



LEIBNIZ UNIVERSITÄT HANNOVER

**Information Systems and Decision Support for
Sustainable Urban Transport, Energy Systems, and
Emerging Methods in Research and Practice**


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Abstract

The dissertation follows a multi-level research approach based on design science principles and integrates different methods to generate insights and develop decision support functions to promote sustainable urban development in the fields of mobility, energy and logistics. The approaches include spatial data analysis, optimization modelling, machine learning, text mining and the development of decision support systems (DSS). Some of the methods used are: Spatial data analysis and geographic information systems (GIS): These methods are used to analyze e-scooter usage patterns, determine the optimal placement of wind turbines, and study the factors that influence the adoption of residential solar systems. Optimization modeling: The dissertation presents optimization models to support strategic and operational decisions in different contexts. For example, optimization models are used to optimize the logistics chain for urban deliveries, support decision making for operators of aging wind turbines, and optimize a smart logistics concept for e-food operations. Data mining and supervised and unsupervised learning: Machine learning and data mining techniques are used to gain insights from unstructured data. For example, web content mining, natural language preprocessing, and topic modeling is used to analyze causes of e-scooter accidents. Semantic analysis and topic modeling is applied to social media data and scientific articles to understand the perception and discourse on large language models such as ChatGPT. Also clustering and regression methods are applied on spatial data and taxonomy-based data. Delphi study: A Delphi study is conducted to gain expert knowledge and validate simulation results in the context of sustainable logistics scenarios.

The core findings can be divided into three main thematic areas:

Sustainable urban transportation and mobility: in the field of urban logistics, a decision support system (DSS) is developed to help decision makers evaluate and compare different urban logistics scenarios to enable informed and environmentally conscious decisions in the design of urban and rural logistics networks. This DSS quantifies the trade-offs between cost efficiency and sustainability, helping practitioners to manage the complexity of green logistics in urban and rural environments.

- Evidence shows that establishing shared freight consolidation centers outside city centers with micro-depots near city cores can reduce truck traffic and fuel consumption.
- Shared micromobility research shows spatiotemporal e-scooter usage patterns, accident causes, and factors affecting shared e-scooter, bicycle, and e-moped usage.

Sustainable energy systems: The dissertation focuses on the management of wind turbines and residential solar systems.

- GIS frameworks are created to support decision making for aging wind turbines, analyze economic viability and regulatory challenges. The results provide important insights for the end-of-funding analysis of wind power plants, whereby a prompt repowering one to two years after the end of a subsidy can generally be suggested.

- The factors influencing the adoption and pricing of residential solar systems in Germany are examined, revealing significant spatial solar system price differences in Germany and a significant positive relationship is between green voters and plug-in solar system adoption.

Emerging technologies and methods in the IS domain: The dissertation also examines the applications of advanced methods and technologies in IS research and practice.

- Taxonomy-based data clustering methods are investigated to gain insights providing guidelines for their application.
- The social and scientific perception of large language models, especially generative, pre-trained, transformer-based chatbots, is analyzed uncovering potential areas for improvement providing guidance for future research and development in the field of conversational artificial intelligence.

Encountered limitations highlight the importance of transparency in the assumptions, scalability, integration with existing IT infrastructures, and evaluation of DSS.

Keywords: Information Systems, Decision Support Systems, Design Science Research, Energy Economics, Urban Logistics, Shared Micromobility, Spatiotemporal Analysis, Accident Analysis, Regression Analysis, Clustering, Photovoltaic System Adoption

Research Summary

Urbanization and technological advancements have significantly impacted urban transport, energy systems, and emerging technologies increasing the need for sustainable and efficient solutions. Tackling the emerging challenges this dissertation explores the development and application of decision support systems (DSS) in sustainable urban transport, energy systems, and emerging technologies, providing actionable insights and tools for policymakers, urban planners, information systems (IS) researchers, and industry stakeholders.

