5-11-2023

A Socio-Ecological-Technical Perspective: How has Information Systems Contributed to Solving the Sustainability Problem

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A SOCIO-ECOLOGICAL-TECHNICAL PERSPECTIVE: HOW HAS INFORMATION SYSTEMS CONTRIBUTED TO SOLVING THE SUSTAINABILITY PROBLEM

Research Paper

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Abstract

This literature review extends the dominant view of Information Systems (IS) as socio-technical. We establish a novel view of IS as socio-ecological-technical systems to steer and unite IS research and scholarship to co-create digitally transformed sustainable futures. Without a commitment to reducing carbon dioxide equivalent emissions (CO_2e), we will reach a tipping point leading to large-scale, dangerous, and irreversible impacts on climate, human liveability, and survivability. Digital technology can potentially mediate human activities to reduce CO_2e, but its production, utilisation, and disposal are multiple sources of CO_2e. In response to the conference theme "Co-creating Sustainable Digital Futures", this paper systematically reviews the IS research over the last twelve years from the socio-ecological-technical and Environmentally Sustainable Digital Transformation frameworks, with a focus on CO_2e. Our holistic approach reveals emerging themes, current gaps and research opportunities, thus contributing to IS knowledge building and proposing future studies in this socio-ecological-technical domain.

Keywords: sustainability, socio-technical-ecological, green information systems, greenhouse gas emissions.

1 Introduction

Average global temperatures have risen by 1.3 degrees Celsius since industrialization and are projected to increase by 1.5 degrees by 2100 unless a 43% reduction in carbon emissions is realized before 2030 (United Nations Climate Change, 2022). The magnitude of this crisis cannot be overstated; at current trajectory we face irreparable changes to sea levels, and increased frequency and scale of weather-related disasters (NASA Global Climate Change, 2022). Millions of people will be placed within life-threatening temperatures (United Nations Environment Programme, 2019).

The impact of Carbon Dioxide Equivalent Emission (CO_2e) on the environment is significant. Greenhouse gases trap heat in the atmosphere, leading to rising temperatures, changes in weather patterns, rising sea levels, ecosystem disruptions, and economic impacts (Ledley et al., 1999, Steffen et al., 2015). According to Steffen et al. (2015), burning fossil fuels has substantially increased atmospheric greenhouse gas levels and contributed to environmental issues, including climate change. Controlling greenhouse gas emissions, including CO_2e, is crucial for managing planetary boundaries and achieving sustainable development.

Despite studies conducted in numerous countries indicating that prosperity results in a net improvement in air, water, and soil quality (Destek et al., 2020), it should be noted that the relationship between the emission of greenhouse gases (GHG) and prosperity has become decoupled. In other words, despite the positive impact of prosperity on air, water, and soil quality, GHG emissions have increased (Saidi and Hammami, 2015, Wang et al., 2018). Driven by energy demands due to urbanisation, industrialisation, and trade (Mardani et al., 2019), CO2e account for +79% of global GHG (Ritchie et al., 2020), and technology plays a key role as both a contributor and a remedy to this crisis.

The dual role of technology stems from emissions generated by their design, production, and usage (Freitag et al., 2021, Zhou et al., 2019), whilst their capabilities can mediate human activities thus offering sustainable solutions that meet both societal and economic demands. Both the urgency of this crisis and duality of technology have been recognised by the Information Systems (IS) community. Early papers from 2010 called for a new research direction of techno-sustainability, or Green IS, focusing on designing and managing sustainable business processes (Melville, 2010, Watson et al., 2010) to reduce energy consumption through awareness, identification and implementation of Green IS. Since then, many studies have been undertaken to explore Green IS, for example a literature review of Green IS research using design science (Brendel et al., 2018), special issues in Management Information Systems Quarterly (Malhotra et al., 2013) and Information Systems Journal (Elliot and Webster, 2017). Of note, Elliot and Webster (2017) echo previous systematic literature reviews on Green IS (Mohammad Dalvi Esfahani, 2015), citing an absence of focus on environmental impacts in current research and calling on a wider perspective to include ecological implications and benefits in organizational IS adoption at both macro and micro levels.

The ECIS 2023 theme "Co-creating Sustainable Digital Futures" and the growing attention of the IS community in recent conference panel discussions and opinion papers call for further research and actions to address sustainability issues (Lokuge et al., 2021, Dwivedi et al., 2022, Pee and Pan, 2022). In response, this paper reports on a comprehensive literature review guided by the socio-ecological-technical (SET) perspective which is new to IS research. Sustainability is an emerging research area in IS, and the foremost problem that our society is facing, and it is still underexplored. Using the new socio-ecological-technical theoretical lens, we were able to develop a holistic picture of current efforts and research agenda in Information Systems. Furthermore, this literature review provides a valuable resource for researchers, practitioners, and policymakers interested in understanding the potential of Green IS to promote sustainability and reduce environmental impact in various settings.

2 Conceptual frameworks for review

2.1 Socio-ecological perspective

The relationship between economic growth, societal advancement and ecological conditions is described as the conversion of natural resources to produce affluence at a cost to the environment (Knight and Schor, 2014). Differing views have emerged on the nature of this relationship. Environmental Kuznets Curve (EKC) proposes a quadratic formula between GDP and pollutants, whilst Rosa and Dietz (2012) assert that a linear relationship exists. Contemporary studies have produced findings concluding neither; Destek et al. (2020) cites over 64 studies alongside their own research findings, in which the phenomenon described by the EKC model is present in both G-7 and developing countries, but is neither linear nor quadratic, instead often cyclical and sensitive to discords.

