THE STATE OF THE ART IN SMART CITY RESEARCH – A LITERATURE ANALYSIS ON GREEN IS SOLUTIONS TO FOSTER ENVIRONMENTAL SUSTAINABILITY

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Abstract

Environmental sustainability is one of the most critical issues worldwide, concerning every individual. The main objective in this area is to preserve scarce resources and reduce CO_2 *emissions in order to prevent environmental degradation. In recent years the potential of information systems (IS) as a driver for environmental sustainability has emerged under the term "Green IS". Given that cities represent a huge share of environmental degradation due to factors such as mobility, energy and water consumption, and waste production, the municipal domain offers huge potentials in terms of sustainability. The advent of smart cites is an attempt to address this concern. In this paper we aim to provide an overview of current publications on environmental sustainability in smart cities, as research in this field is still unstructured. This paper focuses on structuring the research field by providing a research framework to achieve a more holistic view on the application of Green IS. We distinguish between research performed by the IS community and that of related fields, such as urban development, and perform a cross-sectional, exhaustive literature analysis with almost 1,500 articles to uncover the differences and commonalities between the domains.*

Keywords: Smart City, Green IS, Environmental Sustainability, Green Society.

1 INTRODUCTION

Environmental sustainability presents a crucial topic in IS research (Watson et al. 2013) and is addressed in two different approaches: Green IT and Green IS (Loeser 2013). Whereas Green IT considers information technology (IT) to be a cause of environmental pollution, Green IS regards information systems and the inherent IT involved as a possible solution for reducing environmental degradation (Chen et al. 2009). Thus far, a plethora of research has been conducted in the field of Green IT with the goal of reducing CO_2 emissions caused by IT (Dedrick 2010; Tushi et al. 2014). Contrastingly, little research has been performed on Green IS – utilizing IS as an enabler for environmental sustainability (Melville et al. 2010) – and the pace of research is still slow (vom Brocke et al. 2013).

Though early calls for Green IS research within the IS community demonstrate the relevance of the topic and the important role of IS in fostering environmental sustainability, they mainly focused on the organizational context (Chen et al. 2009; Dedrick 2010; Melville et al. 2010). However, alongside businesses and the energy sector (Watson et al. 2013), cities – and particularly their citizens – represent a huge share of the production of greenhouse gas emissions (Lövehagen & Bondesson 2013) and the consumption of limited resources such as water and energy (Granath & Axelsson 2014). In conjunction with urbanization, climate change, and digitalization as global trends, cities have been seeking to meet their climate targets by introducing information and communication technologies (ICT) (Kramers et al. 2013) while demonstrating increased interest in the scientific field with the aim of reducing CO_2 emissions and saving resources through the utilization of ICT (Granath & Axelsson 2014; Lee et al. 2013; Maccani et al. 2014). Consequently, the term “smart city” was recently established among researchers and in practice. While the term still lacks a consistent definition (Ojo et al. 2014), the use of ICT and the topic of environmental sustainability are often described as crucial elements of its concept (Caragliu et al. 2009; Neirotti et al. 2014; Ojo et al. 2014).

IS can be implemented in various ways to reach the goal of CO_2 reduction and resource preservation (Kramers et al. 2013), leading IT corporations to see a potential market for smart city–oriented IT solutions for supporting city administrations in their endeavor toward a smarter city infrastructure (Paroutis et al. 2013). In this paper we aim to outline the current state of Green IS research in the domain of smart cities and identify the potentials of IS solutions, resulting in the following two research questions:

RQ1: What is the state of the art of Green IS research in the smart city domain within the IS community?

RQ2: How do other research domains address the adoption of IS to improve environmental sustainability in smart cities, and how does this compare to the IS community’s approach?

Thus, the goals of this research are to connect two emerging and promising research fields – namely, Green IS and smart cities – by providing insight into the employment of information systems for improving environmental sustainability in the municipal context and to identify shortcomings and gaps in existing research. Furthermore, we define the role of the IS community in this novel research field and answer the call for Green IS research by unveiling a new domain for Green IS research within the IS community. Based on our findings from the literature, we propose a conceptual framework to guide further research in the research field of sustainable information systems solutions in the smart city context.

The remainder of the paper is structured as follows. We first offer a brief insight into smart city and Green IS research and set the scope of the research process, which provides a foundation for the literature evaluation process. Next, we outline the process of literature selection and analysis before presenting and discussing the analysis results. We close with a short conclusion summarizing the key findings and offering an outlook for further research.