Research Objectives and Methodology

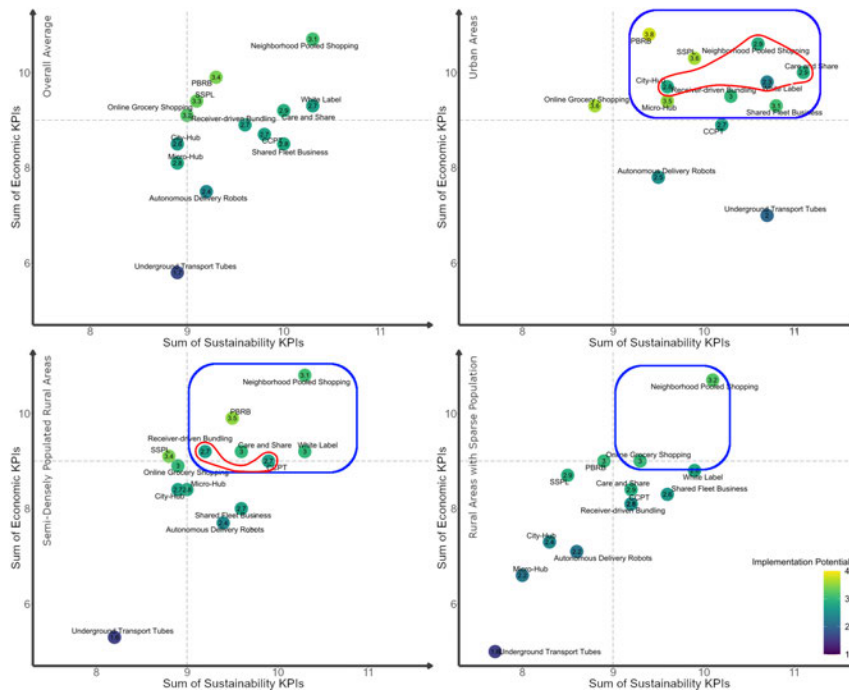
The primary objective of this dissertation is to develop and apply cutting-edge IS methodologies to generate insights and decision support capabilities that advance sustainable urban development in mobility, energy, and logistics. This cumulative dissertation comprises a series of research articles detailing collaborative work with co-authors. Each article addresses different aspects of IS research and practical applications. These include the analysis of spatiotemporal patterns and factors influencing the usage of emerging micromobility services, the development of decision support tools for renewable energy asset management and repowering, developing prescriptive analytics and optimization models for urban logistics concepts, and advancing data mining techniques and IS methods for extracting insights from unstructured data sources.

The research employs multi-method approaches centered on design science principles, including spatial data analysis, optimization modeling, machine learning, text mining, and DSS development. The methodologies applied are designed to not only solve complex real-world problems but also contribute to the theoretical advancement of IS research. The studies collectively emphasize the integration of quantitative and qualitative methods and data to improve the decision-making process.

Sustainable Urban Transport and Mobility

A study on optimizing a smart logistics concept for e-grocery operations in urban areas introduced an eco-friendly and road traffic-avoiding fleet combined with refrigerated lockers. The multi-echelon optimization approach developed in this study divides the complex planning process into manageable sub-problems. The hybrid last-mile system resulting from the implemented optimization approach improved the efficiency of urban e-grocery distribution using refrigerated grocery lockers and electric cargo bicycles.

The research underscores the importance of resilient e-grocery supply chains that go beyond conventional fossil fuel-powered delivery systems. The optimized network of refrigerated grocery lockers allows city dwellers to either pick up their e-grocery orders themselves or have them delivered by electric cargo bicycles. This hybrid last-mile system demonstrated its capability to improve urban e-grocery distribution efficiency.



*Combined Cargo and Public Transport (CCPT), Parcel Boxes for Residential Buildings (PBRB), Self-Service Parcel Lockers (SSPL)

Figure 1: Visualization of the criteria thresholds (dashed gray lines) applied for categorizing logistics scenarios as *sustainable business opportunities* clusters (blue) and *challenging frontiers* clusters (red).

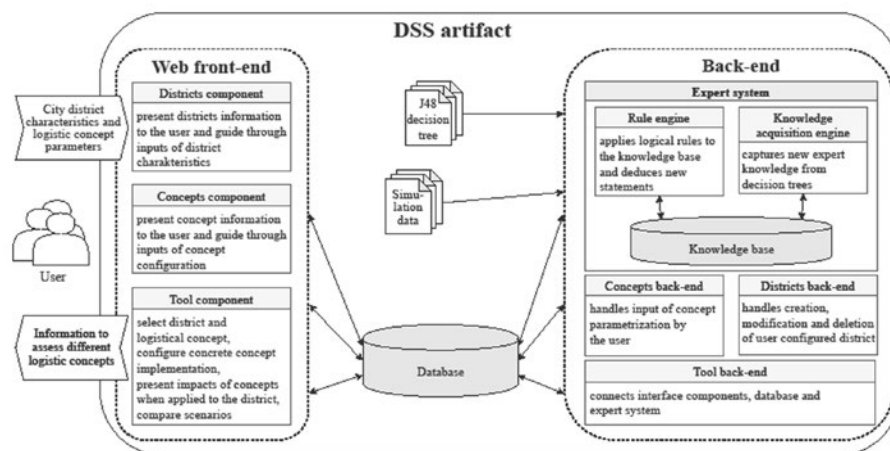
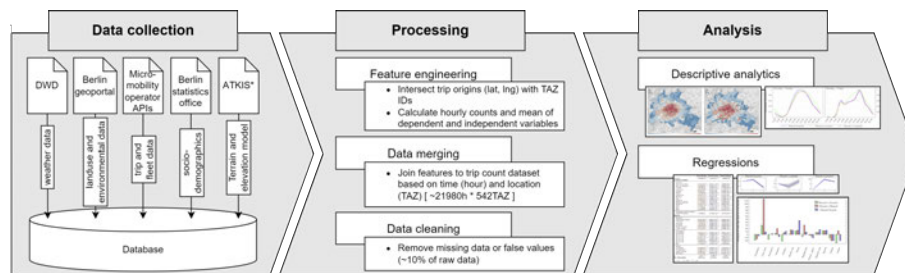


Figure 2: Architecture of the USEful DSS for evaluating logistic systems and scenarios.