However, this relationship between affluence and pollution shows decoupling from the emission of greenhouse gases. Increased wealth (Saidi and Hammami, 2015) and energy consumption (Mardani et al., 2019) shares a causal linear relationship with increased CO_2e, despite improvements in air or water quality. This is attributed by (Ritchie et al., 2020) to both industrial and urban electricity consumption. In 2016, 73.2% of the world's annual 49.4 billion tonnes of greenhouse gas emissions were from energy and heating, but most notably, in industrialized countries where the proportion of renewable energy adoption increased year-on-year, subsequent consistent decreases in CO_2e are observed (Ritchie et al., 2022). This supports the conclusion of Destek et al. (2020) that policies should not only aim to reduce pollution, but also promote environmentally sensitive economic strategies that focus on sustainable growth to reduce emissions. United Nations set an agenda for 2030 with 17 sustainable development goals (SDG) covering a comprehensive range of environmental, social and economic aspects (United Nations, 2015). A prominent model, the 'Doughnut Economics' framework (Raworth, 2017) replaces the measure of growth by GDP with that of two boundaries representing a desired target for sustainable growth: an upper ecological ceiling and lower boundary of societal needs. This model places greater prominence on the adoption and implementation of sustainability and proportionality. Most importantly, it introduces an ecological dimension to the role of technology, expanding its solution-contributions past prosperity, to that of addressing both social shortfalls and ecological overshoots.

2.2 IS Socio-technical perspective

The term 'socio-technical systems' (STS) was originally coined by Emery and Trist (1960) to describe systems that involve a complex interaction between humans, machines, and the environmental aspects of the work system. In other words, STS consist of both a technological subsystem and social subsystem. Hughes argues that "technological systems contain messy, complex, problem-solving components. However, the technological systems are both socially constructed and potentially society shaping" (Dwyer, 2011). It should also be noted deeply embedded systems that utilise sensors (Internet of Things machine to machine communication etc) have no social subsystem.

Socio-technical systems (STS) theory has been an influential component of IS research for many years. The premise of STS theory has been highly relevant to the seminal work of important IS Researchers such as Markus (1983), Orlikowski (1992, 2000), Orlikowski and Scott (2008), and DeSanctis and Poole (1994). It is especially helpful in untangling complex interconnected factors and providing clearer explanations for confusing or contrary outcomes (Orlikowski, 1993). STS theory seeks to address the entangling duality of where society and technology are mutually shaping/editing each other e.g. (Orlikowski and Scott, 2008) and technology mediates human activities (Human-Activity) to meet their demands. STS theory provides a nuanced mechanism for revealing the complexities within technological systems. Understanding that technological systems have an embedded social component is a central thesis of IS research and STS theory. STS theory acknowledges that technological systems are part of social systems such as organisations and increasingly with rapid rise of social media platforms more broadly society.

Orlikowski's (1993, p 423) duality of technology shows how needs and solutions influence each other in a dynamic way. In the context of Doughnut Economics, IS research must extend STS theory to incorporate environmental sustainability as a critical boundary for socio-technical systems to operate sustainably. Environmental sustainability is both a complex predicament, and "an urgent problem to address," (Watson et al., 2010, p23), with IS and ICT playing an increasing role in contributing to the problem. ICT use accounts for up to 2.8% of GHG emissions (Freitag et al., 2021) with a positive significant relationship between CO_2e and internet use (Mardani et al., 2019), IS/ICT energy-consumption (Gelenbe and Caseau, 2015) and indirect-emissions caused by intermediatory inputs (Zhou et al., 2019).

Building on Watson et al. (2010), we propose for the adaptation of socio-technical systems theory to design information systems in new and innovative ways that support environmental sustainability. Increasingly information systems will play a critical role in complex systems such as national electricity grids and international super electricity grids which are needed to produce clean renewal energy to reduce carbon emissions. For these types of systems to be successful, a socio-technical systems analysis approach is required to consider both the political and societal problems for the technological systems that provide sustainable solutions and in turn be adopted at national and international scale (Hojckova et al., 2022). However, we argue that the socio-technical perspective has limitations. In this paper, we propose a more comprehensive understanding of sustainability by using the socio-ecological-technical systems lens in IS research.

2.3 Socio-Ecological-Technical perspective and impact of Green IS

We adapt the socio-ecological-technical (SET) framework from sustainability studies (Ahlborg et al., 2019, McPhearson et al., 2022) to reframe IS sustainability research. Ahlborg et al. (2019) extend their disciplinary socio-ecological systems framework by incorporating the role of technology in shaping social and ecological outcomes. The SET framework combines three key domains - social, technical, and ecological - to understand the complex interactions between them (Figure 1). The SET framework emphasises the need to understand the co-adaptations of and interactions between Technology, Society, and the Environment. We extend IS's socio-technical perspective with the ecological dimension of SET.

