INFORMATION FLOWS IN CIRCULAR ECONOMY PRACTICES

Research paper

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Abstract

Recently, other disciplines and scientific communities discuss the Circular Economy paradigm as a key vehicle to establish more sustainable production and consumption patterns by decoupling economic output and emissions. Conversations about information system solutions for sustainable production and consumption, however, remain notably absent in the Information Systems research community. We develop a taxonomy of information flows relevant for the successful application of Circular Economy practices. Drawing on conceptual and empirical data, we categorized nine Circular Economy practices based on their underlying material flow networks and identified four classes of information flows that enable the proper functioning of these practices. Our work (a) provides a conceptual foundation for Circular Economy-related conversations within the Information Systems research community, (b) stimulates future solution-oriented Information Systems research for environmentally sustainable production and consumption, and (c) strengthens inter-disciplinary research.

Keywords: Circular economy, Material flows, Information flows, Green IS, Taxonomy development.

1 Introduction

Our society is living beyond the regenerative capacity of the biosphere (Lin et al., 2018; Wackernagel et al., 2002; Boyden and Dovers, 1992). Growing, resource-intensive, and mainly fossil-fuel-based material consumption patterns are considered as major drivers of global resource use and key contributor to increasing greenhouse gas emissions (Fleurbaey et al., 2014; Davis and Caldeira, 2010). Recently, the Circular Economy (CE) paradigm is discussed as a key vehicle to establish more sustainable production and consumption practices by decoupling economic output and emissions (Stål and Corvellec, 2018; Lazarevic and Valve, 2017; Ghisellini et al., 2016).

With the uptake of this debate in other scientific (e.g., Environmental Sciences), business, and policy-maker communities, we note comparable conversations about information systems (IS) roles for *CE practices* remain largely absent in the IS research community[1], a few notable exceptions aside (Klör et al., 2018; Seidel et al., 2018). Nonetheless, research on "Green IS" has repeatedly highlighted the IS solution potential for environmental sustainability issues by investigating the diverse IS roles for *sustainable energy* (cf., Ketter et al. (2016), Irani et al. (2015), Wagner et al. (2013), or Watson et al. (2010)), *mobility* (cf., Brendel et al. (2017), Marett et al. (2013), or Sonneberg et al. (2015)), and *organizational work practices* (cf., Degirmenci and Recker (2016), Corbett (2013), Seidel et al. (2013)).

We take steps to extend the IS solution potential towards *sustainable production and consumption practices*. Considering alarming consequences of unsustainable consumption behaviour, on the one hand side, and the scientific track record of Green IS research, on the other, we deem this so-far neglected sustainability phenomenon also relevant to the Green IS research community.

Our motivation for initiating this scholarly conversation is grounded, first, in the observation that information availability and flow play a critical role when establishing CE practices (Kirchherr et al., 2018; European Commission, 2014). For instance, pro-longing a product's life through repairing requires knowledge about its condition, location, and reparability. Second, recent advances in digital technology, such as sensor-based technologies to generate information, or predictive analytics that can utilise such information, provide opportunities to integrate information with material flows, which may exhibit great transformative power in CE application scenarios if leveraged appropriately (French and Shim, 2016).

Our goal is to examine how IS solutions can support, enable, or enact CE practices. Considering the absence of a comprehensive discussion of the CE paradigm in the IS research community as well as its systemic complexities, we believe the most opportune first step is to develop a taxonomy of critical information flows that are at the core of CE practices. Taxonomies reduce complexity and provide scholars a conceptual and structural basis from which advanced scientific discourse, for instance in form of new theories, can emerge (Nickerson et al., 2013). Consequently, the research question guiding the development of this taxonomy is:

RQ: *What information flows are relevant for the application of CE practices?*

We pursue three major goals with this work. First, our taxonomy introduces the CE paradigm and its central practices to IS scholars, providing a conceptual foundation for CE-related conversations within and across the boundaries of the IS research community. We achieve this goal by developing a conceptual lexicon describing the constituent components of the material flow networks underlying the CE practices. Second, we identify information flows that enable the proper application of CE practices and discuss an initial set of roles that IS might play to cater for these information flows. In that way, we hope to facilitate future solution-oriented IS research for environmentally sustainable production and consumption practices. Third, through the combination of the first two goals we attempt to strengthen inter-disciplinary research spanning other scientific communities and the IS field in the long-term, as specifically requested by Seidel et al. (2017) in their 'Sustainability Imperative in IS Research'.

