantial effect on i.e., behavior.
	IV) analytical insight generation	USA	Compile data from previous incidents, analyze data and search for common denominator/pattern, maybe identify which risk factor is the easiest to combat, alter future treatments.
7. Universal access to sexual and reproductive care, family planning and education	III) sensor-based data collection	India	A serious drawback of India's health systems is that it largely neglects rural masses. Thus: use archetype to overcome this and to effectively collect data, via sensors, on, e.g., sexual care, or population. Also use III) for monitoring the progress.
	VII) platforms	USA	Provide universal access to respective information and services needed in this context, maybe align with health care goals.

Table 6. Exemplary specifications of how digital archetypes might contribute to targets

6. Discussion

The UN's 2030 Agenda presents a challenge of utmost importance, and it is now time for the discipline of IS – with its power to transform, automate, and inform – to become involved (Watson et al., 2010; Melville, 2010). Digitalization and digital technologies are resulting in rapid transformations and innovations in business and society (Legner et al., 2017). In this study we investigate whether this potential can be leveraged to achieve the GSDGs; in particular, GSDG3 "good health and well-being." We offer three major contributions:

Firstly, on a general level, we provide a rating of digital archetypes based on their perceived potential to substantially contribute to "good health and well-being" in the USA and India. The results reveal that in India *III) sensor-based data collection*, and in the USA *IV) analytical insight generation* are the digital archetypes most frequently rated by citizens in relation to all health-related targets.

Secondly, and moving to a more concrete level, we investigated whether digital archetypes are rated with equal frequency according to their potential to address targets related to "good health and well-being" in the USA and India. Results indicate that citizens in the USA and India rated different digital archetypes to substantially contribute to achieving respective targets in their country. These differences are significant for most targets, yet not for targets 4 (i.e., mental health) and 5 (i.e., substance abuse). In these two cases, a universal strategy consisting of digital archetypes contributing to these targets in both the USA and India might be applicable.

Thirdly, we investigated contextual variables impacting the potential of digital archetypes to contribute to health target 2 (i.e., deaths < 5) and health target 7 (i.e., sexual care) in the USA and India. Concerning health target 2, the organizational structure of the Indian health care system in India significantly predicts the applicability of *II) actor-based products*. Concerning health target 7, a secured healthcare financing system, the existence of concrete digital health strategies and goals, as well as the existence of digital health competence centers are contextual conditions explaining the applicability of *III) sensor-based data collection*. On the other side, the existence of politically established committees or other institutions managing digitalization processes explains the applicability of *VII) platforms*. Taken together, these insights highlight the salient role of contextual factors hindering or supporting the application of digital archetypes to contribute to target attainment.

Fourthly, we conducted a qualitative survey among Indian and American citizens, which complements our quantitative investigation of how frequently rated digital archetypes might contribute to targets 2 and 7. Results of Phase 2 serve as a qualitative outline of what the operationalization of digital archetypes supporting GSDG3 targets may look like.

6.1. Limitations:

Our study has some limitations that readers must bear in mind. First and foremost, the sample size may be considered small. We do not claim that this is untrue or that our sample is representative of the populations of India or the USA. Instead, we argue that this study uses a diligent combination of quantitative and qualitative approaches to investigate the phenomenon from different perspectives. As such, the study aims to investigate whether it is worthwhile to intensify research on the intersection of digital technology and the GSDGs, and, in particular, on health care and well-being. Our results indicate that further research would be worthwhile. Thus, future researchers need to make their own decisions about the sample size and "strand" (i.e., quantitative or qualitative) when continuing this topic and advancing the results.

Secondly, with respect to the survey, readers might raise the question of bias in our answers due to the sequence in which the GSDG3 targets appeared and the rating of digital archetypes in the survey. To address this, we *a priori* randomized the sequence of targets. What is more, results indicate that the frequency of digital technologies is not dependent on their numbers (i.e., *I*, *II*, etc.). For example, *connectivity* as archetype *I)* was not the digital archetype mentioned with most frequency in our survey. This indicates that bias due to numbering or sequence is not a major issue in our study.

Thirdly, with respect to the survey of citizens, we reached out to individual citizens instead of practitioners or IS researchers. A focus on the latter two target groups would represent a different approach. However, we have consciously chosen this approach as it has been argued that respective research in the context of ICT4D often fails to engage with affected individuals and, thus, is disconnected from their real-world challenges (Qureshi, 2015).