A DSS was developed to support sustainable and efficient urban and rural parcel delivery. A comprehensive literature review provided the foundation for the development of the DSS. Based on this, various models were developed that were incorporated into the simulations of the DSS, such as an optimization of micro-depots to reduce overall operating costs and negative environmental impacts, resilience-oriented e-cargo bike-based delivery, or an innovative e-grocery concept.

The developed DSS empowers decision-makers to assess and compare multiple urban logistics scenarios, enabling informed and environmentally conscious choices in designing urban and rural logistics networks. By quantifying the trade-offs between cost efficiency and sustainability, the DSS helps practitioners navigate the complexities of green logistics in urban settings. The findings support the creation of shared cargo consolidation centers outside city centers with micro-depots near urban cores to reduce freight vehicle circulation and fuel consumption. Figure 2 presents the DSS architecture developed in the project USEFUL and USEFUL-XT. In addition to the quantitative simulations of our DSS we performed a Delphi study to complement and evaluate our DSS results. Logistics experts rated our selected logistic scenarios with regard to different economic and environmental key performance indicators (KPIs). Based on the results we categorized all logistic scenarios as *Sustainable Business Opportunities* or *Challenging Frontiers*. Figure 1 visualizes the criteria thresholds applied for categorizing logistics scenarios.

Regarding urban mobility and the emerging micromobility sharing services, a spatiotemporal study of shared e-scooter usage in Berlin over a nine-month period revealed significant insights into mobility patterns. Novel data filtering techniques using energy consumption rates to detect round trips were developed and advanced spatial analysis methods, such as hierarchical density-based clustering with noise (HDBSCAN), were applied to identify point-of-interest (POI) specific usage patterns. Our spatio-temporal analysis enables e-scooter operators to optimize fleet management strategies and urban planners to address the growing challenges of congested urban space.



*Official Topographic Cartographic Information System, ATKIS [7]

Figure 3: Research design and data pipeline of micromobility analyses.

Our findings can support planning decisions on targeted e-scooter regulations and infrastructure improvements. The temporal analysis of fleet utilization and trip patterns helps optimize fleet management strategies, such as dynamic pricing and vehicle redistribution. The results on the spatial distribution of e-scooter trips and their interaction with

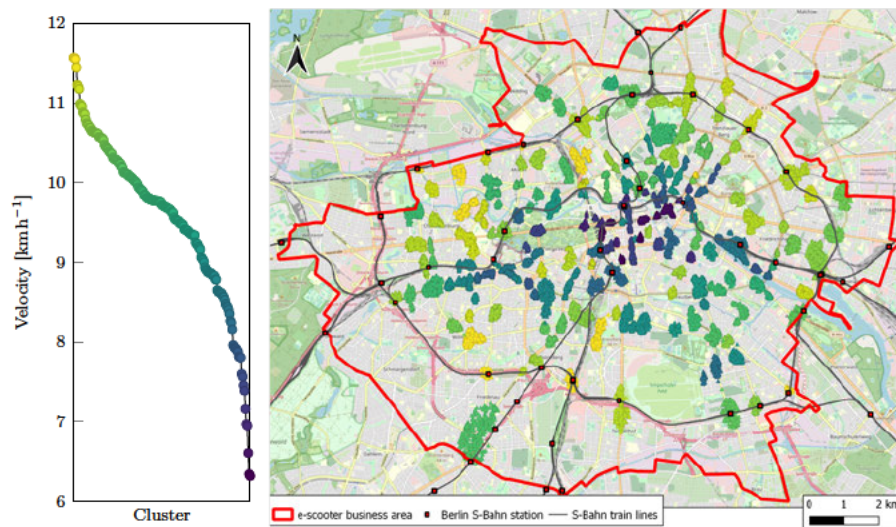


Figure 4: Average velocities of destination clusters in Berlin.

land use types provide an evidence base for transportation planners to effectively integrate micromobility into sustainable urban mobility systems. Figure 3 illustrates the research design and data pipeline for micromobility analyses and Figure 4 shows an analysis of the average shared e-scooter speeds revealing lower speeds in more congested areas closer to the city center.

An analysis of e-scooter accidents in Germany using the Louvain algorithm and web content mining highlighted key safety concerns and behavioral patterns. The identification of sidewalk riding as the main cause of accidents provided empirical evidence demonstrating the need for targeted interventions to improve e-scooter safety calling for policymakers and urban planners to prioritize safety measures in urban mobility policies.

Sustainable Energy Systems

The development of a geographic information systems (GIS) to support decision-making for operators of aging wind turbines in Germany provides useful insights into the sustainable and economically reasonable management of renewable energy assets. The GIS framework integrated various data sources and the modeling of uncertainties to support decision-making for aging wind turbines. Findings highlighted the limited availability of priority wind development zones as a key barrier to repowering projects, despite their financial viability. The economic analysis component of the GIS directly supports wind turbine operators in selecting among lifetime extension, repowering, and decommissioning options for their aging assets.