We proceed as follows: Next, we introduce the concept of a CE, which will inform the initial dimensions and variables of our taxonomy. Furthermore, we offer a short account of the current state of Green IS

[1] In fact, querying the AIS Seniors' Scholars Basket with the keyword "circular economy" reveals the paradigm to be completely absent in leading IS journals.

research to assess the CE paradigm in light of existing knowledge. We collate a brief introduction and history of the taxonomy development method by Nickerson et al. (2013) in Section 3 and describe how this generic method was instantiated in this paper. Drawing on conceptual work from the Environmental Sciences as well as on empirical data on CE-driven business models and initiatives available online, we present the final taxonomy of information flows relevant for CE practices in Section 4. Before concluding, we discuss various future research trajectories – in form of general IS roles in a CE – emerging from the key findings of our taxonomy development.

2 Background

This paper introduces the CE paradigm into the existing Green IS body of knowledge. We use the first subsection to present the key concepts of the paradigm, relying on knowledge from the Environmental Sciences research community, and relate these concepts to existing research on environmentally sustainable IS in the second subsection.

2.1 Circular Economy

The CE is an economic model with the goal of minimizing resource input as well as waste, emission, and energy leakage by slowing, closing, and narrowing material and energy loops (Geissdoerfer et al., 2017; Kirchherr et al., 2017; Potting et al., 2016). This is purportedly realised through the useful application of materials at the end of their lifespan (i.e., *recovering* and *recycling*), an extended lifespan of products and their components (i.e., *remanufacturing*, *refurbishing*, *repairing*, and *reusing*), and a smarter product use and production (i.e., *reduce*, *rethink*, and *refuse*). These objectives and *practices* span the entire value chain (i.e., in sourcing, production, manufacturing, distribution, and use) and can be examined on a micro (e.g., individual producer and consumer), meso (e.g., organization, group, team, joint-ventures), and/or macro level (e.g., city, country, society).

Figure 1 illustrates how the different CE practices (e.g., *recycle*) help transform the traditional linear material flow, from sourcing to disposal (i.e., cradle-to-grave), into a circulating material flow, from sourcing to reuse (i.e., cradle-to-cradle).