2 RELATED WORK AND RESEARCH SCOPE

The concept of smart cities is very broad and concerns a huge variety of tasks, including the improvement of governance processes, the optimization of service provision toward citizens, and the provision and management of information (Nam & Pardo 2011). However, this is just a small subset of what describes the idea behind building smarter cities. To date, the term “smart city” is not yet clearly defined (Lövehagen & Bondesson 2013), as it poses a complex area with several domains, actors, and processes, each with different goals (Kramers et al. 2013). This is further illustrated by the various terminologies that are used synonymously to describe the concept of supplementing urban structures with ICT in research and practice – intelligent city, knowledge city, sustainable city, future city, digital city, innovative city, etc. (Adepetu et al. 2014; Kutami 2014; Lee & Lee 2014; Qingrui et al. 2012; Rezendea et al. 2014) – based upon the respective goals pursued (Kramers et al. 2013). All these concepts strive to modernize cities by improving a city’s growth, service provision, infrastructure (Anttiroiko et al. 2013), and ultimately, its welfare, productivity, and quality of life (Nam & Pardo 2011; Shapiro 2014) by focusing on various key elements, such as knowledge transfer, improvement of infrastructural components, and environmental aspects. Technology plays a major role in all these concepts (Caragliu et al. 2009) and acts as an enabler for ideas and processes to attain the respective goals. Several frameworks and architectures have been designed to describe and sketch smart cities and structure further research agendas (Balakrishna 2012; Chourabi et al. 2012; Debnath et al. 2014; Gil-garcia et al. 2013; Jin et al. 2014; Nam & Pardo 2011; Su et al. 2011). Due to the novelty of smart cities as a research field, these approaches are rather generic and outline the general idea of smart city initiatives. For example, Balakrishna (2012) proposes a broad smart city architecture that consists of six dimensions – environment, economy, people, governance, living, and mobility – that are underpinned by three building blocks (sensors, network infrastructure, and data management) and autonomous decision making, reflecting the broad spectrum of this area. Based on existing research, we focus on a specific subset by assessing smart cities from the environmental dimension and are interested in the ecological goals pursued by the authors. We therefore distinguish between the reduction of environmental pollution, e.g., CO_2 emissions or waste, and the preservation of resources, such as water or energy (Granath & Axelsson 2014; Kramers et al. 2013), achieved by the utilization of information systems (Su et al. 2011), referred to in this context as Green IS.

The research field of Green IS has been garnering increased attention in the IS community within recent years. Green IS are defined as IS products that support the achievement of sustainability initiatives (Chen et al. 2009) as compositions of physical technological entities and software components. Furthermore, this definition can be extended by practices and processes that are enabled by these IS products and contribute to ecological performance improvements (Melville et al. 2010). Vom Brocke et al. (2013) propose five directives for future Green IS research and development, arguing for intensified research concerning IS artifacts in order to address practical issues and for the consideration of insights and solutions from non-IS research fields to enrich IS research in this area. In this vein, we address these perspectives by focusing on concrete Green IS solutions from both the IS community and non-IS research areas that address environmental sustainability. However, the definition of the term “Green IS” in the literature is very vague; it is often merely described as an information system that contributes to environmental sustainability (Chen et al. 2009) and is thought of as an enabler for the change toward sustainable behavior (Vom Brocke et al. 2013). In order to widen the research of Green IS to other areas and away from the business focus, we strive to extend Green IS research to new potential application areas and thus increase the impact of sustainable IS solutions. Based on Watson et al. (2013), who defined the field of energy informatics as a subfield of IS and thereby narrowed the scope of Green IS to the energy sector, we define Green IS for the city context: *A Green IS in the smart city context supports city planners to promote environmental sustainability and provides citizens the opportunity to contribute to ecological improvements or triggers the change toward sustainable behavior*.

Thus, three dimensions arise as the foundation of our research interest (*information systems*, *environmental sustainability*, and *cities*) to address the questions of how, where, by what means, and by whom environmental sustainability can be achieved in urban structures. To provide the reader with an insight into our research focus and the literature selection and review process, we present a short definition of the individual key points to sharpen the scope of our research procedure.

As we aim to assess the impact of information systems and their underlying technologies on ecological sustainability in the city context, we are exclusively interested in the contribution of IS to improving environmental sustainability. We therefore omit every article that focuses solely on social or economic sustainability as elements of the triple bottom line of sustainability (Dao et al., 2011). The focal points of this dimension are the goals pursued concerning environmental sustainability and the underlying processes, answering the questions of what can be done to improve sustainability and how these goals can be achieved from a strategic viewpoint. The classification concerning the sustainable contribution is conducted based on the three milestones of ecological sustainability: eco-efficiency, eco-ubiquity, and eco-effectiveness (Chen et al. 2008).

The city dimension is divided into domains and actors, as these are essential entities concerning the introduction of ICT solutions for improving environmental sustainability. The actors are either responsible for the utilization of IS or direct users, while the domains within cities are highly diverse and involve various key aspects concerning the fulfillment of sustainability goals. As a first approach to clustering solutions in terms of the application domain, we use the extensive and well-derived classification of smart city domains by Neirotti et al. (2014) – with adjustments toward the ecological focus of this paper – as a starting point for further assessment. In this context, the domains describe the areas within the city where IS are deployed to foster environmental sustainability and are represented by *transportation*, *infrastructure*, and *buildings*. The transportation domain covers all forms of mobility, e.g., public transportation; infrastructure comprises the provision and management of the basic needs of citizens, such as water supply, energy grids, and waste management; and buildings encompasses everything that addresses the consumption of resources or the production of emissions in public or residential facilities. The second part is represented by the actors involved, as we are interested in the audience of the IS solutions presented in the articles.

Regarding the IS perspective, we are interested in the strategic role and characteristics of the information systems used. The systems are categorized in automate, informate, and transformate (Dao et al. 2011; Dehning et al. 2014), according to their intended purpose. Automate refers to the execution of processes by ICT and the reduction of resources used to fulfill a task; informate provides information in order to adjust actions, e.g., decision support systems (DSS); and transform describes the redefinition of capabilities and processes to reshape and improve existing processes or generate new services (Chen et al. 2008; Dao et al. 2011; Thambusamy & Salam 2010).