This research highlights the regulatory bottlenecks and economic viability of repowering projects, providing evidence-based insights for policymakers to encourage progressive wind energy development. The initial cash flow-based net present value model for the economic evaluation of old and repowering turbines was gradually developed into a real option model in order to map the possible uncertainties in the planning of investments as realistically

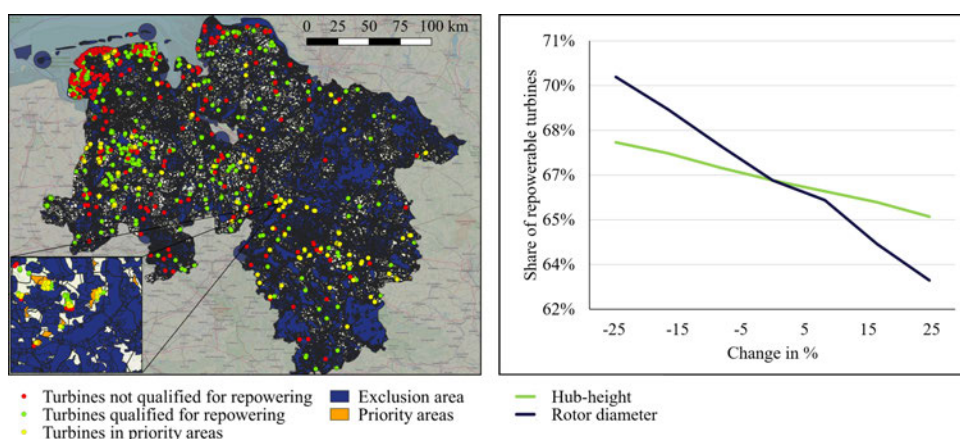


Figure 5: Results of our GIS analysis and corresponding sensitivity analysis.

as possible and to take into account the possibility of waiting for the operator. Figure 5 shows the results of the GIS analysis and corresponding sensitivity analysis.

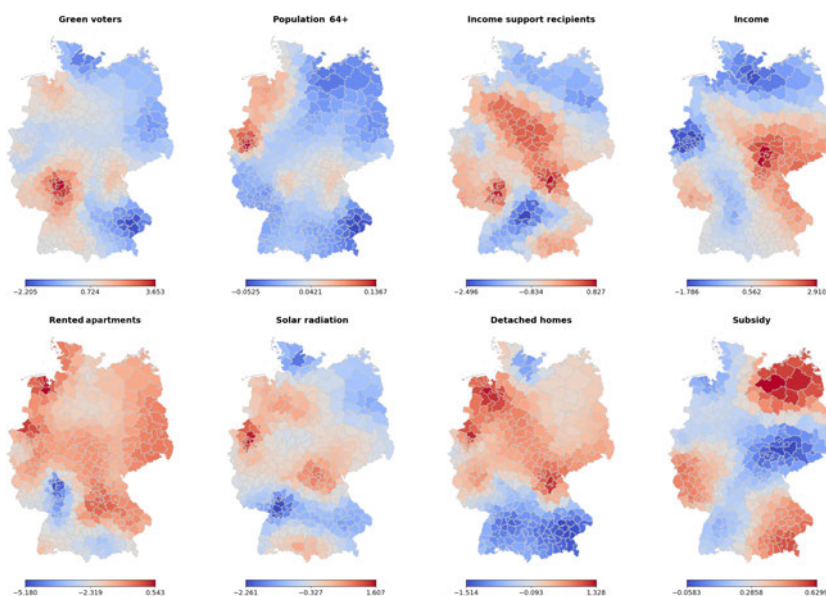


Figure 6: Local GWR estimates for plug-in PV systems in Germany.

Another key aspect of my dissertation in the field of renewable energy is the analysis of spatial and demographic factors for the adoption of plugs in PV systems. Overall, our findings highlight the complexity of factors influencing PV adoption in Germany, with significant spatial variability indicating that regional characteristics and policies play crucial roles. Figures 6 and 7 visually depict these varied local patterns, underscoring the importance of tailored approaches to promoting PV technology across different regions.