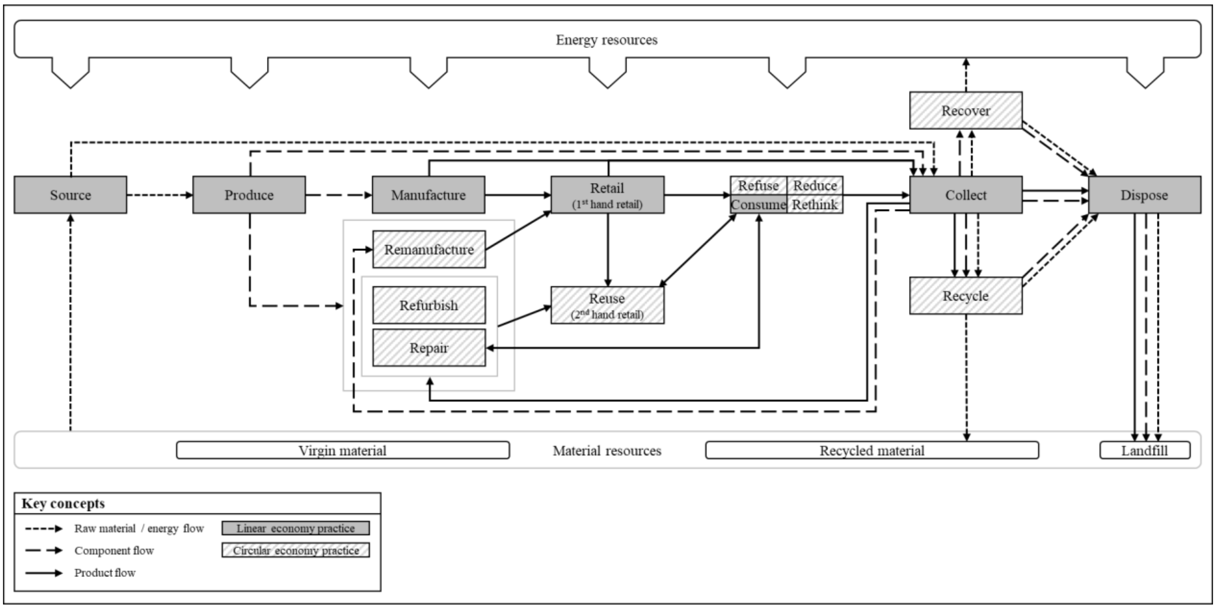

Figure 1. Conceptual model of a circular economy and its material flows

Throughout its development, several so-called 'R-frameworks' have been developed to describe the core practices of the CE (cf., van Buren et al. (2016), Sihvonen and Ritola (2015), or King et al. (2006)). These frameworks represent the holistic lifecycle view characteristic for the CE paradigm and provide a very tangible depiction of corresponding circulating material flows. We draw on Potting et al.'s 9-R-framework (2016) and the definitions by Kirchherr et al. (2017), as they represent the most nuanced and integrated conceptualizations to date (see Table 1).

CE Objective	**CE Practice**	**Description**
Smarter product use and production	R1 Refuse	Refuse product use by abandoning its function or consuming a radically different product with the same function
	R2 Rethink	Rethink product use to increase its utilization rate (e.g., through sharing or lending)
	R3 Reduce	Reduce energy and material resource consumption during product manufacture or use
Extended lifespan of products and their components	R4 Reuse	Reuse a discarded but still working product in good condition by another consumer
	R5 Repair	Repair a defective product to use it with its original function
	R6 Refurbish	Refurbish an old product and bring it up to date
	R7 Remanufacture	Remanufacture parts of discarded product in a new product
Useful application of materials at the end of their lifespan	R8 Recycle	Recycle materials to obtain the same or lower quality
	R9 Recover	Recover energy through incineration of materials

Table 1. R-framework, based on Potting et al. (2016) and Kirchherr et al. (2017)

2.2 Circular Economy in Information Systems Research

Research on IS for environmental sustainability has just celebrated its ten-year anniversary. While the *Green IT* research field – with its focus on IT energy efficiency and equipment utilization over its technology lifecycle (Watson et al., 2008) – is currently attracting comparably little scholarly interest, *Green IS* research – focusing on IS-enabled sustainability phenomena (Melville, 2010) – has persisted as relevant albeit niche topic in the IS research community (Elliot and Webster, 2017).

Despite the diversity of investigated sustainability phenomena (Sedera et al., 2017), we believe that the absence of a discussion of CE, one of the currently most debated topics in the Environmental Sciences (Geissdoerfer et al., 2017; Kirchherr et al., 2017), denotes a key shortcoming of the Green IS literature to date: searching the *AIS Senior's Scholar Basket* for the string "circular economy" yields no results at all; extending the review to proceedings of AIS conferences returned 13 research papers of which ten do not substantively deal with the CE paradigm. The remaining three conference papers are conceptual:

- Benedict et al. (2018) provide guidelines for developing an *Industrial Symbiosis Platform Ecosystem*;
- Schoormann et al. (2018) present design requirements and principles for a *sustainable business model* development tool; and
- Schrödl and Simkin (2014) integrate the CE paradigm with the *Supply Chain Operations Reference* (SCOR) model to create a blueprint for sustainable interorganizational eco-systems.

To substantiate our claim, we broadened our search criteria to also consider articles from AIS Senior's Scholar Basket that primarily address other sustainability phenomena[2] and which, upon reading, could be interpreted as implicitly addressing CE practices. We found two such papers:

[2] search strings: "green IS", "green IT", "sustainab*"; last query date: 18 Nov 2018.

- Seidel et al. (2018) provide design principles for sensemaking support systems stimulating individuals to eventually *refuse* existing consumption behaviour (e.g., drink from plastic cups) and *replace* them with more sustainable alternatives (e.g., drinking fountains) to cut down on waste;
- Klör et al. (2018) develop a decision support system for *remanufacturing* electric vehicle batteries.

In summary, we interpret the above presented current state of knowledge as insufficient in coverage yet promising in application. In our reading, the work to date hints at a lurking solution potential of IS for action-oriented pro-environmental behaviour on individual and organizational levels. However, the CE paradigm extends beyond Seidel et al. (2018) and Klör et al. (2018) with more principles to be supported.

