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Innovation Studies on Sustainability, Frugality, Imagination, and MEMS Technology

- Dissertation exposé -

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Abstract

The present cumulative dissertation contains four manuscripts, a published double-blind peer-reviewed journal article, a journal article that now is in press, a published double-blind peer-reviewed book chapter, and a job market paper. The writings cover the topics sustainability and frugal innovation, imagination and science fiction, and microelectromechanical systems (MEMS) in the context of technological, service, and product innovation as well as innovation systems.

The first two articles investigate the sustainability of frugal innovation cases in developing countries. “Introducing a Sustainability Evaluation Framework based on the Sustainable Development Goals applied to Four Cases of South African Frugal Innovation” with Anne Dreßler was published in Business Strategy and Development. In this article, a novel sustainability evaluation framework is introduced. The framework is based on a literature review and identified, compared, and evaluated earlier studies that evaluated sustainability as well as theoretical contributions that tackle this issue. The framework was tested and revised several times using multiple expert (inter-) raters and expert feedback. It is based on the 17 Sustainable Development Goals and allows a detailed assessment. Based on the evaluation of the sustainability of the cases it is argued, that frugal innovation is often sustainable regarding specific Sustainable Development Goals and especially regarding the social dimension of sustainability, but not necessarily sustainable in general. Roughly 1/3 to 2/3 of the SDG’s were not affected by the investigated frugal innovations, but there were also no negative effects at all. All three of those tendencies also showed up in the second article, “Understanding and Evaluating the Sustainability of Frugal Water Innovations in México: An Exploratory Case Study” with Janet Molina Maturano and Stijn Speelman, both from the Ghent University in Belgium. The article has been peer-reviewed, revised and resubmitted, and is expected to be published soon in the Journal of Cleaner Production. Investigating and evaluating two cases of frugal water innovation in rural regions of México we discovered that there are cultural as well as theoretical overlaps of the frugal innovation concept with the concept of social entrepreneurship as well as catalytic innovation. As mentioned earlier the assessment of the sustainability of the two cases confirmed the findings of the first study. The investigated cases did not negatively affect the SDG’s, but a considerable amount of 39% and 53% of the SDG’s were also not affected by the frugal innovations in general. The innovations had a positive impact on all three dimensions of sustainability, with an emphasis on the social dimension.

The third single-author paper in this dissertation, “The Overlooked Roots of Innovations: Exploring the Relevance of Imagination on Innovation Using Science Fiction”, was peer-

reviewed and published by IGI Global in 2019 in the book “Responsible, sustainable and globally aware management in the fourth industrial revolution”, edited by Ziska Fields and Stefan Hüsig. In this chapter, imagination is investigated and conceptualized as an integral part of any kind of innovation and the innovation process. It is argued, that the examination of the diffusion and evolution of imaginations and their manifestation as innovations can help to understand the imaginative roots of innovations and to create a responsibly chosen path into a sustainable future. Science fiction is chosen as a specific area of manifested imagination and used to show how manifested imaginations influence the social imagination in general and certain individuals like scientists and innovators in particular.

The fourth article in this dissertation, “The Market and Industry for MEMS Technology: Innovation System, Networks, and Disruptive Potential”, is co-authored together with Theresa Gerlach, Marlene Graf, and Lyda Massow and is included as an unpublished job-market paper. The presented study investigated the innovation system for MEMS technology and the status quo and trends of the MEMS industry and market. The investigation focused on the funding landscape, formal networks (legal entities), and expert interviews. Interviews with the representatives of 13 organizations of the MEMS sector were conducted and analyzed using qualitative content analysis to structure, condense, and paraphrase the transcripts. The organizations compromise of two registered societies (large R&D organizations) and 11 companies, four SMEs, and seven MNC’s. The results include insights regarding the strategic orientation and R&D strategy; their competition, partners, and customers; networks, collaboration, and funding; Trends in MEMS Technology; the disruptive potential of MEMS technology and emerging technology that could disrupt segments of the MEMS market.

This dissertation concludes with a final discussion of the findings, the limitations and the implications for policy, practice, theory, and subsequent research, as well as the references.

Structure

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1 Preamble

The contemporary understanding of innovation in the social sciences is rooted in the writings of the Austrian scholar and Harvard Professor Joseph Alois Schumpeter, who described innovation (or development) as 'creative destruction', the process of creating something novel (Schumpeter 1942:82-85). He defined innovation as the carrying out of a new combination and mentioned explicitly the introduction of a new product (1), the introduction of a new method of production (2), the opening of a new market (3), and the conquest of a new source of supply of raw materials or semi-manufactured goods (4) (Schumpeter 1934). His theory of economic development set the starting point for most of the streams of innovation research nowadays – he emphasized the role of the circular flow, of economic activity that produces itself in a stationary economy; of the proactive individual, the entrepreneur, and innovator; of creativity; of business cycles; and markets (Schumpeter 1942).