6.2. Implications for Future Research and Practice

Despite the stated limitations, we believe that the current mixed-methods study opens up interesting opportunities for future research and practice. Overall, more research is needed to understand the opportunities digital technologies present in terms of supporting GSDG3 or all GSDGs. This study is a starting point, and suggests that future research can expand the scope of this study in four directions: (1) as already stated, increase the sample size, (2) increase the spectrum of digital archetypes or refer to a different classification of digital technologies, (3) increase the variety of countries analyzed, and (4) increase the GSDGs analyzed. Concerning practice, results indicate which digital technologies may be accepted in the USA and India, and what an operationalization of digital archetypes supporting GSDG3 targets may look like.

7. Conclusion:

Acknowledging the 2030 Agenda of the UN as a global challenge of utmost importance, it is timely for the IS discipline to broaden its former focus on developing countries. In particular, recent challenges such as the outbreak of the COVID-19 pandemic highlight the salient role of cross-country solutions to UN goals such as “good health and well-being.” This is a mixed-methods cross-country study that investigates the potential that digital technologies hold to substantially contribute to “good health and well-being” in the USA and India. Although there is no solution that “fits all,” cross-country partial solutions are, at least, conceivable for some health targets. We have explored *why* results differ between countries, identified contextual factors greatly moderating results, and provided qualitative insights in support of solutions.

8. Appendix:

8.1. Appendix A

This appendix references *Supplementary Material*, which serves the reader as additional information but is not required for a sound understanding of this article. Please use the anonymized link: https://www.dropbox.com/s/8wq3r983eypi8nk/Appendix%20A_Supplementary%20Material_Design%20Choices%20in%20Mixed-Methods%20Approach.docx?dl=0 to see our design choices in our mixed-methods approach.

8.2. Appendix B

This appendix references a *Supplementary Material*, which serves the reader as additional information but is not required for a sound understanding of this article. Please use the anonymized link https://www.dropbox.com/s/vedtx7tszga7eyh/Appendix%20B_Supplementary%20Material_Original%20Qualitative%20Data%20Collected.xlsx?dl=0 to see the original qualitative data collected.

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V Results, future research, and conclusion

The following chapter contains the doctoral thesis' key findings in Section V.1, an outlook on future research areas in Section V.2, and a short conclusion in Section V.3.

V.1. Results

This doctoral thesis focuses on the two research strands Green IS and ICT4D and thereby addresses research topics on three different levels. After motivating the IS' relevance to address problems in the sustainability arena, this thesis presents new models and approaches at the nexus of IS and sustainability. As their applicability depends upon context, included research questions alternately address an individual, organizational, and societal level. The following sections present the key findings of the included six research papers.

V.1.1. Results of Chapter II: The individual level

Chapter II is embedded in the Green IS research strand and focuses on individuals. Particularly, in this chapter, this doctoral thesis investigates individuals' behavior alongside the life cycle of IT (P1, Section II.1), individuals' acceptance of smart energy technology across contexts, countries, and diffusion phases (P2, Section II.2), and citizens' decision making in a renewable energy context in Germany (P3, Section II.3).

In Section II.1, research paper P1 applies a baseline model to identify factors explaining individuals' behavior alongside different life cycle stages of IT. This baseline model is extended by a further factor capturing environmental sustainability in three major steps: First, a comprehensive structured literature review of 3,098 scientific studies is conducted. The objective of this review is to identify prior studies that employ an environmental sustainability factor to explain individuals' behavior in the context of IT. The review yields 19 different environmental factors. Second, these 19 factors are synthesized via data collection in an online survey and the application of exploratory factor analysis. Third, results of the factor analysis reveal one environmental factor termed "*Environmental Awareness/Concern*" and two moderators. The factor and the two moderators are added to the baseline model. Again, an online survey serves for data collection for the extended model. The extended model is tested across the three life cycle stages of IT via structural equation modeling. Results indicate a significant influence of the newly introduced *Environmental Awareness/Concern* factor in *every* life cycle stage. To conclude, the results of research paper P1 point to individuals' awareness and concern of environmental issues when dealing with IT. This holds true for the complete "cradle-to-grave" process of IT, as depicted in the study. Briefly summarized, results imply that practitioners involved in one of the life cycle stages (e.g., manufacturers of IT) should focus on both, sustainable processes related to IT and sufficient marketing campaigns that ensure its publicity.