The scope of research results in a research framework with three dimensions that form the basis of this paper's literature search and selection process (Figure 1).

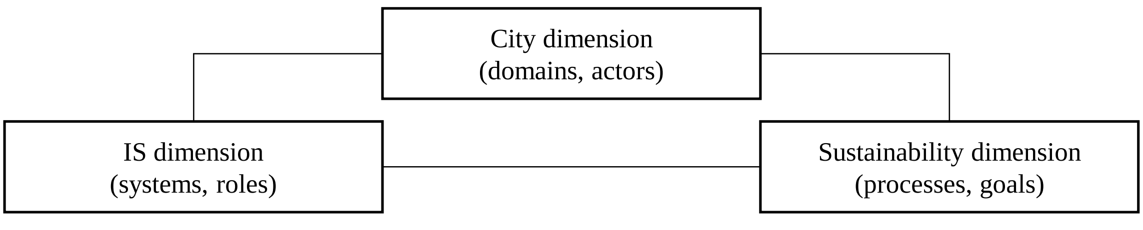

Figure 1. Research framework.

In this context, the city landscape with its inherent, diverse domains constitutes the research object along with the applied information systems and the sustainability-related goals. The literature is assessed along these dimensions regarding the utilization of information systems to foster environmental sustainability in the smart city context. The literature search and selection processes are described in the following section.

3 METHODOLOGY

In order to optimally categorize the existing literature, we conducted two exhaustive literature reviews based on vom Brocke et al. (2009). This approach emphasizes the literature-discovery process and guarantees an elaborated and well-documented selection of references that is reproducible by other researchers (Table 1 and Table 2). The analysis and synthesis of the literature was carried out based on Webster and Watson (2002). The results were then summarized in a concept matrix according to the three dimensions of focus (city, IS, sustainability) and assessed based on their contribution to the topic (Table 3).

Journal	**Database**	**Long List**	**Short List**	**Final List**
ACM Transactions Journals (ACMT)	EBSCOhost, WoS	3	-	-
Communications of the ACM (CACM)	EBSCOhost, WoS	53	-	-
Decision Support Systems (DSS)	EBSCOhost, ScienceDirect	145	5	2
Electronic Markets (EM)	WoS	-	-	-
European Journal of Information Systems (EJIS)	EBSCOhost, WoS	1	-	-
Human-Computer Interaction (HCI)	EBSCOhost, WoS	-	-	-
IEEE Software	EBSCOhost, WoS	5	-	-
IEEE Transactions Journals (IEEET)	EBSCOhost, WoS	81	14	3
Information & Management (I&M)	EBSCOhost, WoS	82	1	-
Information and Organization (I&O)	WoS, ScienceDirect	37	-	-
Information Systems (ISYS)	WoS, ScienceDirect	22	-	-
Information Systems Journal (ISJ)	EBSCOhost, WoS	1	-	-
Information Systems Research (ISR)	EBSCOhost, WoS	-	-	-
International Journal of Information Management (IJIM)	ScienceDirect	82	-	-
Journal of Information Technology (JIT)	WoS	-	-	-
Journal of Management Information Systems (JMIS)	EBSCOhost, WoS	2	-	-
Journal of Strategic Information Systems (JSIS)	WoS, ScienceDirect	46	4	-
Journal of the Association for Information Systems (JAIS)	EBSCOhost, WoS, AISeL	23	-	-
Management Information Systems Quarterly (MISQ)	AISeL	50	4	1
Management Science (MS)	EBSCOhost, WoS	3	-	-
Organization Science (OS)	EBSCOhost, WoS	1	-	-
International Conference on Information Systems (ICIS)	AISeL	115	17	2
European Conference on Information Systems (ECIS)	AISeL	148	3	3
	Total	***900***	***48***	***11***

Table 1. Outlets considered for the literature analysis within the IS community.

In the *first analysis* we only examined leading IS literature, allowing us to categorize the existing articles and assess their diffusion in the IS community (*RQ1*). The *second analysis* covers the same topic but without limitation to this particular community. Thus, we made sure to elaborate the research topic in a holistic way by bridging the gap between the IS community and others, identifying differences and commonalities among them (*RQ2*). The keywords were selected based on the research interest, resulting in the keywords "Green IS", "environmental sustainability", and "smart city". The next step was to search the literature with the selected keywords. Although the search string ("Green IS" AND "smart city" AND "environmental sustainability") is very precise and would perfectly fit the interests, it would also omit potentially relevant articles. In contrast, using OR instead of AND might lead to results that are too broad. Therefore, we decided to use generic keywords, assuring that no literature was omitted, e.g., by having the literature use “sustainability” as an equivalent for “environmental sustainability” or, analogously, using the terms “digital city” or “sustainable city” instead of “smart city”. Hence, for the *first literature review* the keywords (“city” OR “cities”) AND (“smart” OR “sustainable” OR “sustainability”) were selected. The list of journals considered was inspired by Heinzl et al. (2008) and comprises the following outlets (Table 1): *ACM Transactions Journals*, *Communications of the Association for Computer Machinery*, *Decision Support Systems*, *Human-Computer Interaction*, *Information and Organization*, *IEEE Software*, *IEEE Transaction Journals*, *Information and Management*, *International Journal of Information Management*, *Management Information Systems Quarterly*, *Management Science*, *Organization Science*, *Proceedings of the International Conference on Information Systems*, and *Proceedings of the European Conference on Information Systems*. We thus reduce the chances of overlooking suitable contributions outside the core basket of eight journals. To fully cover these journals, we used the following databases: *AIS Electronic Library*, *EBSCO*, *Web of Science*, and *ScienceDirect.*