This dissertation aims to add to the field of innovation research by investigating historic as well as contemporary socio-cultural and technological aspects that influence innovation. Those influences were widely neglected by Schumpeter, although vaguely acknowledged on the first page of his theory of economic developments[1]. Yet it is argued in the presented articles that they have extraordinary importance for human progress in the 21st century: ethics, specifically in its conceptualized form as sustainability and the Sustainable Development Goals (SDGs), imagination, and technology.

In the 1970s the German philosopher Hans Jonas formulated one of the prime arguments for modern concepts like responsibility, sustainability, and the protection of nature in his book "The Imperative of Responsibility: In Search of Ethics for the Technological Age" (Jonas 1979/1984). His ethic is based on the categorical imperative that Immanuel Kant (1785/2004, 1788) brought forth, but because of its teleological perspective, it also shares elements with utilitarian concepts (e.g. Bentham 1781/2009, Mill 1861, Singer 1979/1993). This becomes evident considering that Jonas' so-called ecological imperative has a teleological premise of action: The permanence of genuine human life. Responsible action thus is always an action that considers knowledge regarding the consequences of the action to achieve intergenerational sustainability. His works on technology and bioethics and his notions like 'heuristic of fear' and 'the priority of the bad prognosis' have influenced the ethical and political discourses on technology and bio law, politics, and policy. And with the ongoing growth of the global

[1] Schumpeter (1934): „A fact is never exclusively or purely economic; other — and often more important — aspects always exist."

sustainability, responsibility, and future/environment-oriented social movements and the frequent appearance of natural disasters in the last decade with the current global covid19 pandemic being the apex so far, Jonas' writings fit right in. His ethical concept with the "Imperative of responsibility" at its core, often called environmental ethics, ethics of sustainability, ethics of the future or even ethics of the emergency state, offers a well thought out ethical approach to managing the potential environmental and human-made problems of the 21. century.

On this premise, the innovation studies presented in this dissertation engages with topics highlighted by Jonas or at least derived from Jonas's works – sustainability, technology, and imagination. Sustainability and formalized concepts of it of varying complexity and detail like the Sustainable Development Goals or the triple bottom line are itself a modern form of a global normative ethical telos. The SDGs consider a wide range of aspects of sustainability, including intergenerational responsibility, a concept that Jonas popularized. The SDGs were used in the first two articles to evaluate frugal innovations in the emerging regions of South Africa and México.

One of the key implications of Jonas' ethical concept is the need for research that focuses on the future. Jonas accentuated the growing importance of empirical knowledge in moral decision making (Werner 2003), yet the proposed new research discipline is commonly understood as a speculative philosophy (Flechtheim/Joos 1991: 74) in contrast and addition to mathematical extrapolations. Jonas himself said that a new science (or art) of futurology, allowing us to see long-distance effects, will be an asset to the world of tomorrow, an asset new in its form and function (Jonas 1985: 65). Publication number three introduces an approach to such a futures research based on the foundations of innovation and technology management. The chapter discusses a desideratum of the discipline of innovation and technology research – the imaginative front end of the innovation process before there is an actual managed innovation process, the early stage before the early stages of an innovation, the so-called long-nose of innovation (Buxton 2008). The chapter endorses the consideration of imagination as an integral part of the innovation process in order to understand the heritage of innovations and as a potential tool to inform the creative response (Schumpeter 1947). Imagination can help to promote innovations, and potentially enable the forecasting of future innovations that are already taking shape as imaginations.

Jonas' ethical writings consider technology intensively and in detail, especially contemporary high-tech[2] with its far-reaching implications and emphasized the importance of research on these technologies to allow responsible decision making. Article four presents research on one of the most influential modern technologies driving global modern trends like the digitalization and the automation – microelectromechanical systems (MEMS). Focusing on the innovation system for MEMS technology, specifically funding and industry networks, the article investigates the contemporary and future market, networks, and collaborative activities and funding landscape for MEMS technology. A screening of the funding landscape and interviews with 13 organizations of the sector that are members of two professional industry networks resulted in several insights regarding the use, benefits, and disadvantages of collaboration, networks, and funding. The interviews also provided insights regarding the future applications of the technology and potential disruptors.