3 Method

We developed a taxonomy of information flows in CE principles. The taxonomy provides two things: (a) a set of relevant conceptual components that uniquely form the nine CE practices introduced in Table 1 and (b) a set of recurrent information flows that are central for the successful application of the respective CE practices. With this work, we believe a foundation is set enabling us to theorise an initial set of roles that IS play during the deployment of CE practices in the end of this paper and invites other scholars to conduct future solution-oriented Green IS research for sustainable production and consumption.

A taxonomy is an empirically or conceptually derived set of dimensions and characteristics used to uniquely describe and classify real-world phenomena (Nickerson et al., 2013). While the first taxonomies originated in Biology to hierarchically classify living organisms (Sneath, 1995; Eldredge and Cracraft, 1980), the method diffused into the Social Sciences (Bailey, 1994) and Management Sciences (Doty and Glick, 1994). It, eventually, found its way into IS research and is, today, a well-established and accepted method for theory-building (Oberländer et al., 2018; Prat et al., 2015; Gregor, 2006; Bapna, 2004; Earl, 2001; Fiedler et al., 1996; Sabherwal and King, 1995).

We generated our taxonomy following Nickerson et al.'s (2013) method choosing the conceptual-to-empirical approach (Figure 2). With the Green IS research community as potential taxonomy user in mind, we defined the taxonomy's meta-characteristic as: *'information flows relevant for the application of CE practices'* (step 1). The iterative taxonomy development process was guided by the objective ending conditions proposed by Nickerson et al. (2013) (step 2). Regarding the subjective ending conditions (e.g., concise, robust, comprehensive, extendible, and explanatory), we actively balanced the conciseness and comprehensiveness conditions. While we initially started with four main dimensions (i.e., 'circulating good', 'involved stakeholder', 'activity', and 'information flow') and twelve subdimensions, we iteratively reduced it to three main dimensions (i.e., 'flow network', 'material objects', and 'information flow') and ten subdimensions. In the first iteration, we relied on concepts from the Environmental Sciences literature (e.g., Reike et al. (2018) or Kirchherr et al. (2017)) to derive the initial dimensions and characteristics of our taxonomy (step 3). We then classified real-world objects (Gregor, 2006) from a sample of 46 CE-driven business models and initiatives, which we identified from online public CE-databases[3], a digital sustainability platform[4], and from press releases of an annual green start-up competition[5] (step 4). The cases were included in the sample, if their business model or initiative could be clearly linked to one or more CE principles and sufficient information was available online as input for the empirical analysis part of our taxonomy development. We stopped our online research, once we reached saturation of insights (i.e., new real-world objects did not add new details to already identified real-world objects in the same CE practice). The development process was iterated six times until the taxonomy met the predefined objective and subjective ending conditions (step 5).

[3] Circle Lab Knowledge Hub and Circular Economy 100

[4] Reset

[5] Green Alley Award

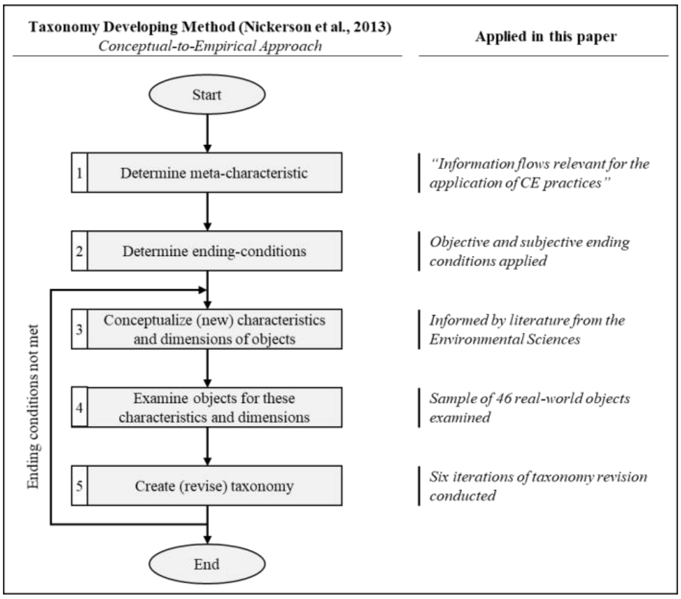

Figure 2. Taxonomy developing method applied in this paper, following Nickerson et al., 2013

4 Information Flows in Circular Economy Practices

We now present the outcomes of our taxonomy development process in Table 2. The final taxonomy covers all nine CE practices, displayed in the table columns, and consists of three main dimensions, structured in the table rows. The first two dimensions represent constituent components of the physical world, with several sub dimensions each, which instantiate differently for each CE practice: a **flow network** and **material objects**. The third dimension categorizes the **information flows** that enable a successful application of CE practices. These information flows are grouped into four sub dimensions. In what follows, we define each dimension and present the results of our classification process.