The results for the first review reveal an extensive list of 900 articles within the outlets considered, depicted schematically in Table 1. To assess their relevance for the research endeavor, these articles were subject to review by the authors in terms of title, abstract, and keywords. Articles regarded as irrelevant for the further context of the paper were sorted out. After the first revision round, we obtained a short list of 48 articles with a resulting inter-coder reliability of 96.1%. Articles with differing assessments between the authors were discussed until concurrence was reached. Within the second revision round, the articles were thoroughly reviewed by the authors, with particular consideration of the requirements regarding IS, environmental sustainability, and smart cities; only articles that met these requirements were kept, resulting in a final list of 11 articles that served as the basis for assessment and discussion.

Analogously to the first review, which focused on the IS community, we conducted a *second review* without limitation to IS-related outlets. However, we used a different search string, as although we still wanted to examine IS solutions for fostering environmental sustainability in smart cities, the focus was no longer on the IS community. Therefore, we chose the following search string: (“information system” OR “information systems” OR “ICT”) AND (“city” OR “cities”) AND (“smart” OR “sustainable” OR “sustainability”) while the selection of databases remained constant.

Finally, both long lists were merged to keep only the additional findings. Again, after reviewing titles, keywords, and abstracts, we sorted out literature that did not meet the requirements, resulting in a reduction of the results from 592 articles to a short list of 108 and an inter-coder reliability of 90.7%. A tabular representation of the journals concerning the other research areas would be disproportionate, as the variety of the journals considered is large for this processing step. Therefore, we classified the journals according to their research focus (environmental science; energy and transportation; cities, buildings, and regional-science; technology and engineering; software and information systems; and miscellaneous); an overview of the articles related to these research areas is presented in Table 2. Within the second round of revisions, the remaining articles were reviewed in detail; eventually, a final list of 24 articles was determined to be valuable for our research endeavor.

Research Area	**Database**	**Long List**	**Short List**	**Final List**
Software and information systems	WoS, ScienceDirect, EBSCOhost, AISeL	202	20	4
Environmental science	WoS, ScienceDirect, EBSCOhost	175	45	7
Energy and transportation	WoS, ScienceDirect, EBSCOhost	51	14	5
Cities, buildings, and regional science	WoS, ScienceDirect, EBSCOhost	45	16	4
Technology and engineering	WoS, ScienceDirect, EBSCOhost	30	12	4
Miscellaneous	WoS, ScienceDirect, EBSCOhost	89	1	-
	Total	***592***	***108***	***24***

Table 2. Classification of the journals considered without focusing on the IS community.

4 RESULTS

The articles selected from the literature review for the IS community (Table 1) and the non-IS research domains (Table 2) were summarized and presented according to the proposed research framework in Figure 1. The results indicate that all derived domains have been addressed by the literature of both research domains. However, the non-IS research domains contribute an additional domain that is not considered by IS research: urban planning. Furthermore, the classification yields an overview of the utilized information systems for the respective use cases. Although the IS and other communities are somehow aware of the ability of IS to foster environmental sustainability in the city context, approaches for addressing the problem are diverging.

Regarding the state of the art of Green IS solutions in the smart city domain addressed by the IS community (*RQ1*), the review of the top-ranked IS journals and conferences yields some interesting approaches for ecological improvements through the use of IS in a city context. However, given the importance of Green IS as a research field, the number of articles is still low. Despite our best efforts, we could not find any publication within the databases that directly addresses the deployment of Green IS in a smart city context. It seems that Green IS, or the deployment of ICT to foster environmental sustainability, has not yet made its way into the city context within the IS community. According to our framework, we categorized the selected articles along three dimensions: environmental sustainability, smart city, and Green IS (see Table 3).

The results reveal that the corpus of published literature in the IS research domain primarily addresses city planners, who are either the city administration itself or service providers supporting municipal tasks (e.g., garbage collection or public transportation providers). In contrast, only four articles of the resulting set directly address citizens. The focus of the solutions employed lies on the development and utilization of information systems that support decision-making processes based on data collected from experts (Chamberlain et al. 2012) and citizens (Lovrić et al. 2013; Wagner et al. 2013, 2014) as well as self-collected data by city administration personnel (Rickenberg et al. 2013; Santos et al. 2011). Hence, six of the eleven solutions are decision support systems (DSS) that are deployed in the infrastructure and transportation domains. In the infrastructure domain, the DSS are used to identify sustainable wastewater solutions (Chamberlain et al. 2012) and optimize city service vehicle routing, i.e., trash collection (Santos et al. 2011). Within the transportation domain, the DSS are used to improve charging infrastructure for car-sharing stations – electric and otherwise – (Rickenberg et al. 2013) and advance public transportation services by integrating separate transport information systems (TIS) (Lovrić et al. 2013). Feedback systems are the second-most applied information system; they aim to motivate citizens to engage in more sustainable transportation alternatives, such as biking (Flüchter et al. 2014), or to shift toward the energy efficient use of household appliances (Liu et al. 2013; Loock et al. 2012, 2013). The main purpose of all these solutions is to collect, process, and provide information to trigger behavior change (feedback systems) or support decision-making processes (DSS). In addition to Chamberlain's DSS, three more articles go beyond the solely informing and aim to automate processes (Hounsell & Shrestha 2012; Lovrić et al. 2013; Santos et al. 2011). Hounsell and Shrestha (2012) propose an intelligent transport system with the goal of reducing passengers' waiting times by prioritizing buses at traffic signals, thereby increasing the attractiveness of public transportation through increased comfort. The approach considers the use of automatic vehicle location systems to facilitate the communication between buses and traffic infrastructure, e.g., the urban traffic control center. This is extended by Lovrić et al.'s (2013) solution of collecting and analyzing travel data gathered from customers' smart-card tickets to optimize public transportation services, resulting in lower waiting times and increased passenger comfort, and Santos et al.'s (2011) vehicle routing optimization. Furthermore, other IS solutions aim to trigger a transformation from conventional conditions toward the establishment of more sustainable innovations, such as the optimization of electric-vehicle charging (Wagner et al. 2013, 2014) or car-sharing infrastructure (Rickenberg et al. 2013) to promote the switch from individual car use to sustainable mobility alternatives.