In Section II.2, research paper P2 applies a meta-analytic structural equation model, to test a comprehensive model explaining individuals' smart energy technology adoption across contexts, countries, and diffusion phases. First, the study provides detailed insights in respective adoption models in prior literature. A comprehensive literature review comprised of 8,144 scientific studies spanning across IS and sustainability. This review yielded seven prior studies (i.e., "primary studies"), which tested adoption models for different types of smart energy technology using more than 4,000 individuals in Europe, Asia, and North America. Second, having identified the seven primary studies, the research paper develops and tests a comprehensive adoption model representing a synthesis of prior adoption models. Results indicate that the factors *Attitude* and *Performance Expectancy* are the main drivers of individuals' smart energy technology adoption. Further, results reveal that the factor *Environmental Concern* has a significant impact on technology-specific beliefs (such as *Attitude* or *Performance Expectancy*). From a policy perspective, findings of P2 suggest the introduction of indirect policy instruments, such as providing firms with incentives to foster smart energy technology diffusion. Moreover, results indicate that targeting environmentally concerned people by fostering campaigns informing residents about current environmental conditions could be an appropriate policy measure to improve individuals' uptake of smart energy technology.

In Section II.3, research paper P3 develops an IS-based tool to support citizens' decision-making. To guarantee a meaningful engagement of citizens with the tool, it is designed in accordance with gamification principles. The performance of the gamified tool is evaluated in the context of renewable energy i.e., onshore windfarm acceptance in Germany. Therein, the tool visualizes the consequences of the proportion of renewable energy selected by the users in an online survey with 352 citizens. The key results are threefold: First, the tool draws a realistic picture of citizens' preferences for renewable energy in Germany, when compared with current German trends and socio-economic developments. Second, individuals preferring high levels of renewable energy before interacting with the tool still do so afterwards and vice versa. Third, results indicate that the tool influences citizens' decision-making: In particular, results reveal that all analyzed cross-sections of citizens within the sample significantly change the amount of renewable energy initially desired, after interacting with the tool. From a practical perspective, this work enables policy makers to formulate regulations, which are more realistically grounded in citizens' preferences. What follows therefrom are future projects that might receive improved support from the public and create less resistance – a calculation that underlies the involvement of citizens in political decisions.

V.1.2. Results of Chapter III: The organizational level

Chapter III of this doctoral thesis is also embedded in the Green IS research strand and focuses on organizations and their contributions to address sustainability issues. In Section III.1, research paper P4 applies a game-theoretic model of an all-pay auction setting, which captures the competition for a market share in a conceptualized sustainability market. Thereby, it considers different scenarios where symmetric and asymmetric, weak and strong, as well as a varying number of organizations interact. Results reveal four broad strategies organizations apply when transforming their business model towards sustainability:

- Organizations' willingness to transform their business model towards sustainability increases with the sustainability market potential exemplarily reflected in customers' demand for sustainability products. However, this market potential must reach a critical value before organizations start transforming.
- Strong players (i.e., organizations with a high market share in the regular, non-sustainability market) only invest if the sustainability market potential is large enough. However, the larger the sustainability market gets, the more likely it is that weak players challenge their strong competitor(s). Further, the introduction of insecurity about competitors' sustainability efforts by tendency deters strong players from transformations. Thus, the larger the sustainability market is, the larger the benefit of weak organizations.
- Profit margins play a negligible role for sustainability transformation of the business model for strong players, but trigger weak players to start transformation earlier.
- In case of low or zero transformation costs, an organization can establish systematic market entry barriers that discourage competitors from entering the market and improve their economic performance.

In sum, results suggest different strategies that organizations can apply to gain competitive advantage. The formal model presented in the study can be applied by scholars and practitioners to specific industry settings or different natures of market settings with large degrees of freedom.