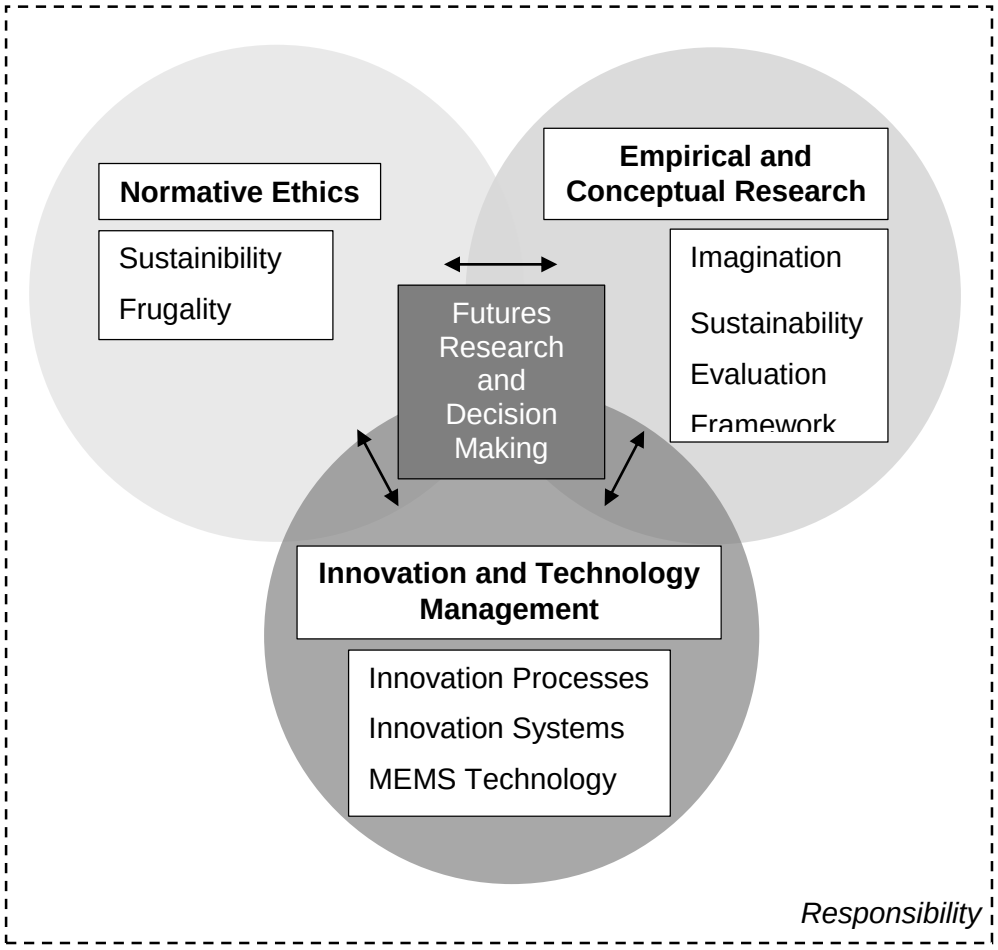

Figure 1: General research framework derived from Jonas (1979/1984, 1985)

[2] E.g.: His casuistic study on genetic engineering in ‚Technik, Medizin und Ethik' (Jonas 1985).

1.1 Overview and Contributions

This cumulative dissertation contains one multiple blind peer-reviewed published journal article, one Journal article currently under review, one multiple blind peer-reviewed published a book chapter, and one job market paper. The writings cover the topics sustainability, imagination, and microelectromechanical systems (MEMS) in the context of technological, service, and product innovation as well as innovation systems. The first two articles investigate the sustainability of frugal innovation cases in developing countries. "Introducing a Sustainability Evaluation Framework based on the Sustainable Development Goals applied to Four Cases of South African Frugal Innovation" together with Anne Dreßler was published in Business Strategy and Development. In this article, a novel sustainability evaluation framework is introduced. The framework is based on a literature review and identified, compared, and evaluated earlier studies that evaluated sustainability as well as theoretical contributions that tackle this issue. The framework was tested and revised several times using multiple expert (inter-) raters and expert feedback. It is based on the 17 Sustainable Development Goals and allows a detailed assessment. Based on the evaluation of the sustainability of the cases it is argued that frugal innovation is often sustainable regarding specific Sustainable Development Goals and especially regarding the social dimension of sustainability, but not necessarily sustainable in general. Roughly 1/3 to 2/3 of the SDG's were not affected by the investigated frugal innovations, but there were also no negative effects at all. All three of those tendencies also showed up in the second article, "Understanding and Evaluating the Sustainability of Frugal Water Innovations in México: An Exploratory Case Study" together with Janet Molina Maturano and Stijn Speelman. The article has been peer-reviewed, revised and resubmitted, and is expected to be published soon in the Journal of Cleaner Production. Investigating and evaluating two cases of frugal water innovation in rural regions of México we discovered that there are cultural as well as theoretical overlaps of the frugal innovation concept with the concept of social entrepreneurship as well as catalytic innovation. As mentioned earlier the assessments of the sustainability of the two cases were consistent with the findings of the first study. The investigated cases did not negatively affect the SDG's, but a considerable amount of the SDG's were not affected by the frugal innovations in general. The innovations had a positive impact on all three dimensions of sustainability, with an emphasis on the social dimension.