Following our previous discussions of two socio-ecological and socio-technical perspectives, we further examine the role of technology in two widely adopted definitions of Green IS which 'launched' the IS discourse on sustainability. Firstly, Watson et al. (2010) defined Green IS as: “an integrated and cooperating set of people, processes, software, and information technologies to support individual, organizational, or societal goals.” Secondly, Melville (2010) defined an information system for environmental sustainability as “IS-enabled organizational practices and processes that improve environmental and economic performance”. The former inclines towards the socio-technical perspective and less explicit on ecology, while the latter inclines towards the socio-ecological perspective and less explicit on defining IS. Based on the SET perspective, we have synthesised the previous definitions to propose the following comprehensive definition: "Green information systems are an integrated and collaborative set of people, information and knowledge, structures and processes, software, digital technologies and platforms that enable individuals and organisations to harmonise their environmentally, socially, and economically sustainable performance.

This definition is in line with the panel discussion on the role that IS plays in facilitating environmentally sustainable digital transformation, reported on by Lokuge et al. (2021). Specifically, Lokuge et al. 2021 proposes environmentally sustainable digital transformation as the process of integrating sustainable practices into digital transformation initiatives. However, notwithstanding the expected outcomes of digital transformation outlined earlier, digital transformation can also have negative environmental impacts. For example, production, use, and disposal of digital devices and infrastructure can contribute to greenhouse gas emissions, electronic waste, and other environmental problems. Environmentally sustainable digital transformation seeks to address these issues by integrating sustainable practices into digital transformation initiatives (Feroz et al., 2021). They proposed the Environmentally Sustainable Digital Transformation (ESDT) framework to help IS researchers examine the impact of Green IS initiatives on environment sustainability at four levels of individual, organizational, country, and global, across three pillars of incentives, awareness, and impediments. Incentives refer to motivation, Awareness refers to knowledge, and Impediments refers to obstructions for sustainable digital transformations. This research proposes that efforts to transform sustainable practices should not be deterred by the ‘impediments’, but rather achieve realisation through implementation and continuous evaluation of the initiatives, further optimisation and advancement. The modified framework that results in realisation is well aligned with the Green IS impact through the belief-action-outcome (BAO) framework (Melville, 2010). According to the BAO framework, green IS can influence individuals' beliefs and attitudes towards environmental sustainability by providing new information, raising awareness, and promoting the importance of sustainability. This can then lead to changes in behaviours and actions, such as reducing energy consumption and waste production, which in turn, produce positive environmental outcomes such as reduced greenhouse gas emissions.

This research combines the Socio-Ecological-Technical (SET) and Ecological Sustainable Technology Design (ESTD) frameworks to propose that information systems (IS) should recognise the complex interactions between social, ecological, and technological perspectives throughout the entire life cycle of IS, from conception, design to disposal. Subsequently, we would like to explore the potential of integrating the frameworks together as a useful lens to review IS research efforts, to understand the role and impact of IS on environment sustainability. At this exploratory stage, we review studies reporting CO_2e due to its prominent contribution to GHG emissions. In our review, the SET serves as a high-level perspective of the interactions whereas the ESDT provides a way of positioning IS studies in terms of its contribution to addressing the sustainability problem.

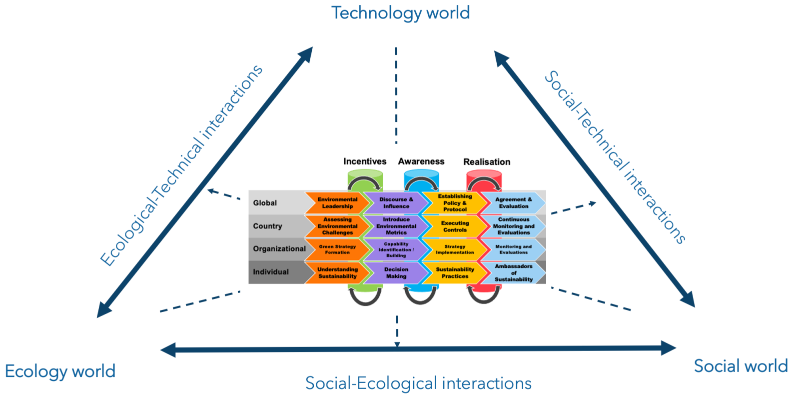

Figure 1. Proposed integrated framework of SET (extended on McPhearson et al., 2022) and ESDT (adapted from Lokuge et al., 2021)

2.4 Research questions

In response to the conference call for "Co-creating Sustainable Digital Futures", we systematically review the IS research efforts through lens of the SET and ESDT frameworks in terms of:

- RQ1. What are the current IS research efforts on environmental sustainability, specifically carbon emission reduction? This question will be addressed in terms of number of papers in total and by year, channels of publications, study locations (countries), research approaches, and contributions.
- RQ2. What does IS research study and what has been found through the lens of (Q2a) the SET framework (McPhearson et al., 2022) and (Q2b) the ESDT framework (Lokuge et al., 2021).

In addition, the research team conducted a reflection on the application of the SET and ESDT frameworks to supplement answers to the research questions, informing an agenda for IS research to continue building a sustainable digital future.

3 Research Method

To address the research questions, a Systematic Literature Review (SLR) was conducted. SLR is defined as "*means of identifying, evaluating and interpreting all available research relevant to a particular research question, or topic area, or phenomenon of interest*" (Kitchenham et al., 2009). We follow the SLR justification and process described by Okoli (2015). A SLR was chosen for three reasons: to examine the IS research effort of a specific research stream (Green IS with a focus on carbon emission), to develop a socio-ecological-technical perspective and make recommendations for future research.