4.1 Flow Network

We define a CE flow network as a *heterogenous set of connected but spatially distributed actors between whom the material objects move with or without changing the ownership*. If involved, the actors either represent the origin (cf., start of an arrow in Table 2) or destination (cf., end of an arrow in Table 2) of a material flow. As depicted in the conceptual CE model in Figure 1, actors in the CE processes comprise producers, manufacturers, retailers, repairers, consumers, collectors, recyclers, and incinerators.

As a result of the classification of real-world objects, we specified three types of flow networks: peer-to-peer (P2P), peer-to-business (P2B), and business-to-business (B2B). **Peer-to-peer flow networks** emerge from transactions created between peers (e.g., *Drivy*), **peer-to-business flow networks** involve transactions between consumers and organizations (e.g., *Patagonia*), and **business flow networks** characterise themselves by transactions between individuals and businesses (e.g., *Car2Go*).

Furthermore, we identified various manifestations of material flows: For instance, in peer-to-peer *reuse*-cases (e.g., *LoopRocks*) we observe **single one-way material flows** (i.e., a used product flows from one consumer to another consumer), in business-to-business *remanufacture* cases (e.g., *Vege*) we see **multiple one-way material flows** (i.e., a used component flows from a collector and a new component flows from a producer to a manufacturer), and in peer-to-business *repair* cases (e.g., *clickrepair*) we identified **multiple one-way** (i.e., a new component, the spare part, flows from a retailer to a repairer**) and return** (i.e., a used, defective product flows from a consumer to a repairer and back) **material flows**. Both peer-to-peer and peer-to-business *rethink* cases (e.g., *Style Lend* or *Vigga*), where products are shared and lend among several users, are special cases of **continuous material flows**. We also observe CE practices with **no material flow** at all. These include situations, where an actor refuses to consume or alters the handling or use of a previously acquired (i.e., already flowed) material object.

Circular Economy Practices

Dimension	Subdimension	Characteristic	Refuse	Rethink		Reduce	Reuse		Repair		Refurbish	Remanufacture	Recycle	Recover
Flow network	Type	P2P		x			x		x					
		P2B			x			x		x				
		B2B								x	x	x	x	x
	Actors	Producer								a. ●	●	●		
		Manufacturer									↑ ↓	↑ ↓		
		Retailer			a. ● b. ↑			●	●					
		Repairer								a. ↑ ↓ b. ●				
		Consumer x		a. ● b. ↑	a. ↓ b. ●		●	↓	↓	a. ● b. ↓				
		Consumer y		a. ↓ b. ●			↓							
		Collector									●	●	● ● ●	● ●
		Recycler											↓ ↓ ↓	
		Incinerator												↓ ↓
	Change of ownership						x	x	x	x	x	x	x	x
Material objects	Product ●⟶|	Used		x	x		x	x		x	x		x	
		New												
	Component ●- -▸|	Used										x	x	x
		New							x	x	x	x		
	Raw material ●----▸|	Used											x	x
		New												
Information flows	Market	Supply/Demand		x	x		x	x	x	x	x	x	x	x
	Actor	Location		(x)			(x)			x				
		Availability		(x)			(x)			x				
		Behaviour		x	x					x				
	Material object	Properties	x	x	x	x	x	x	x	x	x	x	x	x
		Location		x	x		x	x	x	x	x	x	x	x
		Utilization		x	x									
		Condition		(x)	(x)	x	x	x	x	x	x	x	x	x
	Activity	Use	x	x	x	x								
		Transformation							x	x	x	x	x	x
Real-world objects (Circular Economy-driven business models or initiatives)			*- codecheck - ecoGator - Evocco - LoopedGoods - ToxFox*	*- Airbnb - Car2Go - Drivy - Nebenan.de - Neighbourly - Nextdoor - peerby - Style Lend*	*- Bundles - Gerrard Street - Grover - Readymade Furniture - Vigga*	*- GreenMeter - Nest Mobile*	*- Kleiderkreisel - LoopRocks - Nebenan.de - Neighbourly - Nextdoor - peerby - Restado - The Next Closet*	*- kaputt.de - Patagonia*	*- Fairphone - ifixit - kaputt.de - Patagonia - Shiftphone*	*- clickrepair - kaputt.de - ReplaceDirect - Twindis - veloyo*	*- Amazon Renewed - Circular Computing - MUD Jeans - refurbed - RICOH*	*- Excess Materials Exchange - Roetz Fair Factory - Van Hulley - Vege*	*- binee - Dutch Awearness - renewi - Scrap Connection - Wasted*	*- plethora of 'waste-to-energy' or 'energy-from-waste' cases*