Authors	**Use Case**	**Type of Green IS**	**Environmental Sustainability**			**Smart City**						**Role of Green IS**		
			Eco-efficiency	Eco-equity	Eco-effectiveness	Citizens	City planners	Transportation	Infrastructure	Buildings	Urban planning	Automate	Informate	Transformate
(Amado & Poggi 2014)	Utilizing regenerative energy sources	GIS		x			x			x			x	
(Ascione et al. 2014)	Energy demand planning on city scale	GIS	x				x			x			x	
(Battista et al. 2014)	Analysing energy efficiency intervention	Simulation software	x				x			x			x	
(Baz et al. 2009)	Settlement suitability analysis	GIS		x			x				x		x	
(Bridges 2008)	Urban forest analysis	GIS		x			x				x		x	
(Chamberlain et al. 2012)	*Sustainable wastewater solutions*	*DSS*	*x*				*x*		*x*			*x*		
(Flüchter et al. 2014)	*Motivating e-bike usage*	*Feedback system*		*x*		*x*		*x*					*x*	
(Girardin et al. 2010)	Energy requirement planning	GIS	x				x		x			x		
(Hilpert et al. 2013)	GHG emission tracking	Feedback system		x			x	x					x	
(Hounsell & Shrestha 2012)	*Bus prioritization at traffic lights*	*TIS*	*x*				*x*	*x*				*x*		
(Ki 2013)	Landscape and urban planning	GIS		x		x					x		x	
(Kodysh et al. 2013)	Utilizing regenerative energy sources	GIS		x			x			x			x	
(Kuzyk 2012)	Ecological footprint calculation	GIS		x			x			x			x	
(Liu et al. 2013)	*Motivating energy consumption reduction*	*Feedback system*		*x*		*x*				*x*			*x*	
(Loock et al. 2012)	*Motivating energy consumption reduction*	*Feedback system*		*x*		*x*				*x*			*x*	
(Loock et al. 2013)	*Motivating energy consumption reduction*	*Feedback system*		*x*		*x*				*x*			*x*	
(Lovrić et al. 2013)	*Load balancing for public transportation*	*DSS*	*x*				*x*	*x*				*x*		
(Mahmoud & El-Sayed 2011)	Sustainable urban development	GIS		x			x				x		x	
(Mastrucci et al. 2014)	Energy efficiency planning	GIS	x				x			x			x	
(Namdeo et al. 2002)	Traffic and emission modelling	GIS		x			x	x					x	
(Pandey et al. 2012)	Waste disposal location planning	GIS	x				x		x			x		
(Reiter & Marique 2012)	Residential energy use assessment	GIS	x				x			x				x
(Ren et al. 2013)	Sustainable urban development	GIS		x			x				x		x	
(Rickenberg et al. 2013)	*Discovery of car-sharing stations*	*DSS*			*x*		*x*	*x*						*x*
(Rybarczyk & Wu 2010)	Bicycle facility planning	GIS			x		x	x						x
(Rylatt et al. 2001)	Utilizing regenerative energy sources	GIS		x			x			x			x	
(Sánchez et al. 2013)	Autonomous street light adaption	Automated mgmt. system	x				x		x			x		
(Santos et al. 2011)	*Vehicle routing for urban trash collection*	*DSS*		*x*			*x*	*x*				*x*		
(Shin & Jun 2014)	Smart parking guidance	DSS			x	x		x						x
(Theodoridou et al. 2012)	Utilizing regenerative energy sources	GIS		x			x			x			x	
(Tibaut et al. 2012)	Travel planning	TIS			x	x		x						x
(Wagner et al. 2013)	*Charging station infrastructure planning for EVs*	*DSS*			*x*		*x*	*x*						*x*
(Wagner et al. 2014)	*Charging station infrastructure planning for EVs*	*DSS*			*x*		*x*	*x*						*x*
(Wang & Zou 2010)	Sustainable urban development	GIS		x			x				x		x	
(Winters et al. 2013)	Bike track planning	GIS			x		x	x						x
		Total	***11***	***18***	***6***	***7***	***28***	***13***	***4***	***12***	***6***	***7***	***20***	***8***

Table 3. *Classification of the results from the literature analysis based on the proposed research framework*[1].