We followed the process including four phases and eight steps recommended by Okoli (2015). During the planning phase, the review purpose and research questions were formulated, and a research protocol was developed and agreed by the researchers. During the selection phase, a search for peer-reviewed publications was undertaken within the specified sources. Due to the multidisciplinary nature of sustainability issues and carbon emissions, to ensure that we find relevant, and major IS research efforts, we specified the sources to include leading IS journals, i.e., the basket of eight and ABDC A* ranked, see Appendix A. To capture latest research, we also include leading IS conferences: International Conference on Information Systems and the European Conference on Information Systems.

We conducted the search from Scopus (which is the largest database) for titles and abstracts and retrieved papers from the AIS eLibrary, managed by the Association for Information Systems. The time period includes all papers published prior to October 2022. The research team conducted two searches. The primary search was conducted based on the presence of the terms carbon emission and its variations in the title, abstract and keywords, such as: "carbon" OR "CO2" OR "greenhouse" OR "emission". The secondary search was conducted based on the presence of "environment sustainability" or "green" or "sustainable development" or "climate analysis" and variations in the title, abstract and keywords. Duplicates were removed. We conducted two screening steps: by title/abstract/keywords and full text. In each step, each paper is screened by at least two researchers independently and paper selection was decided by all researchers at the team meetings. Inclusion and exclusion criteria are listed in Table 1.

Inclusion criteria	Exclusion criteria
• published prior to Oct 2022 • aim/focus of the study is relevant to CO_2e • research paper	• not written in English • non-peer-reviewed • opinion and literature review papers • CO_2e or sustainability is a context, not a focus

Table 1. Inclusion and exclusion criteria

Papers on general topics of environmental sustainability were excluded. In total, 36 papers with a clear focus on carbon emission reduction were eligible for inclusion in the review. See the SLR References at the end of this paper for paper ID and associated reference details. The screening results are reported using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009) (Figure 2).

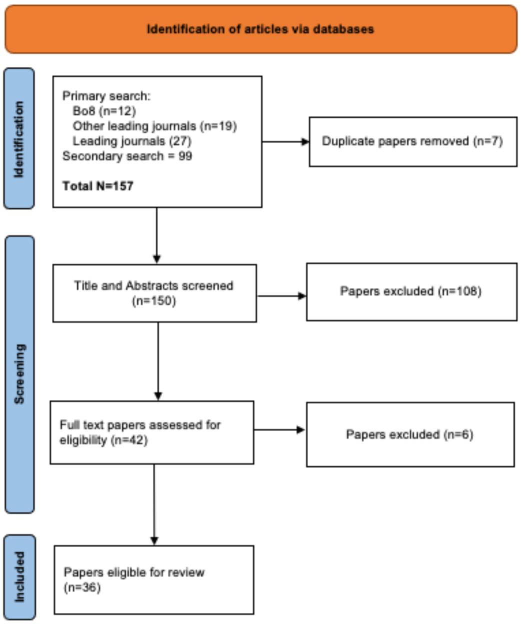

Figure 2. Paper screening process and results

In the extraction phase, each paper was reviewed in detail by at least 2 researchers. Using Excel and Nvivo, data were extracted on (a) study characteristics (e.g., author, title, source title, year, country) (b) study design (research objective, IS theory, theory from other disciplines, research strategy, research method, data, data collection, data analysis), (c) SET domains (McPhearson et al., 2022) and ESDT levels and pillars (Lokuge et al., 2021), and (d) key findings, knowledge and practical impacts and acknowledged limitations. Data extraction by at least two researchers was appraised and discussed with the team. In the execution phase, the data extracted from the papers were subject to both quantitative analysis and thematic analysis to answer the RQ1 and RQ2. Findings are reported in section 4.

4 Findings

4.1 RQ1. What are the current IS research efforts in relation to CO_2e?

IS research focusing on carbon emissions fluctuate over time. Among the papers (n=36) included in the review, 21 (58.3%) were published in European Conference on Information Systems (n=14, 39.9%) and International Conference on Information Systems (n=7, 19.4%). The rest (n=15, 41.7%) were published in several leading IS journals: Decision Support Systems (6), MIS Quarterly (3), International Journal of Information Management (2), Journal of the Association for Information Systems (2), Information Systems Research (1), Journal of Strategic Information Systems (1). There is a scarcity of research reporting on sustainability in leading IS journals and conferences.

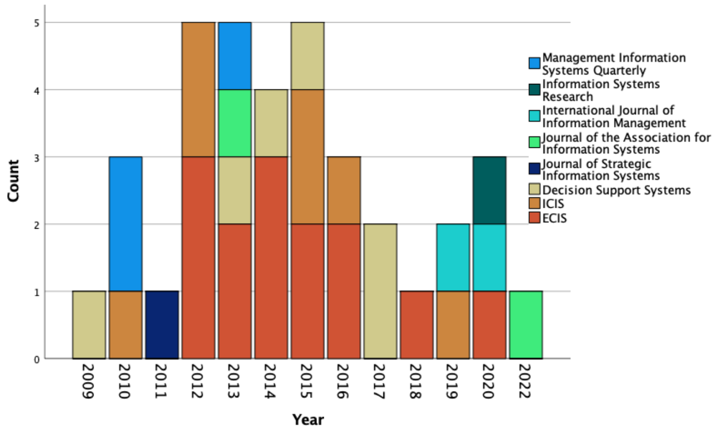

Figure 3. Frequency of papers published per year by channel of publications

USA has the highest number of studies, n= 12. Germany has the second highest number of studies: n=5. The next group is including Canada, Greek, Ireland, Italy, and the UK has 2 studies in each country. Australia, China, Demark, France, India, Taiwan, and Thailand each has 1 study. Several studies were conducted in more than one country or involve multi-national companies. Seven studies were either conceptual or used secondary data and did not specify any country.