The third single-author-paper in this dissertation, " The Overlooked Roots of Innovations: Exploring the Relevance of Imagination on Innovation Using Science Fiction", was peer-reviewed and published by IGI Global in 2019 in the book "Responsible, sustainable and

globally aware management in the fourth industrial revolution", edited by Ziska Fields and Stefan Hüsig. In this chapter, imagination is investigated and conceptualized as an integral part of any kind of innovation and the innovation process. It is argued, that the examination of the diffusion and evolution of imaginations and their manifestation as innovations can help to understand the imaginative roots of innovations and to create a responsibly chosen path into a sustainable future. Science fiction is chosen as a specific area of manifested imagination and used to show how manifested imaginations influence the social imagination in general and certain individuals like scientists and innovators in particular. It is even used to sell ideas (or make them stick) and give them heritage, again influencing the social imagination. The chapter further argues, that the accelerated fusion, development, and progress of technologies in the wake of the digitalization is enabling fast and vast diffusion and distribution of imaginations, creating a need to explore, understand, and responsibly utilize them.

The fourth article in this dissertation, "The Market and Industry for MEMS Technology: Innovation System, Networks, and Disruptive Potential", is co-authored together witch Theresa Gerlach, Marlene Graf, and Lyda Massow and is included as an unpublished job-market paper. In the presented study the innovation system for MEMS technology and the status quo and trends of the MEMS industry and market were investigated. The investigation focused on the funding landscape, formal networks (legal entities), and organizations of the MEMS sector. An opportunistic literature review on MEMS technology in the social sciences literature was followed up by a screening of the subsidy programs that apply for the MEMS sector on the regional (Saxony), national (Germany) and supranational (European Union). A regional (Silicon Saxony) and an international (IVAM) MEMS network were selected to compare their offering. Guided expert interviews with the representatives of 13 organizations of the MEMS sector were conducted and analyzed using qualitative content analysis to structure, condense, and paraphrase the transcripts. The participating organizations compromise of two registered societies (large R&D organizations) and 11 companies, four SMEs, and seven MNC's. The results include insights regarding the strategic orientation and R&D strategy; their competition, partners, and customers; networks, collaboration, and funding; Trends in MEMS Technology; the disruptive potential of MEMS technology and emerging technology that could disrupt segments of the MEMS market. Table 1 gives an overview of the four publications.

Table 1: Overview Publications

	Writing	Authors	Contribution in terms of content	In percent	Total percent
1	Introducing a Sustainability Evaluation Framework based on the Sustainable Development Goals applied to Four Cases of South African Frugal Innovation	Anne Dressler Julien Bucher	Conceptualization of the research framework, especially the methodology. Conceptualization, review, and partial writing of the original draft, especially the methodology, discussion, and conclusion. Empirical sustainability evaluation. Administration of the manuscript as the corresponding author. Review and editing of the manuscript. Conduction and management of multiple article revisions. Validation of the framework.	40 %	100%
2	Understanding and Evaluating the Sustainability of Frugal Water Innovations in México: An Exploratory Case Study	Janet Molina Maturano Julien Bucher Stijn Speelman	Conceptualization of the research framework, especially the methodology. Empirical sustainability evaluation. Validation of the framework. Writing of the original draft, especially methodology and sustainability evaluation. Administration of the manuscript as the corresponding author. Review and editing of the manuscript. Creation, review, and editing of the visualizations.	33%	100%

			Conduction and management of multiple article revisions.		
3	The Overlooked Roots of Innovations: Exploring the Relevance of Imagination on Innovation Using Science Fiction	Julien Bucher	Recherché and data collection for as well as writing, and editing of the chapter. Administration of the manuscript as the corresponding author. Completion of multiple revisions of the article.	100%	100%
4	The Market and Industry for MEMS Technology: Innovation System, Networks, and Disruptive Potential	Julien Bucher Theresa Gerlach Marlene Graf Lydia Massow	Conceptualization of the research framework. Analysis and interpretation of the collected data. Writing, Editing, and revision of the article.	70%	100%
			Total:	243	400

1.2 Research methodology and methods

The research methodology and methods used in the presented research articles are introduced in this segment to create a basic understanding of the approaches taken.

1.2.1 Case study research

Three of the four research projects articulated in this dissertation were based on a case study research methodology. Case study research is commonly used in various disciplines including but not limited to law, history, health, and the broad field of social science to explore, investigate and understand phenomena in their complex real-world settings (Harrison et al. 2017). To do so cases are mostly approached using multiple forms and sources of data and multiple forms of research methods to approach and analyze them, incorporating the ideas of triangulation (Denzin 1978) and mixed-methods (Boring 1953, Campbell/Fiske 1959, Denzin 1978, Johnson et al. 2007). Case study methodology is often used in exploratory studies and has been recognized as particularly beneficial for addressing ‘how’ and ‘why’ questions while preserving the real-life events (Yin 2014). Also, the case approach is suitable to study phenomena with limited information because of its capacity to combine primary and secondary data.

In the included articles different case study approaches were taken. To investigate the role of imagination in the innovation process an abductive case study approach (Dubois/Gadde 2002) was chosen. Theoretical inference and various forms of secondary data (including archival material, live video and audio material, transcripts as well scholarly and official publications) were used to explore and develop the concept of imagination and the imaginator from an interdisciplinary innovation research perspective.