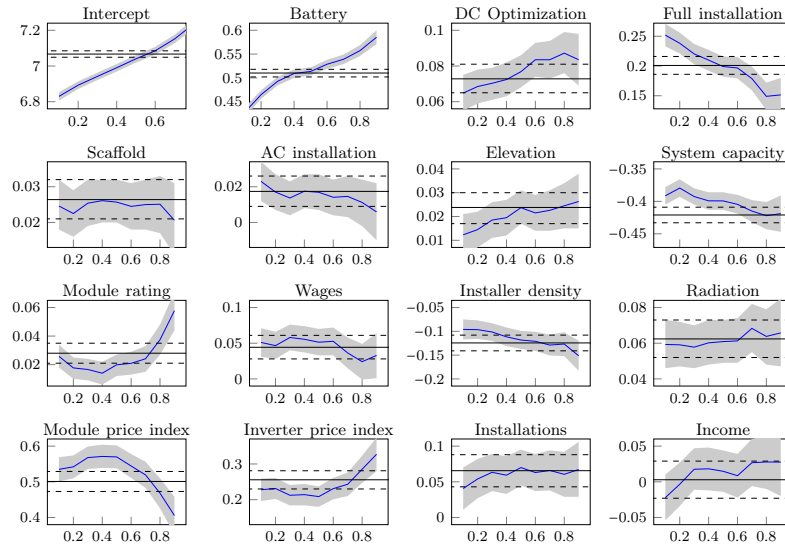


Figure 7: OLS (REF) estimates (continuous horizontal line) with respective 95 % CI as dashed lines, quantile regression estimates (blue line), with respective 95 % CI as shaded gray area.

Emerging Methods and Technologies in Information Systems

Contributing to the IS research taxonomy-based data clustering methods are assessed and guidelines for a rigorous application of clustering categorical taxonomy-based data are developed.

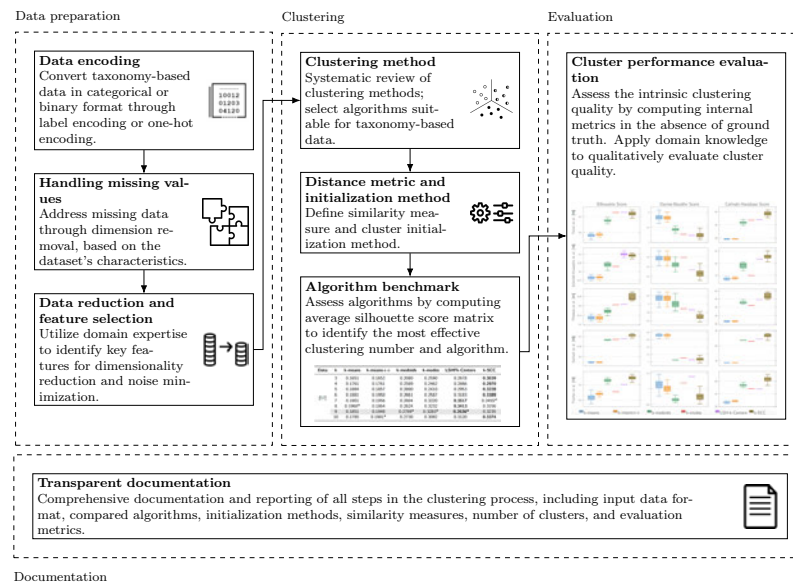


Figure 8: Overview of developed guidelines for clustering taxonomy-based data.

These techniques help to uncover patterns and provide guidelines for practical application in various IS contexts. The study emphasizes the importance of methodological rigor and presents a benchmark of different clustering approaches leading to our detailed guide-

lines to ensure reliable and reproducible results. Our developed guidelines for clustering taxonomy-based data are shown in Figure 8.

In another study on the analysis of social and research perceptions of artificial intelligence (AI) chatbots the perceptions of large language models and generative pre-trained transformer-based chatbots like ChatGPT are being explored in the research community and society. By analyzing sentiment and topics within social media and academic literature, the study provides insights into the evolving landscape of AI and its implications for research and practical applications for the further development and regulations of generative AI.

Contributions to Information Systems Research and Practice

Our spatiotemporal study of shared e-scooter usage in Berlin over a 9-month period makes significant contributions to information systems research and practice. From a research perspective, we expand the literature by applying spatiotemporal data analytics to understand emerging mobility services, providing one of the first comprehensive analyses of e-scooter sharing in a major European city enabling valuable cross-cultural and geographic comparisons.

Methodologically, we introduce novel data filtering techniques, such as using energy consumption rates to detect round trips, which have so far been ignored in e-scooter research. This can guide future researchers in refining data processing pipelines. Additionally, we advance spatial analysis methods by applying Hierarchical Density-Based Spatial Clustering of Applications with Noise (HDBSCAN) to identify point-of-interest specific usage patterns, yielding more granular insights.

In practice, our findings on POI-specific usage patterns help policy makers and urban planners to develop appropriate e-scooter regulations and infrastructure improvements. In addition, our analysis of the spatial distribution of e-scooter trips and the relationship to land use types provides a basis for the integration of micromobility sharing into sustainable urban mobility systems.

Our study on developing a GIS to support decision-making for aging wind turbines in Germany also contributes to information systems research and practice by integrating spatial data analytics with domain-specific knowledge. Our findings especially highlight the limited availability of priority wind development zones as a key barrier to repowering projects. The GIS also supports wind plant operators in selecting among lifetime extension, repowering, and decommissioning options, enabling more informed and financially sound decisions. We provide actionable insights for renewable energy planning and our GIS architecture, data inputs, and workflows provide a replicable template for further research.

Optimizing a smart logistics concept for e-grocery operations, we introduce a novel last-mile concept that combines eco-friendly fleets with an intelligent infrastructure of refrigerated lockers. Our concept improves the efficiency of urban e-grocery distribution by shortening last-mile distances and enhancing sustainable transportation. This hybrid

system was evaluated for the city of Hannover, Germany, demonstrating its capability to improve urban logistics.