The most dominate research strategy was quantitative (n=21, 58.3%). A clear majority were simulation and various mathematical modelling methods using secondary datasets. A smaller number of papers reported qualitative (n=5, 13.9%) or design science research (n=5, 13.9%). Four (n=4, 11%) papers reported conceptual development. One paper reported a mixed method study. The source papers are available on request from the authors.

In terms of IS theoretical lens, one third of the papers stated institutional and organisational theories, including institutional theory, resource-based theory, IS business value, and design decision. The Belief-Action-Outcome framework (Melville, 2010) was adopted by other authors, for example Huber et al. (2020), Mithas et al. (2010). Energy informatics (Watson et al., 2010) was also built upon by subsequent works (Bradshaw and Donnellan, 2013, Watson et al., 2015, Watson et al., 2013). Five papers used IS theories from psychology, such as behavioural, persuasive systems, and affordance. Behavioural economics was used in several papers.

We categorise research contributions claimed by the authors of the papers based on a taxonomy described by Collins et al. (2021) which describes six types of research contributions: framework/method, model, tool, guideline, lesson learned, and advice/implication). Framework/method includes conceptual/theoretical as well as technical contributions. Papers tended to list more than one types of contributions and some of these are vaguely connected to data analysis, therefore we selected only primary research contributions directly linked to their findings. Two most frequently presented contributions are framework/method/technique and model. Compared to these, the numbers of papers with direct contributions to practice (guidelines, lessons learned, and tools) are less frequent. The papers reporting on the quantitative research strategy are often associated frameworks, methods, techniques, and models as contributions. Qualitative and design science research papers are also associated with frameworks or models. Design science papers are also associated with tools as contributions. As opinions papers were filtered, advice/implications were excluded.

Contribution type	Description	Papers	Number of papers
Framework/ Method/ Technique	Particular conceptual framework, new understanding, method, or technique that can facilitate IS construction and management	P2, P6, P8, P12, P13, P14, P24, P26, P27, P28, P30, P31, P32, P39, P41, P42, P43	17
Model	Representation of an observed reality in concepts or related concepts after a conceptualisation process	P1, P3, P7, P10, P18, P19, P20, P22, P25, P29, P35, P40	12
Guidelines	List of advice or recommendations based on synthesis of the obtained research results	P5, P9, P15	3
Lessons learned	Set of outcomes based on the research results obtained from the data analysis	P4, P8, P11, P33	4
Tool	Technology, program, or application that is developed to support different aspects of information	P14, P16, P20, P26, P28,	5
Advice/Implications	Discursive and generic recommendation based on opinion		

Table 2. Contributions across studies based on the taxonomy adapted from Collins et al. (2021)

4.2 RQ2 Examining current IS efforts using SET and ESDT frameworks

4.2.1 Conceptualisation of Green IS

Two papers conceptually positioned Green IS in the Technology solution space as business leaders and organizations (Society) that embrace environmental sensitivity into their corporate vision (Ecology) by incorporating sustainability targets and measures as part of their organisational performance (e.g., increasing productivity, reducing costs, and enhancing public image). In P41, Green IS was 'launched' as technology solutions to mediate Society-Ecology through shaping beliefs and informing actions, thus achieving outcomes of reduced carbon emissions (Melville, 2010). In paper P42, energy informatics was proposed as technology (in terms of information) to reduce energy consumption (Watson et al., 2010). These papers focused on creating awareness, identifying strategies, and implementing Green IS capability predominantly for organisations and individuals.

4.2.2 By source of carbon emission

Electricity generation and consumption in residential, commercial, and industrial sectors accounts for 40-41.5% of global CO2e emissions (Ritchie et al., 2020). Seven papers focus on this source of emissions, with four papers reporting research into the energy consumption in home/building (P6, P16, P32), data centres (P1), and energy auction market (P7, P25). In P1, IS was seen as both a problem and solution, as societal and business demand for data storage and computation power (Society), data centres (Technology) were a major source of energy consumption and subsequent CO_2e (Ecology). Green data centres (GDC - Green IS) were a potential solution providing satisfaction of organisational requirements of energy efficiency and organizational performance to justify investment. P28 proposed a decision support system to assist an Australian regional industry park including power production utilities to optimise both eco-efficiency and energy production investment. In the other papers, optimal solutions (Green IS) were proposed to allow energy stakeholders such as consumers, suppliers, wholesalers, retailers, and market analysts to meet their energy demand while minimizing the use of fossil-based power generators and maximising the use of renewable energy sources (Society), thus reducing CO_2e (Ecology). All these papers focused on the ESDT Incentives and Awareness pillars at the organisational and/or individual levels.