[1] Italicized entries are articles from the IS community.

The results concerning the second research question (*RQ2*) show that the vast majority of IS deployed in the non-IS community domains are geographical information systems (GIS) with a focus on collecting and monitoring environment-related data. This is surprising because this kind of IS is completely neglected within the IS community but could be explained by the particular focus of the other research domains such as urban planning, which is addressed by one-fourth of all articles. The corpus of the information systems employed within the non-IS research domains are concerned with energy management solutions (Amado & Poggi 2014; Ascione et al. 2014; Battista et al. 2014; Girardin et al. 2010; Kodysh et al. 2013; Kuzyk 2012; Mastrucci et al. 2014; Reiter & Marique 2012; Rylatt et al. 2001; Sanchez et al. 2014; Theodoridou et al. 2012) and the decrease of environmental deterioration in the context of urban planning (Baz et al. 2009; Bridges 2008; Ki 2013; Ren et al. 2013; Wang & Zou 2010). The articles regarding energy management cover solutions for city-wide energy requirement planning (Girardin et al. 2010) and optimized city illumination (Sanchez et al. 2014) on an infrastructural level, the reduction of energy use in buildings (Ascione et al. 2014; Battista et al. 2014; Kuzyk 2012; Mastrucci et al. 2014; Reiter & Marique 2012), and the evaluation and prediction of energy alternatives to supply buildings from regenerative energy sources (Amado & Poggi 2014; Kodysh et al. 2013; Rylatt et al. 2001; Theodoridou et al. 2012) in order to reduce CO_2 emissions caused by traditional energy production. Environmental deterioration is addressed via decision support processes supported by information provided from GIS. The underlying data is either self-collected (Baz et al. 2009; Ren et al. 2013; Wang & Zou 2010), provided by citizens (Ki 2013), or gathered via remote sensors (Bridges 2008). CO_2 reduction is also the primary goal of solutions employed in the transportation domain. The systems implemented monitor CO_2 emissions on a city-wide scale by utilizing sensors and extrapolations (Namdeo et al. 2002) or on an individual level within vehicles of a logistics company (Hilpert et al. 2013). While the characteristic of these solutions is rather passive, as they merely measure and display information upon which actions may be based, other solutions aim to address the root cause by reducing individual car use. This is achieved by promoting bicycle use through the implementation of a bicycle-route platform (Winters et al. 2013), the creation of a decision support system for city planners to assist in the planning process of bike facilities toward a multi-model city (Rybarczyk & Wu 2010), and the service integration of multiple transport information systems to promote and improve public transportation services (Tibaut et al. 2012). In case people do drive their own car, one solution supports the driver in finding a suitable parking spot, aiming to reduce search time and the resulting CO_2 emissions (Shin & Jun 2014).

Like the results from the IS community, the integration of citizens within the non-IS communities is very low. Overall, only 7 of the 35 articles reviewed (20%) consider citizens in their IS solutions at all. Given that the solutions in the non-IS fields are heavily data driven in order to provide important information inside the GIS applications, citizens were considered merely for the data-collection process, and the core role of the information systems employed was to informate, as it is within the IS literature.

The distribution of information systems types between the two scopes of analysis is displayed in Table 4, depicting the different foci of the respective communities in addressing the problem concerning the utilization of Green IS.

Information System	**IS Community**	**Non-IS Communities**
Decision Support Systems (DSS)	6	1
Geographical Information Systems (GIS)	0	19
Feedback System	4	1
Transportation Information Systems (TIS)	1	1
Automated Management System	0	1
Simulation Software	0	1
Total	***11***	***24***

Table 4. Types of information systems in the examined research fields.

The findings of the literature review extend our original research framework from Section 2, illustrated in the following figure (Figure 2).