The first conceptualization of the sustainability evaluation framework presented in article one (see 2.1) is based on a qualitative mixed-method case study research approach (Stake 1995 & 2005, Yin 2014), incorporating a literature review and interrater that were used to test, develop and revise the framework.

To explore the sustainability of frugal water innovations in rural regions of Mexico a postpositivist case-study approach was taken (Yin 2014), incorporating expert interviews and translation, document analysis, an online questionnaire, and the sustainability evaluation framework developed and tested in article two (see 2.2) of this dissertation.

1.2.2 Mixed-Method Research

One article (see 2.4) in this dissertation is based on a research project with a mixed methods research design, which means that "elements of qualitative and quantitative research approaches" were combined "for the broad purposes of breadth and depth of understanding and corroboration" (Johnson et al. 2007: 123). The presented research project investigates certain aspects of the innovation system(s) for MEMS technology on the supranational, national, and regional level, focusing on the funding landscape, two selected networks and 13 organizations of the sector with membership in at least one of these networks.

Quantitative data was used in the first phase of the study to examine the current situation in the MEMS markets. Market reports were analyzed to capture the status quo in the industry of MEMS. Furthermore, a screening of the financial funding programs in Europe, Germany, and the state Saxony and formal MEMS-industry-networks was conducted. The gained data was used to select two well-established networks and to identify suitable companies and experts for the semi-structured expert interviews. The data was also used to get in-depth knowledge about the different aspects of the research question (funding, market, networks) and to design the interview guideline. Finally, expert interviews with representatives of organizations of the MEMS industry that are also members of at least one of the selected networks were conducted to achieve a "multilayered view of the nuances of social reality" (Hesse-Biber 2010: 456) in the MEMS sector. The recorded interviews were transcribed and subsequently analyzed using qualitative content analysis – paraphrasing, condensing, and categorizing the data using a

combination of deduction (to structure the data in general) and induction (generating new categories that emerge while analyzing the data).

1.3 Limitations

The limitations of the sampling and methodological approaches taken in the four presented papers are considered in this segment. It is also stated how the shortcomings and biases of the empirical approaches were addressed in the studies.

1.3.1 Methodology

According to its critics, case study research (see publication 2.1 and 2.2) has certain limitations in general. The main being a lack of representativeness, especially generalizability, but also validity and reliability due to the small sample size and researcher bias. The arguments resemble the criticism on qualitative research approaches, and also apply to the qualitative approach in publication 2.3 and the qualitative dominant mixed-method approach in publication 2.4, as do the counterarguments in the following.

There is no reason to believe that there is any difference compared to other forms of research methodologies regarding the researcher-bias since research inherently involves humans - even in the case of using AI for research purposes somebody has to program and develop the software first. Which makes it an important bias to consider in any type of research project. To address the human factor in the research process, especially the analysis, and interpretation of data, researcher triangulation was used in three of the four articles of this dissertation to counter the research bias. In addition, external experts and scholars were used to develop and validate the sustainability evaluation framework used in 2.1 and 2.2. The single-authored publication 2.3 is based on a long-term and continuing research project and the cases, approach, and concept have been presented at conferences and lectures various times in the last years. The gained feedback was used to challenge and reconsider the own perspective and interpretations to reduce the researcher bias, rework and improve the concept, and plan further steps. As described in the previous paragraph, the presented case study research projects were conducted using multiple forms of data (data-triangulation) and research methods (method-triangulation, mixed-methods) to investigate the cases in their complex setting comprehensively from multiple perspectives and to counteract researcher-bias (Denzin 1978). The articles follow the terminological distinction between method and methodology introduced by Mills (2014), where methods refer to procedures, techniques, or tools employed in the study, while methodology refers to the lens through which the researcher(s) views and bases decisions on. Accordingly,

the term method-triangulation is used instead of the original term methodology-triangulation (Denzin 1978) in this dissertation.

1.3.2 Framing and Data Selection

Due to the specific framing of the studies and the focus on specific kinds of empirical data, the four articles with their specific layout don't allow a generalization of the results beyond the scope of the studies without considering additional studies and data due to a lack of representativity. The focus on frugal innovations and emerging regions in publication 2.1 and 2.2, on science fiction in 2.3, and on Europe, Germany and Saxony in 2.4 illustrate this shortcoming, as does the low number of cases in all four publications. The selection of the data and cases was based on the explorative nature of the research project (2.1,2.2,2.3), and to get rich and detailed, as well as context-specific insights (2.1, 2.2, 2.3, 2.4), proved to be the right choice, even though more cases, additional regions (2.1, 2.2, 2.4), and kinds of imaginations (2.3) as well as incorporating additional quantitative data would potentially enable more far-reaching and pluckier interpretations and hypotheses.