In Section III.2, research paper P5 takes an IS design science perspective and identifies four design principles and 15 more detailed design guidelines. These principles and guidelines form a tool that supports the facilitator of a crowdsolving system to measure, and facilitate cross-fertilization. To demonstrate the tool's value added and feasibility, the tool is prototypically instantiated in the facilitation of a real-world crowdsolving task with 181 participants. Results of this instantiation refer to the feedback from the facilitation team, ex-post survey data from the crowd members, and quantitative analyses of the digital trace data that emerged on the crowdsolving platform. Taken together, these sources support effectiveness, efficiency, and impact on the user's environment of the prototype. Particularly, results indicate that proposed design guidelines and principles encourage cross-fertilization within the crowd. Further, results indicate that cross-fertilization is observable over time and is of interest to the facilitator. The research paper is triggered by the needs of practitioners, and resulting design principles and guidelines primarily aim at supporting and advancing their daily operations. Yet, our tool is not only useful in research focused on finding solutions to wicked problems. It will also assist organizations that employ crowdsourcing in ideation competitions or open innovation, wherein cross-fertilization is desirable.

V.1.3. Results of Chapter IV: The societal level

Chapter IV is embedded in the ICT4D research strand. In section IV.1, research paper P6 applies a comparative mixed-methods research approach. As such, it contains quantitative and qualitative insights *whether*, *why*, and *how* digital technologies have the potential to contribute substantially to "good health and well-being." In the quantitative part, online surveyed citizens of the USA and India assess the potential of different digital technologies to contribute to "good health and well-being" in their country and also state potential contextual conditions impacting this assessment. The qualitative part elaborates on the quantitative results. In a subsequent online survey, it investigates *how* particular digital technologies may substantially contribute to "good health and well-being" in the USA and India. Results are fourfold: First, from an overall perspective, "III) sensor based data collection" in India and "IV) analytical insight generation" in the USA are the digital technologies most frequently rated across all health-related targets from a citizens' perspective. Results indicate that citizens in the USA and India rated different digital archetypes to substantially contribute to achieving respective targets in their country. These differences are significant for most targets, yet not for targets 4 (i.e., mental health) and 5 (i.e., substance abuse). In these two cases, a universal strategy consisting of digital archetypes contributing to these targets in both the USA and India might be applicable. Third, a regression analysis revealed contextual variables impacting the potential of digital archetypes to contribute to health target 2 (i.e., deaths < 5) and health target 7 (i.e., sexual care) in the USA and India. Fourth, a qualitative survey reveals brief insights on how particular instantiations of digital technologies may look like. With respect to practice, results indicate which digital technologies may be accepted in the USA and India and how an operationalization of digital technologies may be fostered.

V.2. Future research

Based on the results of the six research papers presented above, the following sections present starting points for future research. Further, these starting points address the limitations of each research paper.

V.2.1. Future research in Chapter II: The individual level

In Section II.1, research paper P1 has several limitations. The first limitation refers to sample attributes and generalizability of results. As the online survey was conducted in the USA, results may vary by country especially in countries coined by a different level of IT availability. Further, different demographic attributes (e.g., age or gender) of our sample may have influenced results. Future research may employ the research model in different geographic areas and/or with samples being characterized by different demographic attributes. Second, although the study accounted for marker questions to exclude unconscious answers, results may still be prone to other biases. One such bias may refer to the social desirability bias, since the study’s focus on sustainable behavior was communicated to survey participants in advance. Third, future research may apply different theoretical models as baseline and test different factors explaining individuals’ behavior and the role of environmental sustainability therein. Similarly, future research may also account for integrating further sustainability dimensions in respective models (i.e., social and economic). Finally, future research may use this study as a starting point to start a deep dive analysis of certain life cycle stages (e.g., “disposal”).

In Section II.2, research paper P2 has limitations that may reveal opportunities for future research. These refer to the sample and the applied method. First, Asia only represents 3% of the total primary study sample size. Although it was controlled for the effect of “sample origin,” future research may employ the model in different geographic areas. Second, further studies, which were not identified or not published so far and might have implications for the model, may be included in the meta-analysis. Third, with respect to the applied method, primary data does not exclusively reference individuals living in smart cities, which is the motivating context of the study. Future research might test model validity and robustness in this regard.

