A Critical Success Factor Analysis of AI Applications to enhance Environmental Sustainability

Masterarbeit

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Outline

1 Introduction

1.1 Motivation

Sustainable development and, in particular, environmental sustainability is one of the most important issues facing society today. Through the Paris Agreement on climate change (UNFCCC 2015, p. 3) and the commitment to the SDGs in 2015 (United Nations 2015, p. 1), the member states of the United Nations (UN) have reached a common consensus on the necessary measures in the area of sustainability. Nevertheless, progress towards achieving the targets is still limited, which is why efforts for its improvement need to be intensified (Seele and Lock 2017, p. 183; Sachs et al. 2021, p. 15). The same conclusion can be drawn from the Global Risks Report 2022 of the World Economic Forum, which determines climate action failure, extreme weather and biodiversity loss as the three most important current global risks (World Economic Forum 2022, p. 14). One phenomenon that should be considered to improve environmental sustainability is the increasing urbanization. More than 50% of the global population already lives in cities, and estimates suggest that this number will rise to well over 70% by 2050 (Zhang 2016, p. 241). Urbanization affects the quality of the environment and can lead to degradation of air and water as well as to increased noise pollution (Zhang 2016, p. 250). Another relevant field of action for emission reduction is the energy sector. In the context of improving environemental sustainability, it primarly includes the substitution of fossil fuels with renewable energies (RE) and the improvement of energy efficiency in order to achieve the goal of energy decarbonization (United Nations 2021, p. 1).

In parallel, society is evolving into a digital era as a result of the ongoing digital transformation. This is changing people's daily lives and leading to adjustments in economic, social and environmental areas (Mondejar et al. 2021, p. 2). The digital transformation is associated with the availability of new smart applications based on disruptive technologies such as AI. Their increasing adoption is creating potential for new value propositions, improvements in operational performance as well as efficiency gains (Del Río Castro et al. 2021, p. 15).

A convergence of the two trending topics can be observed in academic research and practice (George et al. 2021, p. 999). Smart technologies are used with the intention of contributing to sustainable economic growth while complying with the SDGs. In particular, AI and machine learning (ML) are expected to have high potentials which is why both private companies as well as governments are investing in the development of the technologies in order to realize their benefits (Mondejar et al. 2021, p. 3; George et al. 2021, p. 1000). In the academic literature, the convergence is considered either positively or negatively. On the one hand, it is understood as a “winning combination, not exempt of challenges, offering opportunities within and across organizational boundaries for overcoming informational void” (Del Río Castro et al. 2021, p. 15). For example, it is possible that an implementation of AI within an appropriate infrastructure could have a net-positive contribution to environmental sustainability and may lead to emission reductions in urban areas (Jacob 2018, p. 134). Thus, the integration of digital technologies can become a driver for achieving the SDGs that should lead to an intensified integration. On the other hand, further experts consider the two concepts as conflicting goals, which is why their combination may lead to social and ecological paradigm shifts. These concerns are based on the assumption that a widespread implementation of digital technologies can have unintended negative consequences for the environment, for example through the overconsumption of natural resources (Del Río Castro et al. 2021, pp. 15–17). AI solutions require high quantities of data and the necessary data storages. The associated data centers as well as the computation for processing consume large energy amounts, which are estimated to exceed the total global energy production in 2040. Due to the resulting emissions, the energy consumption represents a negative environmental effect and leads to a deterioration rather than an improvement for a sustainable future (Villani 2018, p. 101). Additionally to these concerns, there are further risks related to the adoption, such as cybersecurity issues, which should also be considered in the assessment (Bissio 2018, p. 77).

The two contrary positions about integrating AI for sustainable purposes are resonable, as it has not yet been clearly demonstrated whether and to what extent digital technologies contribute to or detract from improving environmental sustainability (Seele and Lock 2017, p. 184). That is why this master thesis seeks to analyze the potential of the technologies in the context of energy decarbonization and sustainable cities and, based on this, to identify those factors that must necessarily be met for the successful integration of AI in these areas. Thus, the following two research questions can be derived:

RQ1: *What are the key application fields of AI in the area of energy decarbonization and sustainable cities?*

RQ2: *What are the CSFs in integrating AI applications to enhance environmental sustainability?*

1.2 Research structure

The structure of this master thesis is as follows. After the relevance of the problem and the resulting research questions have been determined, the theoretical background of this paper is presented in chapter two. First, for this purpose, the concepts of sustainable development and environmental sustainability are defined and the most important milestones described, starting from the Club of Rome until the resolution of the SDGs. In order to introduce the focus areas of energy decarbonization and sustainable cities, the six transformations defined by Sachs et al. (2019) are additionally presented, which illustrate the necessary changes towards the achievement of the SDGs. In chapter 2.2 the theoretical foundations of AI and ML follows, in which already first opportunities and risks of the technologies are discussed. Chapter 2.3 combines the technical and domain area and presents an overview of possible AI applications to improve environmental sustainability. Lastly, Chapter 2 ends with a definition and a brief literature review on CSFs in information system research (ISR), which will form the basis for the research subject.