Transport accounts for 16.2% of global CO_2e (Ritchie et al., 2020). Nine (n=9) papers reported IS research related to reducing the environmental footprint of human and goods movements by: adopting electric vehicles (EV): P10, P20, P30; traffic management: P13 and P33: bike: P5; green aviation: P14, green steaming: P12; and P24: four cases of car, bike, road, rail, and a city transportation system. From the Society perspective, a range of stakeholders including air travellers, road users, shipping companies, airlines, traffic controllers, electric car companies, etc. and their movement interests represent the Society. The Society-Ecology interaction manifests through the movements of human and goods leading to the increased carbon footprints (Ecology). The mediating role of Green IS on the Society-Ecology interactions was demonstrated in the evidence for CO_2e reduction through changing EV drivers' behaviours (P10), traffic management (P33), taxi-rider matching (P30), vessel coordination (P12). Except P5 reporting the Realisation (ESDT) of Green IS in bike sharing initiatives in several cities at the international level and P33 evaluating the benefit of intelligent traffic management systems in reducing CO_2e at the national level, other papers contributed to Awareness (capability identification and building) for individuals and organisations in adopting and optimising their use of Green IS.

Direct Industrial Processes account for 5.2% CO_2e (Ritchie et al., 2020). Two papers (P29, P35) reported proposed strategies for industrial organisations to embrace sustainability at different stages of business processes (Society). P35 offers a system dynamics model (Technology) to explore strategic paths to reduce CO_2e in cement production, whereas P29 offers a methodology to design ecology-friendly electronic products. Both papers focused on Green IS (as Technology) at the organisational level, contributing to Incentives (green solution formulation) and Awareness (capability identification and building). Whilst the Agricultural sector contributes to 18.4% of CO_2e (Ritchie et al., 2020), only one paper pertains to improve crop yields for food production. P31 offered farming organisations with a solution enabling to make informed decision-making support on the optimal time (Technology) to harvest the crop to reduce production costs (Society) and reduce CO_2e (Ecology). The implication is at the organisational level through creating Awareness (capability identification and building). There are no papers reporting research into food consumption or food waste.

4.2.3 By level of analysis

Most prominent levels of analysis are organisational and individual. A clear majority of papers reported research into organisational behaviours (n=14) to address ‘social responsibility’ (Society) of businesses to wider environmental concerns (Ecology), by augmenting processes, decision making or governance through Green IS initiatives (Technology). Such initiatives occur in various forms of corporate social responsibilities, Green IS strategy and investments, carbon management systems and other IS to support enterprise-wide sustainability transformation. In P2 and P9, Society refers to the public sector (United Kingdom and Ireland) exploring the role of Green IS strategies in governance to reduce CO_2e within operations. In these papers the influences of cultural, political, and social mechanisms, and economic rationale, on Green IS strategies and practices provide nuances in context to a wider array of stakeholders within their depiction of Society. In P22 and P26, Green IS adoption is viewed in both the monitoring and management of Greenhouse gas (GHG) emissions by business activities and subsequent outcomes to a firm’s ‘social responsibility’. Many organisations were concerned that Greens IS implementation may affect organisational performance, however evidence for benefits of Greens IS started emerged including both tangible (reduction of expenses, emissions) and intangible (improvement of public image, meeting societal needs) in P3, P11, P18, P22, P26, P40. Various Green IS solutions are offered to reduce carbon emission in the organisational settings (P5, P27, P43). Four papers (P15, P19, P26, P39) explored Carbon Management Systems (CMS) to enhance efficiency of supply-chain networks with benefits to both business value and reduction of both energy consumption and CO_2e. The evidence of impact of Green IS was demonstrated through data analytics (P18) and simulation (P19). Most of the studies focused on the ESDT organisational levels of Incentives (green strategy formulation) and Awareness (capability identification and building). Three studies reported Green IS impact at the Realisation level through implementation (P27, P43) and evaluation (P5, P13).

Eight papers conducted analysis at the individual level in different phases of Green IS solution design, acceptance and use behaviours. Green IS solutions were proposed to support energy consumers through Electric Vehicle (EV) charging flexibility (P20) and energy consumption efficiency (P25). Paper P4 examined Thailand university students' orientation toward Green IS products and services. These papers focused on the ESDT individual levels of Incentives (understanding sustainability) and Awareness (decision making). Other papers examined individual ecologically responsible behaviours using implemented Green IS initiatives: CMS at workplace (P27, P43), bike sharing (P5), paying for CO_2 offsets in flight booking processes (P14), and EV smart-driving behaviours (P10). These papers focused on the Realisation level of Sustainability practices and potentially Ambassador of sustainability.

In summary, IS research efforts address significant carbon emission sources (Ecology). Table 3 outlines the involved stakeholders and their interests from Society. In most of the papers, various forms of Green IS (Technology) and energy informatics were proposed as solutions were proposed and evaluated.

5 Discussion

5.1 Progress and current gaps

The IS community has responded to calls for studies into environmental sustainability with seminal papers by Watson (2010) and Melville (2010). Based on the SET and ESDT frameworks, our review reveals a significant IS research progress in developing or proposing solutions to help organisations optimise their strategic paths and operations, citing benefits of reducing energy consumption and CO2e, as well as to motivate and encourage environmentally responsible behaviours. Current IS efforts have attempted to address key sources of CO_2e with a clear focus on energy and transport sectors.