2 Concluding discussion

The four studies presented in the last chapter investigated topics with importance for the future development of the humankind as emphasized by Hans Jonas (1979/1984, 1985) – informed ethical decision making (sustainability and frugality), futures research and forecasting (imagination and science fiction), and far-reaching high-tech (MEMS technology). In this segment, the dissertation is concluded with a summary of the main findings, a consideration of the achieved contributions to the theory and practical implications, and an outlook for each of the three areas of research. The dissertation completes with concluding remarks.

2.1 Frugal Innovation and Sustainability

In the first two articles (2.1, 2.2) the sustainability of frugal innovation projects in South Africa and Mexico was investigated using a sustainability evaluation framework developed by the authors of the first publication. Both studies showed that frugal innovation is not necessarily sustainable regarding all three dimensions of sustainability, especially not regarding all of the 17 comprehensive SDGs, supporting the findings Albert (2019) produced with a literature review on the matter. Nevertheless, both studies showed that the frugal solutions did not impair any of the SDGs and had a positive impact on sustainability in general, with an emphasis on the social dimension. The frugal innovations also proved to be more sustainable than alternative incumbent solutions. The investigations concluded that it is necessary to put further research

efforts in the investigation of the sustainability of innovation projects in undeveloped and emerging regions. Especially water-related research is necessary, with water scarcity being one of the main issues in these regions. Both investigations showed that the specific political and socio-cultural context needs to be considered to draw meaningful conclusions. It is also recommended to consider the managerial or entrepreneurial perspectives and motives. The studies showed that the ventures claimed to be driven by social or ecological ideas, yet they also had a positive impact on other dimensions of sustainability. Especially the economic dimension, which makes sense, since the ventures need to be economically sustainable to survive on the market and be able to foster the other two dimensions of sustainability.

This raises the question if the economic dimension of sustainability makes sense. The ability of an organization to be profitable (or at least generate enough influx of resources) is a basic and necessary goal for any organization to survive in the global economic system. While the social and ecological dimensions are normative concepts of sustainability to be considered, the economic dimension is not a norm but a requirement. Looking at it this way the triple bottom line seems like an effort to compromise the social and ecological dimension of sustainability by reintroducing the already inherent economic aspects as an equal dimension, devaluing the other two dimensions.

The sustainability evaluation framework used in the first two publications proved to be a powerful and comprehensive, yet simple enough to use tools to evaluate the sustainability of an innovation or innovation project at any stage. As such we recommend this tool for researchers that want to assess sustainability, especially in emerging regions, resource-constrained contexts, and un- or under-researched research domains.

2.2 Innovation and Imagination

The third manuscript in this dissertation argues that imagination is a hardly considered, yet crucial element of innovation processes. Individuals, as well as socio-historical imagination, influence each other, leaving traces in the form of manifested imaginations (like science fiction themes and ideas in the media), creating paths over time that lead to later implemented innovation. The focus on science fiction as a very prominent and scientifically rather sound segment of imagination leads to the conclusion, that such manifested imaginations do not predict the future, but they are documents of plausible potential innovations and developments based on the contemporary state of research. And manifested imaginations like science fiction scenarios, narratives, applications, and use cases sediment. They get picked up, reproduced, evolve, and become historically embedded in the culture, like in literature, movies, or video

games. And those cultural artifacts, in turn, influence the social imagination in general and creative individuals like scholars, entrepreneurs, innovators, and artists, as well as open-minded individuals like kids and adolescents. This way individual, social, and manifested imagination interrelate and influence each other, leaving a path of sedimented imaginations to be discovered and considered for future innovation and decision making.

Further research on imagination and innovation will focus on investigating and developing this concept using historic and contemporary cases. The role of individual and collective actors as well as media in the sedimentation, evolution, and diffusion of imaginations seems especially promising. In this article the interrelation of innovation and imagination is further conceptualized, introducing the imaginator and emphasizing the role of imaginations, media, and the imaginator in the making of an innovation. An imaginator uses sedimented imaginations or intentionally produces or commissions them in order to influence the social imagination and drive innovation.

Entrepreneurs, Innovators, and organizations could use imaginations actively to gain inspiration, like it is already promoted with the concept of Science Fiction Prototyping, or to promote vision to gain legitimacy among customers, investors, and society.

2.3 MEMS Technology Market and Industry

The fourth publication in this dissertation presented the results of a research project that investigated the innovation system, market and sector for MEMS technology using secondary data like industry reports, a screening of the funding landscape, and guided interviews with 13 organizations of the MEMS sector. The interviews covered the topics collaboration, cooperation and networks, funding, customers and rivals, the current market, emerging market segments and applications for the technology, and technology and product development.