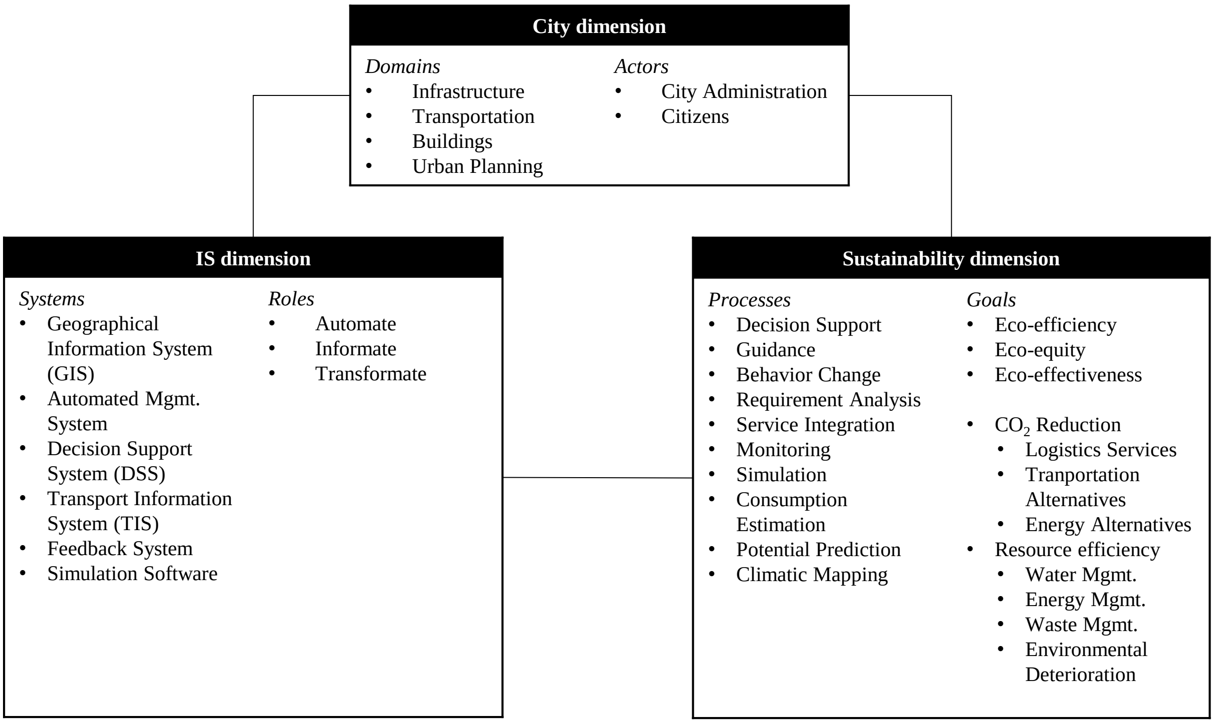

Figure 2. Research framework extended with the results of the literature analysis.

5 DISCUSSION

The results of the literature analysis and the resulting final framework serve as a starting point for future research and initiatives regarding the implementation of Green IS solutions in the smart city context. It pinpoints existing employments of different types of information systems, processes considered, and sustainability goals. Researchers and practitioners can find out whether their intended projects have already been implemented and gain additional insights from existing research. Furthermore, the proposed solutions may serve as an inspiration for future sustainability initiatives and research endeavors.

The major difference between both research scopes is that the non-IS communities focus on the utilization of GIS to collect and monitor environment-related data. However, the systems employed primarily aim to display information and provide DSS-like functionality by guiding governmental decisions. These solutions have a rather reactive character, since they mainly serve as planning tools and actions are performed based on historical data. Therefore, these systems can be considered long-term solutions because the time span of data acquisition, processing, and taking action can be very lengthy. However, the literature – especially that from the IS community – also offers short-term solutions. Flüchter et al. (2014), Liu et al. (2013), and Loock et al. (2013), for example, use feedback systems to provide real-time visual feedback of energy consumption and CO_2 reduction to individual users with the goal of influencing them to behave more sustainably through proactive behavior. Despite the limited integration of individuals in the identified literature and the divergence of Green IS solutions between the different research fields, feedback systems were covered by both reviews and show promising results for short-term, proactive IS solutions to foster environmental sustainability. We therefore argue that the sort of information systems that directly address citizens can have large positive effects on environmental sustainability. Feedback systems could be implemented in various domains and fields within these domains, e.g., waste management (infrastructure), public transportation (transportation), water consumption (analogous to energy consumption in the building domain), and more. Given the sheer number of people in cities, even minor adjustments regarding a more sustainable behavior can scale up to huge effects.

Furthermore, non-IS communities emphasize the domain of urban planning, which remains unaddressed by IS research. Leaving this fact aside, both research fields share some commonalities. The building domain, for example, is addressed by both communities, though in a different manner. While non-IS researchers aim to determine optimal energy plans concerning consumption and supply on a spatial level as well as city wide by addressing city planners or energy suppliers, IS research focuses on the reduction of individual energy consumption in households by utilizing smart meter–based feedback systems. However, the implementations in the transportation domain are similar, as both research fields offer solutions for improving the transportation infrastructure (Rybarczyk & Wu 2010; Wagner et al. 2013, 2014; Winters et al. 2013) and contribute to an increased willingness to use public transportation or transportation alternatives (Hounsell & Shrestha 2012; Lovrić et al. 2013; Rickenberg et al. 2013; Tibaut et al. 2012). Approaches in the infrastructure domain vary the most among the commonly addressed city domains. In the broadest sense, both research fields share the goal of optimizing waste management by improving trash vehicle routing (Santos et al. 2011) and the location analysis for solid-waste disposal sites (Pandey et al. 2012) or wastewater management (Chamberlain et al. 2012). Overall, the building and transportation domains are the most frequented regarding the implementation of information systems to foster environmental sustainability. However, the solutions in the building domain are rather monotone, solely addressing energy management tasks. In contrast, the transportation domain has a high variance of targeted areas and solutions, and turns out to be a very promising domain with high potential for further research.

Another interesting finding within the results is that we could not find any mobile application–based solutions. Although this can be explained by the lack of focus on individuals in the articles discovered, mobile devices can still be utilized in the given scenarios. For example, pervasive computing devices such as smartphones or tablets can be used as sensor nodes (Ganti et al. 2011) to collect and provide data in a crowd-sensing manner (Ganti et al. 2011; Miorandi et al. 2013) for GIS- or DSS-oriented systems. Mobile applications could provide valuable services for inducing sustainable operations in the individual context, particularly in the context of feedback systems; we encourage further research in this direction along all domains discussed within this analysis. Furthermore, the results indicate that more than half of all IS solutions aim to informate a certain instance – be it the city administration, service provider, or citizens – in order to provide decision support for decision processes or feedback on behavior; few systems aim to automate or transformate tasks and processes to foster environmental sustainability. This could be explained by the lack of clearly defined processes regarding the achievement of urban sustainability goals. Hence, we argue for research on scenarios and IS solutions to fill this gap. Moreover, we encourage the design and development of user-centric IS solutions to directly support citizens' sustainable actions. While citizens constitute one of the most important assets of cities, few solutions within the literature reviewed focus on them, and the city administration takes no part in the whole system, e.g., as a moderator or sponsor, to proactively promote sustainable initiatives.