Studies examining the implementation of Green IS, and subsequent benefits, focus on Society at organisational and individual levels in multiple industry sectors, with impacts predominantly at Incentives and Awareness stages. Cited research shows emerging evidence that organisational and ecological performance are complementary, addressing suggested research directions by Mohammad Dalvi Esfahani (2015), and Elliot and Webster (2017).

We identified the following gaps in current IS research:

- Lack of sustainability and green IT studies from lower-middle- and low-income economies, despite papers focused on emissions originating from a wide spectrum of countries (Mardani, Streimikiene, Cavallaro, Loganathan, & Khoushnoudi, 2019) and a global bidirectional causality between growth, energy consumption and emissions (Wang, Li, & Fang, 2018).
- Lack of studies into food consumption and food waste. In terms of individual carbon footprint, food account for 10-30% of a household's carbon footprint (Center for Sustainable Systems, 2021).
- Lack of impact and translation of research, hence contributions to practice. In most studies, impact awareness through capability identification and building is dominant. Not many organisations have yet reached the realisation maturity stage of ESDT, thus limiting the potential impact of Green IS practices. The 3U framework by Pan and Pee (2020) emphasises the need for research to be not only "usable" but also "in-use" and "useful" to achieve real-world impact. Evaluating research based on usability, in-use, and usefulness can identify areas for improvement and optimise impact. Our use of ESDT with SET aligns with the 3U framework and enables examination of the ESDT stages of sustainability IS research from a broader SET perspective.
- Underrepresentation of interdisciplinary research into Green IS extending beyond enterprise or business contexts, with overrepresentation of benefits framed primarily in terms of fiscal returns or corporate public relations, indicating persistence of absences in research directions Elliot and Webster (2017).

		Society, Ecology and Technology elements – SET - RQ2a	Impact of environmental sustainability ESDT - RQ2b	Papers
Conceptualisation		Society is at a crossroad of Ecology crisis. IS, as Technology, plays a role in addressing the Ecological issue.	Awareness at individual and organisational level	• Green IS P41 • Energy informatics: P42
Source of CO_2e	Energy	Stakeholders in energy chain: electric power generators, wholesalers and retailers, market makers and analysts, business and individual consumers seek renewable energy or optimise power consumption for business profits, life comfort, and CO_2e reduction. Data centres are a source of CO_2e.	Incentives and Awareness at organisational level Incentives and Awareness at individual level	• Energy production: P28 • Energy consumption by businesses and homes: P1, P6, P16, P32 • Energy market: P7, P25
	Transportation	Society includes stakeholders participating in movement of human and goods by air, road and sea, such as consumers, providers, traffic control and management systems, and regulators. Green IS was developed or implemented to optimise movements, reduce traffic, save time and costs, facilitate carbon-offsetting, biking, and thus reducing CO_2e.	Realisation at Country level (P13) Incentives and Awareness at individual and organisational level (other papers)	• Aviation: P14 • Road: P5, P10, P13, P20, P24, P30, P33 • Sea: P12
	Industry	Companies developing strategic paths to reduce carbon emissions or designing while gaining economic performance, or designing eco-friendly electronic products, while reducing time and costs.	Incentives and Awareness at organisational level	• Production of goods/materials: P29, P35
	Agriculture	Crop producers who wish to optimise harvesting time to maximise profits by reducing costs are offered with new a yield monitor algorithm.	Awareness at organisational level	• Food production: P31 • Food consumption: none
Level of analysis	Organisational	Governments, businesses and supply chains respond to environmental sustainability (reducing CO_2e) in consideration of organisational performance and public image. Response takes different forms of corporate social responsibility and governance, green strategy, green IS investment, carbon monitoring, management and reporting, and business and environmental performance evaluation.	Incentives, Awareness and Realisation at organisational level	• Green government: P2, P9 • Corporate social responsibility: P22, P26 • Environmental performances, organisational performances and image: P3, P11, P18, P22, P26, P40 • Implementation in organisations: P5, P27, P43 • Supply chain: P15, P19, P26, P39
	Individual	Technology solutions include digital nudging, persuasive systems, smart assistance, thermal comfort automation, incentives, ridesharing, and bike riding, introduced by different organisations (governments and businesses) to motivate and facilitate people's ecologically responsible behaviours.	Incentives and Awareness at individual level.	• Solution design: P20, P25 • Acceptance: P4 • In use: P5, P10, P14, P27, P43

Table 3. Review of Green IS research using the SET and ESDT frameworks

5.2 Reflection on the review frameworks

SET was found to be useful in framing both the sustainability problem and the corresponding impact or role of IS. For example, in reviewing P1 (Hertel and Wiesent, 2014), economic growth from the Society leads to increased demand for data storage and computational power, necessitating large and powerful data centres (Technology) that cause carbon emissions from burning of fossil fuels for electricity generation (Ecology). In this way, IS/Technology plays a harmful role to the environment. However, through a combination of ventilation optimisation and use of renewable energy, Green Data Centres (GDC) can reduce their carbon emissions. In this way, GDC can be a solution, playing a less harmful role to the environment. However, businesses need to be convinced of the cost-effectiveness of GDC investments, which was examined within the study in the form of costs and energy savings derived from GDC adoption. Thus, SET would enable researchers to study the mediating effect as well as the moderating effect of Technology on the Society-Ecology relationship, and explore other relationships, for example, how human activities can moderate the relationships between Technology and Ecology, see the dotted lines in Figure 1 in our extended SET framework. A SET-based approach can enable researchers to delve deeper into the role of IS from three perspectives of Society, Ecology and Technology, to unpack their elements and examine the relationships between each dimension.