The most interesting results that the study yielded concern the interrelation of collaboration, networks and funding programs, and emerging market segments, applications, and alternative, potentially disruptive technologies. The interviews revealed that all of the interviewed organizations endorse networks, collaboration/cooperation, and funding programs and that they screen and evaluate the funding programs. The organizations use networks to get access to resources like information and knowledge, but also get to know the other members and identify potential partners for joint funding applications, collaborative projects, information and knowledge exchange, and potential co-use of fabrication and production facilities. The fabrication and manufacturing tools in the MEMS sector are quite expensive, which leads to a certain openness of especially the SMEs to cooperate with other organizations to use their

facilities, and to apply for funding to finance R&D projects or new machinery, tools or staff. The statements and answers of the interviewed experts, as well as the screened funding projects, show, that in the investigated innovation system for MEMS technology formal industry networks act as interfaces and brokers. They enable information exchange and organize events that allow their members to get familiar with other entities of the sector and present themself. The existing funding programs often promote or expect collaboration and knowledge exchange and are considered and used, and the networks help to find the right partner(s) to apply for funding, to realize collaborative projects.

Another finding is, that the organizations often made a clear distinction between regional and international networks and emphasized, that the regional network is more important because it offers more than an international network due to the close geographical proximity. The closeness allows direct and faster contact, exchange, and help, and there are no (or less) cultural and legal barriers to overcome.

As emerging market segments the medical sector was mentioned as 'the new automotive'. For specific applications, alternative wafer materials are emerging, like silicon carbide or gallium nitride-based wafers for environmental sensors. Intelligent Microsystems were mentioned as an emerging evolution or extension of the MEMS technology and the NEMS technology was mentioned as a better alternative to MEMS for certain applications like RF MEMS. The incumbent MNCs stated that they focus on MEMS and don't consider NEMS much.

The results indicate that an investigation of the disruptive potential of NEMS technology could yield interesting insights. NEMS technology is more effective in certain applications, producible in large quantities, and smaller in size while being more energy-efficient than MEMS. It is recommended to further investigate the role of networks in different industries (e.g. low- vs. high-tech), distinguishing between regional and international, as well as formal and informal networks and the role they play in the innovation system.

2.4 Concluding Remarks

The four manuscripts in this dissertation presented innovations studies that investigated the historic as well as contemporary socio-cultural and technological aspects that influence innovation. The studies generated valuable insights regarding the sustainability of frugal innovation at the BOP and also regarding the innovation system, status quo, and future of the MEMS technology and MEMS industry. Imagination was conceptualized as a historic socio-cultural phenomenon driving, promoting, and preparing for innovation. Further research on all of the investigated research objects and topics is encouraged to test the findings and concepts,

ideally with longitudinal studies using mixed-method research designs. Yet the results presented allow to draw certain managerial recommendations. Sustainability has become an established concept, recognized by law- and policymakers, as well as business organizations. The framework utilized in the first two articles has the potential to be a useful tool for responsible managers in the western world as well as emerging regions and the BOP, that allows them to evaluate the sustainability of their services, products, or business models, identifying weaknesses and strengths.

Imaginations of future technology, products, environments, or social systems and organizations influence the social imagination, inventors, and innovators. They prepare the market for innovation, address desires, and create needs. Imagination has the potential to be a powerful tool allowing managers to inform creative processes (like Science Fiction Prototyping), give their innovations heritage, and promote them.

Networks and funding are useful tools to get access to immaterial resources like information and knowledge, material resources like raw goods and manufacturing facilities, and to potential partners for collaborative projects, that are often necessary to realize resource-intense R&D projects and finding solutions for complex problems. Collaboration is also a requirement for a lot of funding programs. An informed and strategic approach, a careful selection, and evaluation of the network(s), funding programs and partners are necessary, since the application for funding, the screening of information from the network(s) and on funding programs, the preparation and pre-financing of funded projects all require attention, energy, and resources. But this can be said about all of the presented topics – responsible research and innovation in the means of Hans Jonas require attention, energy, and resources to investigate the status quo and potential future developments to act sustainable and responsible. Fortunately, technology is evolving rapidly and providing the devices, data, computing power and rudimentary artificial intelligence to aid this approach.

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4 Appendix – The abstracts of the four manuscripts

4.1 Publication 1: Introducing a Sustainability Evaluation Framework based on the Sustainable Development Goals applied to Four Cases of South African Frugal Innovation

Authors: Anne Dressler, Julien Bucher

Status: Published in Business Strategy and Development (Special Issue)

Year: 2018

DOI: 10.1002/bsd2.37

Abstract

Evaluating sustainability based on the Sustainable Development Goals (SDGs) is a complex but purposeful approach with a broad field of application. In order to handle the complexity of the SDGs and achieve flexibility at the same time, this paper introduces a three-step evaluation system based on the SDGs for the assessment of the sustainability of innovations. It was used to assess four cases of South African frugal innovation with the conclusion that all four examined cases were sustainable, indicating an interrelation between the frugality and the sustainability of an innovation. The framework was reviewed and revised several times and tested successfully and so far has proven to be applicable to a wide spectrum of innovations.