Chapter 3 describes the research methodology used within this master thesis. We perform the DSR approach according to Hevner et al. (2004), which is a problem-solving research paradigm (vom Brocke et al. 2020a, p. 1). The goal is to generate a design artifact and/or design knowledge. For the individual steps of the DSR process, further research methodologies are applied, which are presented in chapter 3.2 to 3.5 and include the foundations of a systematic literature search according to Webster and Watson (2002), text mining, statistical analysis of data from Crunchbase as well as the evaluation necessary for the DSR process, which is carried out using a static analysis.

Chapter 4 is the core of this thesis and describes the DSR process, which consists of eight consecutive steps. First, the underlying problem is described. This is followed by gathering knowledge from academic literature and hierarchical clustering of the relevant articles in order to identify key topics of AI applications for environmental sustainability in the field of energy decarbonization and sustainable cities. Based on this, the extraction of the intial set of CSFs from scientific literature is performed. Step four of the DSR process then involves the analysis of corporate data from real-world services provided on the platform Crunchbase. Based on this, an advanced set of CSFs is developed. Finally, the research result is evaluated by domain experts using a questionnaire to assess its usefulness and comprehensiveness.

In the following chapter 5, the findings of the DSR process are discussed giving implications and recommendations for companies, governments and academic research. In addition, the limitations of this master thesis and the resulting future research needs are described. This chapter ends with a presentation of the contribution of this thesis to theory and practice.

Finally, chapter 6 concludes the master thesis by summarizing the findings and answering the research questions.

6 Conclusion

In this master thesis, we first analyzed the potential of AI to improve environmental sustainability (RQ1), followed by the identification and extraction of the CSFs that need to be met for its successful integration (RQ2). Thematically, we focussed on the application areas of energy decarbonization and sustainable cities, as these are two major fields of action concerning the environmental dimension of sustainable development. To generate research contribution, we conducted a DSR process according to Hevner (2007), including seven consecutive steps. Starting with the underlying issue that the progress in achieving the SDGs in the area of energy and sustainable cities is still limited, efforts for its improvement need to be intensified, where AI could potentially have a positive impact. Therefore, we performed an extensive literature review and a subsequent hierarchical clustering in order to explore the key application fields of AI in the two focus areas. Based on this, we analyzed the clusters with regards to risks and challenges that may arise within the development, implementation and operation of the AI solutions resulting in an initial set of 19 CSFs. In order to additionally incorporate knowledge from real-world services into the design cycle, we examined 549 companies from Crunchbase that offer AI solutions for energy decarbonization and sustainable city services. Thereby, we again attempted to extract the key application fields as well as to confirm the existing CSFs and, if possible, to identify additional ones. This step led to an extension of the set to 21 CSFs that need to be evaluated regarding its usefulness solving the underlying real-world problem. For this purpose, an expert evaluation in form of feedback through questionnaires was conducted which, however, was only completely answered by five participants, so that the usefulness and quality of the set could not be ensured with certainty.

Regarding the first research question, the results from the DSR process illustrate that there is a high degree of similarity in the key application fields identified in scientific literature and practice. Thereby, IoT and sensor technologies show high relevance enabling a continuous generation of environmental data as input for the intelligent systems. For energy decarbonization, AI is primarily applied to manage smart energy systems, to forecast RE generation and load as well as to reduce energy consumption in residential and commercial buildings, while, in the context of sustainable cities, AI solutions are implemented in ITS and autonomous mobility particularly. The findings demostrate that AI has potential in several application fields which is why an intensified integration could lead to realize improvements regarding environmental sustainability.

To answer the second research question, the analysis of the CSFs of the AI applications shows that *data availability*, *data quality*, *data privacy and security*, and *effectiveness* are particularly relevant in the context of this master thesis. Furthermore, the design artifact illustrates that the CSFs identified are depended on several stakeholders with different roles and responsibilities, as not only companies but also governments and academic research affect meeting them and thus influence the success of AI integration. For this reason, we developed a framework including twelve recommendation that serve to support the realization of multiple CSFs. Due to the limited expert evaluation, however, the usefulness and quality of the design artifact could not be confirmed with certainty, so it is possible that the CSFs are not equally relevant in all application areas. Consequently, open future research needs can be derived aiming to evaluate the design artifact on a larger scale. For this purpose, a focus group discussion with domain experts or the performance of one or more case studies would be appropriate methodologies in order to verify and/or adjust the results of this paper. Furthermore, a CSF analysis within a more restricted application domain such as autonomous mobility may also complement the findings presented in this master thesis. This future research could further improve the quality of the design artifact contributing to theory and practice in the field of AI applications to enhance environmental sustainability.