We further introduce an optimization approach that not only addresses environmental and economic aspects but also considers system resilience against regulatory uncertainties.

Reflecting on contributions highlighted by citing authors, our article on "Web Content Mining Analysis of e-Scooter Crash Causes and Implications in Germany" has advanced urban mobility safety and information systems through our methodological approach and empirical findings that have been recognized and validated by various researchers.

Introducing our web-based USEFUL DSS we showcase how a simulation-based rule mining inference machine can enhance the scalability and transferability of simulation results for complex logistics scenarios in urban and rural settings.

Our study on price dispersion of residential solar photovoltaic systems serves as a basis for multiple analyses in the literature, providing a reference for quantifying PV component costs.

Reflections on Research Limitations

Acknowledging limitations is crucial for contextualizing our findings and guiding future research. Reflecting on research limitations elucidates the challenges faced during the research process, identifies specific barriers and gaps, and provides a foundation for future studies.

A prevalent limitation encountered in our research pertains to data availability and quality. Comprehensive analysis of urban transport, energy systems, and emerging technologies requires access to extensive datasets that are accurate, current, and representative. However, heterogeneity in data collection methodologies, temporal and spatial gaps, and varying data accessibility pose significant challenges.

Methodologically, the methods adopted in this work, while established and robust, have limitations. Design science research faces challenges in establishing rigorous evaluation criteria for designed artifacts and can be resource-intensive. The contextualized nature of design science research can limit the transferability of its findings to other domains or settings.

Quantitative models and simulations necessitate simplifications and assumptions that may not fully capture real-world complexity. For example, our optimization model for urban parcel delivery assumed fixed parameters for vehicle emissions and operational costs, which may not fully capture the dynamic nature of real-world logistics operations.

A significant limitation during DSS development was balancing simplification and transparency. Simplification led to criticisms regarding the intransparency and perceived "black box" nature of the DSS. Despite being designed to provide optimal decisions, the inability of decision-makers to fully grasp underlying processes reintroduced a form of bounded rationality, affecting users' trust and understanding of outputs.

Technological and computational resources also presented limitations. The intricate

models developed for simulating urban transport and energy systems demand substantial computational power. Despite leveraging advanced techniques, the scale and complexity of models were constrained by available technology.

The scope of our analysis, while comprehensive, is limited by the breadth of the topic. The artifacts developed are specific adaptations with biases due to our research focus. Different approaches may exist that we have not considered.

While DSS are crucial for providing strategic insights, they possess inherent limitations. One significant limitation is users' unawareness of DSS assumptions. Transparency in the system's assumptions and calculations is essential for accurate interpretation and trust. Scalability and transferability are major limitations, as DSS effectiveness relies on input data quality. When applied to different urban areas, additional data collection and validation processes are necessary. Cost and complexity also present challenges. Developing and maintaining DSS can be resource-intensive. Post-project, maintenance and deployment of developed tools often face hurdles, including personnel changes and lack of financial support. DSS often focus on quantifiable data, limiting their effectiveness in considering qualitative factors crucial for comprehensive analysis. Interface problems can hinder integration into existing IT infrastructure and processes, affecting adoption and utilization. Validating DSS effectiveness is challenging. DSS often deal with innovative topics that are hard to comprehend without the system, and there is frequently a lack of experience among personnel regarding results. Ethical considerations of fairness and social bias are increasingly important when working with AI models as part of a DSS. Transparency, accountability, and human control are essential to address these challenges. Incorporating qualitative research methods or participatory approaches may provide richer insights into the socio-cultural dimensions of sustainable urban development. Broadening the scope of environmental studies to include diverse urban contexts and technology scenarios will enhance future research relevance and applicability. Future research should explore the application of these methodologies in other contexts and extend economic models to include additional factors. By integrating rigorous spatial analytics with deep domain expertise, this dissertation exemplifies the potential of information systems research to deliver actionable decision support tools that help tackle grand societal challenges like the sustainable energy transition and urban logistics efficiency. The work contributes meaningfully to the growing body of green IS scholarship and provides a solid foundation for future research and practical applications in urban planning and logistics.

Contents

Abstract	I
Research Summary	III
List of Figures	XIV
List of Tables	XVI
Overview of Publications and Task Allocations	XVII
1 Introduction	1
2 Research Methodology	2
3 Sustainable Urban Transport and Mobility	6
3.1 Decision Support Systems and Strategic Insights for Efficient Transportation Operations of Urban Logistics	6
3.2 Analyzing Shared Micromobility: Spatiotemporal Dynamics, Crash Causes, and Usage Patterns	15
4 Sustainable Energy Systems	24
4.1 End-of-Funding Analysis of Wind Turbines Potentials and Decision Support	24
4.2 Pricing and Adoption of Residential Solar Systems in Germany	29
5 Emerging Methods and Technologies in Information Systems	34
5.1 Taxonomy-Based Data Clustering in IS Research	34
5.2 Social and Research Perceptions of Large Language Models and Generative Pre-trained Transformer-Based Chatbots	39
6 Contributions to Information Systems Research and Practice	41
6.1 A Review of Citation Impact: Evaluating Research Contributions	41
6.2 Reflections on Research Limitations	46
7 Conclusions and Further Research	50
Acknowledgements	51
References	52
A Appendices	65
A.1 Lifetime Extension, Repowering or Decommissioning? Decision Support for Operators of Ageing Wind Turbines	65