In Section II.3, research paper P3 comes along with several limitations future research may address. First, in the context of wind energy, there are many relevant variables, such as local pollution, air-quality, health issues, grid development, storage, CO2-emission, global warming, etc. However, the concrete research objective of P3 was not to design an IS tool that comprehensively informs German citizens about the entire complexity. Rather, the research paper focuses on the narrow but specific aspects for the sake of a clean research design and a clear research question. Particularly, the focus was on the variable land use by wind power, which is a current topic in Germany's expansion of wind energy. Thus, the disclaimer in P3 is made that we know that the world is not quite as simple when it comes to replacing coal with wind power as focused on in the online survey. However, given the plethora of interesting variables, including all of them within one research project simultaneously is challenging. Thus, the findings reported in P3 should encourage further research to extend this work and explore additional aspects in more detail. Further, future research might also expand the research by exciting related aspects, such as the dangers of a blackout that comes with the coal exit. Second, future research might improve the current design of the IS-based tool by turning to other or additional design principles. Third, results may change with context or sample characteristics. As stated above, the online survey was conducted in Germany, the European country with the highest proportion of wind energy. In other countries or with regard to other topics, the results may differ. Future research can build on this specific study to move toward other research settings. Fourth, future studies could explore additional ways beyond an IS tool to support individual citizens with decision-making. Additionally, the study is also limited by the assumptions associated with the use of the IS tool. In this regard, the access to and the acceptance of the technology on which the tool is based upon should be mentioned as examples.

V.2.2. Future research in Chapter III: The organizational level

In Section III.1, research paper P4 holds the following opportunities for future research. First, the applied game-theoretic solution concept of Nash equilibria in pure strategies only partly explains competition behavior in situations where competition for sustainability is not very profitable for market participants (within the friction interval). Future research may apply advanced equilibrium concepts to examine the friction interval. Second, limitations refer to the theoretical research method and "feeding" of the model with simulated data. Future research may employ the model in real-world contexts and refer to empirical data. Third, all observed results are subject to the very strong assumption of modeling a static game and do not consider a time dimension or multi-period competition. Fourth, the assumption of the organizations to include expectations of profits is crucial in outcomes. Although this assumption is uncritical for organizations that are active in multiple product markets, for organizations only active in one or a small number of product markets, this assumption would not be met. Fifth, comparing and contrasting results of the study with insights from existing studies is difficult, since to the best of the authors' knowledge, this was the first study using a game-theoretic framework to analyze business model innovation. However, future research may refer to literature on auction and game theory in a general competition context for new markets and derive further insights.

In Section III.2, research paper P5 presents an approach with some limitations that may stimulate further research. First, future research might analyze the effectiveness of single design principles and guidelines, or the entire design, by running multiple and parallel comparable crowdsourcing processes (i.e., crowdsolving). Second, the provided assessment of cross-fertilization is not suitable to compare processes with each other due to the variability of participants, goals, knowledge domains, and the time horizon. Other processes for example require different labels that hinder comparability. Third, future research may develop a more sophisticated measure of cross-fertilization. Such a measure may also consider whether certain participants login more often or cross-fertilize more than others do. This might have implications for the results presented in the study. Fourth, the presented identification of different knowledge domains cross-fertilizing cannot detect the extent to which ideas and concepts from different knowledge domains are discussed in parallel or synthesized to form comprehensive concepts. To this end, we assume that stakeholders of a crowdsourcing endeavor would ask for or provide further explanation when concepts are insufficiently integrated. Consequently, this may lead to actual cross-fertilization. Finally, further research may instantiate the design in further crowdsourcing endeavors.

V.2.3. Future research in Chapter IV: The societal level

In Section IV.1, research paper P6 bears the following limitations: The first limitation refers to the small sample size, which future research may address when continuing this topic, and advancing results. Second, although it was controlled for some biases (e.g., sequence of content in the survey), future research may choose to instantiate other/further control mechanisms to improve survey data. Similarly, future research may also choose to reach out to practitioners or researchers instead of citizens for their survey. Finally, future research might control for further country-related variables and their effects in participants' answers (e.g., culture). Additionally, future research may expand the scope into the following additional directions: Future research could increase the spectrum of digital technologies or refer to a different classification of digital technologies. Furthermore, future research could analyze the potentials of digital technology for other sustainability development goals than “good health and well-being.”

V.3. Conclusion

Summarizing the research papers presented in Chapter II, III, and IV, this doctoral thesis contributes to scientific knowledge in Green IS and ICT4D research. Thereby, the included six research papers address topics and questions on an individual, organizational, and societal level. As such, presented models and approaches investigate how to contribute to sustainability issues occurring on all three levels. As sustainability will continue to play an important role in the upcoming years, this doctoral thesis hopefully provides valuable theoretical and practical insights.