Keywords: BOP innovation, evaluating sustainability, frugal innovation, South Africa, Sustainable Development Goals

4.2 Publication 2: Understanding and Evaluating the Sustainability of Frugal Water Innovations in México: An Exploratory Case Study

Authors: Janet Molina Maturano, Julien Bucher, Stijn Speelman

Status: In press at the Journal of Cleaner Production

Year: 2020

DOI: 10.1016/j.jclepro.2020.122692

Abstract

Due to their potential economic, social and environmental benefits, frugal innovations have gained the attention of firms, policy-makers, and researchers, particularly with respect to the needs of communities at the Bottom of the Pyramid. However, there is a lack of comprehensive systematic approaches to evaluate their impact on sustainable development certainly in geographical regions with limited available data. Hence, this study evaluated the sustainability of two latent frugal innovations in México and the motivation of their innovators, specifically of an ecological wastewater treatment plant and a rainwater harvesting system. Applying a case study methodology, the two cases were investigated using an online questionnaire, expert interviews, document analysis, and a recently developed sustainability evaluation framework. The results showed that frugal innovations are related to the concepts of catalytic and social innovation, sharing motivations by innovators and innovations' features. In addition, the results of the sustainability assessment by experts, which is rooted in the Sustainable Development Goals showed that both cases did not infringe any of the 17 goals, had a neutral impact on 39% and 51% of the SDGs and positively impacted all three dimensions of sustainability with a slight emphasis on social sustainability (with 36% and 21% of the overall impact). The present study proved that the framework is a useful and accessible tool for diverse actors, including innovators aiming to communicate the impact of their solutions or identifying risks/alerts at scaling-up phases. While the explorative nature and the limited number of cases investigated limits the scope for generalisation, the in-depth study of the selected cases of water innovation in their specific contexts nevertheless produced valuable insights for further research, especially regarding the integrated investigation of social, frugal and catalytic perspectives on innovation in Central and Latin America, and the quantification of impacts on sustainable development using comprehensive research approaches.

Keywords: Frugal Innovation; Social Innovation; Water; Mexico; Sustainability; Sustainable Development Goals SDGs

4.3 Publication 3: The Overlooked Roots of Innovations: Exploring the Relevance of Imagination on Innovation Using Science Fiction

Authors: Julien Bucher

Status: Published in Fields, Z. & Hüsig, S. (2019): Responsible, sustainable and globally aware management in the fourth industrial revolution. Hershey, PA: IGI Global.

Year: 2019

Abstract:

Imagination is an often overlooked integral element of human progress in general and innovations in particular. In this chapter, it is argued, that the examination of the diffusion and evolution of imaginations and their manifestation as innovations can help to understand the imaginative roots of innovations and to create a responsibly chosen path into a sustainable future. Science fiction as a specific area of manifested imagination is used to show how manifested imaginations influence the social imagination in general and certain individuals like scientists and innovators in particular. It is even used to sell ideas (or make them stick) and give them heritage, again influencing the social imagination. And the accelerated fusion, development and progress of technologies in the wake of the digitalization is enabling fast and vast diffusion and distribution of imaginations, creating a need to explore, understand and responsibly utilize imaginations.

Keywords: Technological Innovation, Social Change, Social Imagination, Space Travel, Imagination Age, Information Age, Social Innovation, Science Fiction Prototyping

4.4 Publication 4: The Market and Industry for MEMS Technology: Innovation System, Networks, and Disruptive Potential

Authors: Julien Bucher, Theresa Gerlach, Marlene Graf, Lydia Massow

Status: Unpublished Job Market Paper

Year: 2020

Abstract:

This article presents the results of an investigation of the microelectromechanical systems (MEMS) industry focusing on a regional, national, and supranational innovation system, especially funding opportunities and industry networks. Aside from the innovation system the contemporary state of the MEMS industry and its market have been investigated regarding the disruptive potential left in it. The presented study is based on a mixed-method methodology to approach this complex technology and market accordingly.

The study provided insights regarding the interrelation of networks, collaboration, funding, information & technology, and R&D in the innovation system for MEMS technology. There are several funding programs on the European, German and Saxon level that apply for entities of the MEMS sector, supporting and funding technology and knowledge transfer, R&D, collaboration among private as well as between private companies and public research organizations, aiming at companies in general or specifically at entrepreneurial ventures and start-ups. All of the participants stated that they use funding as well as networks and endorsed them. While both, international as well as regional networks are valued, the participants stated that international networks can't replace regional networks, which offer more opportunities to collaborate with less formal and cultural hurdles due to the close geographic and cultural proximity and often similar (or at least familiar) social as well as legal systems.

The investigation of the disruptive potential of MEMS confirmed that MEMS was an emerging technology and disruptive innovation that enabled products that created new markets and captured niches before disrupting markets, and has become a sustaining technology with a market that is still expanding and growing. In the interviews, potential emerging technologies that could disrupt MEMS were identified, as well as potentially growing market segments due to new applications.

Key Words: MEMS Microelectromechanical Systems, Innovation Systems, Disruptive Potential, Networks, Fundings