The sustainability goals in this paper are classified based on the conceptual model of IS and ecological sustainability by Chen et al. (2008). However, the framework and its proposed ecological milestones (eco-efficiency, eco-equity, and eco-effectiveness) are constructed for the organizational context and settled in the industrial sector, e.g., concerning cleaner production (Chen et al. 2008). According to the framework, the roles of information systems (informate, automate, transformate) are strongly coupled with the sustainability goals, e.g., the automation of production processes increases the eco-efficiency. However, this concept is not easily adaptable to the city context because there are little to no defined processes regarding the contribution to environmental sustainability and the production of goods cannot be automated to achieve eco-efficiency. In this paper we categorized DSS functionality and goal attainment as automate when the underlying algorithms and solvers directly contributed to the efficiency of the examined object, e.g., optimized vehicle routing leads to reduced CO_2 emissions (Santos et al. 2011). On the other hand, the feedback provided to a citizen about the potential reduction of CO_2 emissions by biking instead of using a car (Flüchter et al. 2014) yields transparency about individual behavior and has an educational character; therefore such feedback was considered as eco-equity. IS solutions were classified as eco-effective when a transition from the norm takes place, e.g., the switch from individual car use to car sharing (Rickenberg et al. 2013; Wagner et al. 2013, 2014).

This paper contributes to the theory of Green IS research by providing a foundation for further investigation of environmental information systems solutions in a new research field separate from the business focus within the IS community. It establishes a different perspective on both the potentials of IS-driven solutions to foster environmental sustainability across the borders of organizations as well as the benefits of integrating individuals to participate in the process of ecological improvement. Furthermore, we enrich the concept of smart cities by concentrating on a particular facet of urban information systems capabilities. Practitioners and city planners who are interested in contributing to environmental sustainability in the municipal context can use the findings of this paper as guidance for further efforts.

Although we performed the literature analysis according to our best knowledge and intention, a few limitations must be considered. First, the articles reviewed were limited to journals; aside from the leading IS conferences ICIS and ECIS for the literature analysis focusing on the IS community, research published in conferences proceedings or other outlets were not considered. It is therefore possible that fruitful contributions to the topic of Green IS in smart cities were omitted. Second, we focus on IS implementation or deployment, meaning that frameworks, models, or theoretical strategic measures were not taken into account within the review. Third, the final selection of literature was subjective, based on the authors' opinions; a classification of the literature by different authors may lead to divergent insights. Furthermore, the selection of the keywords for the search process limited the results regarding the broadness of other possible solutions. The keyword "information systems" is rather generic and likely does not reflect potential specific solutions that concern the non-IS research domains, as "information systems" or the keyword "ICT" might not be as common for these communities as they are for the IS community. Therefore, further research should focus on specific implementations of IS artifacts and their potential applications for particular tasks in the respective domains. Research in the field of Green IS in smart cities should explore the requirements – ideally by directly consulting the target groups, i.e., city planners/administration – to determine what kind of information is desired, which processes need to be supported, and what design principles for application development are postulated. Given the recent, immense technological innovations, including pervasive computing devices such as smartphones and tablets that have a multitude of sensors and are mobile, we recommend working out solutions that make use of these capabilities. Citizens could be used as mobile sensor nodes to gather data in a crowd-sensing manner (Cardone et al. 2013), feeding existing systems such as GIS tools or even creating innovative methods for ecological contributions (transformate). In this regard, there develops a need for a motivation mechanism (e.g., gamification) to incentivize the user to provide data to such a system (Ueyama et al. 2014).

6 CONCLUSION

This paper analyzes the current state of research in the domain of smart cities with a particular focus on the impact of Green IS on fostering environmental sustainability in the city context. The goal of this paper is to structure this research field to achieve a holistic view on the application of Green IS solutions in smart cities. To do so, we performed a cross-sectional, exhaustive literature analysis with almost 1,500 articles reviewed, distinguishing between research performed by the IS community and that conducted in related fields, such as environmental sciences. One of the central findings is the rising number of recently published articles, indicating that the field is garnering increased attention worldwide. In this regard, almost 75% of the final lists' articles were published within the last four years. The analysis of the literature reveals that the vast majority of information systems aim to support city planners in decision-making processes with the goal of reducing CO_2 emissions or preserving resources. The major difference between solutions produced by the IS community and those of other research domains is the frequent use of GIS tools outside of the IS community. However, both research domains have a low integration of citizens in their approaches, which we recommend emphasizing in future research projects. Based on the number and type of results, we argue that the research field of Green IS solutions in the city context is heavily underexplored and that the focus of Green IS research is oriented toward the organizational context, e.g., concerning cleaner production or greener business processes. Our findings provide evidence that little work has been conducted in this field. We believe that the requirements for solutions are unclear, and therefore the accessible technologies have not been utilized to a great extent. Furthermore, the role of the city within such a data-intensive construct is yet to be determined.

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