ESDT was also found to be effective in examining the impact of IS. For example, Hertel and Wiesent (2014) offered a decision model for technology companies to optimise the GDC investment budget through reconciling long-term economic and environmental performances. Thus, the study focused on Awareness (knowledge) through capability identification/building at the organisational level. Applying SET and ESDT together in this SLR, Table 3 provides an overall picture of the IS efforts and what impact Green IS has. There are opportunities to further develop an integrated SET and ESDT framework to guide researchers to frame their studies and examine the ecological perspective. Furthermore, SET presents opportunities to examine the dual roles of technology as both a cause and solution to ecological problems.

5.3 Research agenda

We call for a new discourse for examining IS using the Socio-Ecological-Technical (SET) systems lens. The SET was not explicitly described in any of the papers in the review. Our extracted SET 'stories' demonstrated that SET has the potential to be useful not only for Green IS research but also for wider IS education and research. We propose the following research agenda (see Table 4).

Research agenda	Description	Example research ideas
Foe or Friend	Green IS should not only study solutions but also examine the negative impact of technology on the ecological system.	• What are the types of the impact of technology through the value chain from design, deployment, use, and disposal (e-waste)?
Mitigation / Mediation	The future is not only digital but rather digitally mediated. More empirical studies are needed to understand, discover, and assess the role and impact of technology in mitigating the negative impact on the environment and mediating the relationship between society and ecology.	• To design and implement low carbon technologies (e.g., shared computing) • How technology (e.g., digital nudge) can inform and persuade consumer behaviours, such as shopping locally, consuming low-carbon foods, avoid food waste etc.)?
Translational research	Translation of optimisation models into practice through knowledge and technology transfer and implementation in real-world settings	• Develop guidelines, lessons learned, and tools for businesses and consumers • Evaluate the outcomes
Scaling	Conduct Green IS at a large scale and progress into Realisation	• Role of technology in different organisations and countries • Benefit evaluation of large-scale Green IS implementation

Research agenda	Description	Example research ideas
IS as SET systems	IS education and research from the Social-Ecological-Technical perspective to ensure ecologically and socially responsible design, use and disposal of technology.	• Further examine IS as SET systems and the complex interactions among the components • Integration of impact assessment into SET • Design and diffusion of future technologies should consider the SET perspective holistically • Examine cultural and socio-economic factors influencing the role and impact of technology

Table 4. Research Agenda for IS and Socio-Ecological-Technological Systems

6 Conclusion

This paper responds to the conference theme "Co-creating Sustainable Digital Futures", proposing an integrated SET and ESDT framework as a lens to understand the role and impact of IS on environmental sustainability in a systematic literature review of IS research efforts over the last 12 years. Our findings reveal three important themes: i) conceptualisation of Green IS as environmentally responsible IS, ii) majority of research addressing sustainability problems are in the energy and transport sectors which are significant sources of carbon emissions, and (iii) organisational and individual being the dominant levels of analysis. Using the SET and ESDT frameworks, the SLR reveals several gaps in the current literature and suggests research agendas for future IS research. Therefore, we contribute to the literature in Green IS by providing a cumulative account of research progress in response to the climate crisis.

Furthermore, our study extends the currently held views of IS as socio-technical and proposes a forward-thinking perspective of IS as socio-ecological-technical systems. Our application of SET calls for future studies to unpack the SET components and examine the complex interactions among them and their co-adaptations. For example, how Technology (IS) can mediate human and organisational sustainability behaviours i.e., the relationship between Society-Ecology worlds, how Society collectively mediates the dual relationships between the Technology-Ecology worlds. We also demonstrated an application of both SET and ESDT frameworks to explore the impact of co-adaptions of SET components in the digital past and present. In our future work, we will integrate these two frameworks to assess the impact of human, organisational and government interventions on the relationships. An integrated framework of SET and ESDT has the potential to view and examine the digital past, present, and futures as complex adaptive systems, where sub-systems react and co-adapt to the turbulence of the broader environment. Such a comprehensive framework will guide IS research and education towards co-creating socio-economically and environmentally sustainable futures mediated by digital technology.

There are several limitations. Firstly, to explore the use of SET and ESDT, the review previous research had a strong focus on CO_2e. Secondly, we searched only papers from leading IS journals and conferences where significant findings are more likely to be published. Thirdly, we excluded previous SLRs and opinion papers to look for original studies to examine SET and EDST perspectives. Opportunities exist to broaden the literature review with a wider range of sustainability aspects and to include more journals from IS and other disciplines, previous SLRs and opinion papers.

Appendix A Specified journals: European Journal of Information Systems, Information Systems Journal, Information Systems Research, Journal of Information Technology, Journal of Management Information Systems, Journal of Strategic Information Systems, Journal of the Association for Information Systems, MIS Quarterly, ACM Transactions on Computer-Human Interaction, Decision Support Systems, Information & Management, Information and Organization, Journal of the Association for Information Science and Technology, International Journal of Information Management

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