A.2	Individually Optimized Commercial Road Transport: A Decision Support System for Customizable Routing Problems	66
A.3	Decision support for sustainable and resilience-oriented urban parcel delivery	67
A.4	A Real Options Approach to Determine the Optimal Choice Between Lifetime Extension and Repowering of Wind Turbines	68
A.5	Shortening the Last Mile in Urban Areas: Optimizing a Smart Logistics Concept for E-Grocery Operations	69
A.6	Towards Sustainable Transport: A Strategic Decision Support System for Urban Logistics Operations	70
A.7	A Spatiotemporal Study and Location-Specific Trip Pattern Categorization of Shared E-Scooter Usage	71
A.8	Web content mining analysis of e-scooter crash causes and implications in Germany	72
A.9	ChatGPT and GPTZero in Research and Social Media: A Sentiment- and Topic-based Analysis	73
A.10	Disentangle the price dispersion of residential solar photovoltaic systems: Evidence from Germany	74
A.11	Open Access Decision Support for Sustainable Buildings and Neighborhoods: The Nano Energy System Simulator NESSI	75
A.12	Modeling and Calibration of Last-Mile Logistics to Study Smart-City Dynamic Space Management Scenarios	76
A.13	Continuous Health Monitoring on Shared Mobility Devices: A Health-eScooter Prototype	77
A.14	Factors Influencing the Usage of Shared Micromobility: Implications from Berlin	78
A.15	Adoption and Spatial Distribution Disparities of Residential Plug-In and Rooftop Photovoltaic Systems in Germany	79
A.16	Unpacking the Last Mile: An Agent-Based Geospatial Exploration Model of Last-Mile Logistics	80
A.17	Impacts of Sustainable Logistics in Urban and Rural Areas: A Delphi Study	81
A.18	Reassessing Taxonomy-Based Data Clustering: Unveiling Insights and Guidelines for Application	82
A.19	Continued Operation or Repowering? A Financial Decision Support System for Onshore Wind Turbine Investments in Germany	83
A.20	USEFUL: Untersuchungs-, Simulations- und Evaluations-Tool für Urbane Logistik: Schlussbericht zum Teilprojekt: FKZ 03SF0547B	84
A.21	USEFUL-XT: Untersuchungs-, Simulations- und Evaluations-Tool für Urbane Logistik: Schlussbericht: FKZ 03SF0609	85
	Ehrenwörtliche Erklärung	86

Overview of Publications and Contributor Roles

The dissertation comprises 18 scholarly articles and two research project reports authored by diverse teams between 2019 and 2024. A systematic summary is presented in Tables 1 and 3, which outline each paper's and report's title, authors, publication outlet, and key performance indicators. The VHB Rating 2024, commonly referred to as "VHB ranking," is a recognized benchmark in the German business research community. It assigns ratings from "A+" to "D" to established academic journals, based on evaluations by prominent German scholars in business research [44]. This system is widely regarded by German information systems researchers as a measure of a publication's academic integrity. However, considering the interdisciplinary scope of this thesis, which spans energy informatics and engineering, not all articles are assessed under the VHB scale. Therefore, an additional interdisciplinary journal rating is employed: the *SCImago Journal Rank* (SJR), which is established internationally [121]. The SJR categorizes journals into quartiles within their specific research fields, with a Q1 rating indicating a position in the top 25% of publications in that domain [121]. Each paper in this thesis represents a significant research endeavor, subjected to stringent single or double-blind peer review processes. The following section provides a concise summary of each article, emphasizing the shared responsibilities among co-authors. Importantly, citations for each article are included where applicable, to demonstrate their individual impact within the academic community.

Table 1: Overview of peer-reviewed publications and submissions under review.

App.	Status	Title	Authors	Journal & Conference	VHB ¹	IF ²	SJR ³	Citations ⁴
A.1	2019	Lifetime extension, repowering or decommissioning? Decision support for operators of ageing wind turbines	Piel, J.H., Stetter, C., Heumann, M., Westbomke, M., Breitner, M.H.	Journal of Physics: Conference Series	-	-	-	40
A.2	2019	Individually optimized commercial road transport: a decision support system for customizable routing problems	Leyerer, M., Sonneberg, M.O., Heumann, M., Kammann, T., Breitner, M.H.	Sustainability	-	3.89	Q1	6
A.3	2019	Decision support for sustainable and resilience-oriented urban parcel delivery	Leyerer, M., Sonneberg, M.O., Heumann, M., Breitner, M.H.	EURO Journal on Decision Processes	B	1	Q2	25
A.4	2020	A real options approach to determine the optimal choice between lifetime extension and repowering of wind turbines	Stetter, C., Heumann, M., Westbomke, M., Stonis, M., Breiter, M.H.	Operations Research Proceedings	-	-	-	3
A.5	2020	Shortening the last mile in urban areas: Optimizing a smart logistics concept for e-grocery operations	Leyerer, M., Sonneberg, M.O., Heumann, M., Breitner, M.H.	Smart Cities	-	6.4	Q1	49
A.6*	2019	Towards Sustainable Transport: A Strategic Decision Support System for Urban Logistics Operations	Heumann, M., Pump, R., Breiter, M.H., Koschel, A., Ahlers, V.	Proceedings of the 16th International Conference on Wirtschaftsinformatik	B	-	-	8
A.7	2021	A Spatiotemporal Study and Location-Specific Trip Pattern Categorization of Shared E-Scooter Usage	Heumann, M.; Kraschewski T.; Brauner, T.; Tilch L.; Breitner, M.H.	Sustainability	-	3.89	Q1	27
A.8	2022	Web Content Mining Analysis of E-Scooter Crash Causes and Implications in Germany	Brauner, T.; Heumann, M.; Kraschewski, T.; Rehse, J.; Prahlow, O.; Kiehne, C.; Breitner, M.H.	Accident Analysis & Prevention	-	6.38	Q1	10
A.9	2023	ChatGPT and GPTZero in Research and Social Media: A Sentiment-and Topic-based Analysis	Heumann, M., Kraschewski, T., Breitner, M.H.	Proceedings of the 29th Americas Conference on Information Systems	C	-	-	6
A.10	2023	Disentangle the Price Dispersion of Residential Solar Photovoltaic Systems: Evidence from Germany	Kraschewski, T., Brauner, T., Heumann, M., Breitner, M.H.	Energy Economics	B	9.25	Q1	6
A.11	2023	Open Access Decision Support for Sustainable Buildings and Neighborhoods: The Energy System Simulator NESSI	Eckhoff, S., Hart, M.C.G., Brauner, T., Kraschewski, T., Heumann, M., Breitner, M.H.	Building and Environment	-	7.09	Q1	3
A.12	2023	Modeling and Calibration of Last-Mile Logistics to Study Smart-City Dynamic Space Management Scenarios	Wage, O., Heumann, M., Bienzeisler, L.	Proceedings of the 1st ACM SIGSPATIAL International Workshop on Sustainable Mobility	-	-	-	-
A.13	2024	Continuous Health Monitoring on Shared Mobility Devices: A Health-eScooter Prototype	Warnecke, J., Baumgartner, C., Breitner, M.H., Brieche, D.F., Deserno, T., Heumann, M., Johns, M., Picker, A., Rausch, A., Wolf, L.	Proceedings of the 57th Hawaii International Conference on System Sciences	C	-	-	-
A.14	Under review 1 st rev.	Factors influencing the usage of shared micromobility: Implications from Berlin	Heumann, M.; Tilch, L.; Otto, P.; Kraschewski, T.; Brauner, T.; Breitner, M.H.	Journal of Transport Geography	B	6.1	Q1	-
A.15	Under review 1 st rev.	Adoption and Spatial Distribution Disparities of Residential Plug-In and Rooftop Photovoltaic Systems in Germany	Kraschewski, T., Heumann, M., Breitner, M.H.	Renewable and Sustainable Energy Reviews	B	15.9	Q1	-
A.16	Under review 1 st rev.	Unpacking the Last Mile: An Agent-Based Geospatial Exploration Model of Last-Mile Logistics	Bienzeisler, L., Wage, O., Heumann, M., Lelke, T., Friedrich, B.	Transportmetrica B	-	6.1	Q1	-
A.17	Under review 1 st rev.	Impacts of Sustainable Logistics in Urban and Rural Areas: A Delphi Study	Heumann, M., Bäckmann, F., Staritz, J., Bienzeisler, L., Wage, O., Breitner, M.H.	European Transport Research Review	-	2.6	Q1	-
A.18**	Under review 2 nd rev.	Reassessing Taxonomy-Based Data Clustering: Unveiling Insights and Guidelines for Application	Heumann, M., Kraschewski, T., Werth, O., Breitner, M.H.	Decision Support Systems	B	7.5	Q1	-
A.19	Under review 1 st rev.	Continued Operation or Repowering? A Financial Decision Support System for Onshore Wind Turbine Investments in Germany	Wang, Y., Kraschewski, T., Heumann, M., Breitner, M.H.	Hawaii International Conference on System Sciences	B	-	-	-

Σ 183
h-index 6

¹ German Academic Association for Business Research [44], VHB ranking 2024

² Clarivate Analytics [24] and Journal homepages

³ SCImago [120] Scientific Journal Rankings (SJR)

⁴ Google Scholar [46], as of August 2024

* Best Practice Oriented Paper nominee

** Association for Information Systems [6], Senior Scholars' List of Premier Journals