Table 2. Taxonomy of information flows in circular economy practices

Finally, dynamic ownership structures create an additional layer of complexity. While *refuse*, *rethink*, and *reduce* practices do not involve any **change of ownership**, the remaining practices all come with a proprietary ownership change.

4.2 Material Objects

We define a material object in a CE as a *physical artefact, whose life and use are extended and intensified, respectively, through the application of CE practices*. Material objects are purposefully created from virgin or recycled material resources and, over their lifetime, circulated between and owned by one or more actors. Every material object, therefore, (a) requires input of material resources in the beginning of its life, (b) requires energy input for material transformation, transportation, and utilization during its life, and (c) causes waste emissions at the end of its life.

In our taxonomy, we classify material objects according to their level in the **product hierarchy** and **utilization history**. Based on the analysis of real-world objects (i.e., CE-driven business models or initiatives), we specified the product hierarchy into **products**, **components**, and **raw materials** and the utilization history into **used** and **new**. A product decomposes into two or more components and a component consists of one or more processed raw materials. Please note that we consider repair tools as products and spare parts as components. We call (a) a raw material "new", if it is sourced from virgin material resources, (b) a component "new", if it is freshly produced from raw material, and (c) a product "new", if it only consists of new components and was never used by an actor before. Contrasting, our understanding of "used" material objects logically establishes as negated definitions of "new" material objects.

We observe that most of the CE practices involve the **movement of used products**, for instance, in peer-to-peer or business *reuse* (i.e., second hand retailing) and *rethink* (i.e., sharing and lending) cases (e.g., *The Next Closet* and *Bundles*, respectively). In addition, the CE practices *repair* (e.g., *kaputt.de*), *refurbish* (e.g., *Circular Computing*), and *remanufacture* (e.g., *Roetz Fair Factory*) characterise themselves by the **movement and combination of used and new material objects**, including both products and components. The case for moving material objects on all hierarchy levels, including raw materials, can be found in *recycle* (e.g., *binee*) and *recovery* (i.e., *waste-to-energy*) practices, which form the "last resort" in a material object's life cycle.

4.3 Information Flows

So far, the developed taxonomy classifies main components of the underlying material flow networks that uniquely constitute a CE practice. Recalling the target users and the meta-characteristics of the taxonomy, we extended it in a second step to include recurrent information flows that are critical enablers of these practices. Building on literature on data and information quality (cf., Boritz (2004), Bovee (2004), Lee et al. (2002), or Wang and Strong (1996)) we define **information** as *structured data, which is accurate, relevant, timeliness, complete, and accessible to actors*. We talk of an **information deficit** in *situations where structured data is either unavailable or available in poor quality* (e.g., lack of accuracy, relevance, timeliness, completeness, accessibility).

In our sample of real-world objects, we identified four classes of information flows that are critical for the successful application of CE practices: **market**, **actor**, **material object**, and **activity-related information flows**. In the following subsections, we introduce these classes, describe their specifying characteristics, and explain why they are critical for the application of CE practices.

4.3.1 Market-related Information Flows

Market-related information flows concern the availability of structured data about **supply and demand of material objects**. They represent a prevalent information flow class among the investigated CE practices in our sample. Except for *refuse* and *reduce*, all other practices critically rely on market-related information.

The market-related information flows are critical as their absence increases **ex-ante transaction costs** (UNEP, 2016; World Economic Forum, 2016). In particular, these costs add up from **initiation costs** (e.g., search for available quantities of specific circulating material objects, for instance, spare parts or used components) and **agreement costs** (i.e., short-term individual ad-hoc contracting dominates long-term general agreement contracting). Initiating and agreeing on a transaction is particularly cumbersome in secondary or shared markets (i.e., flow networks with used or shared material objects), where supply and demand are spatially scattered and temporally asynchronous and irregular (Wilts and Berg, 2017).

Deficient market-related information, eventually, lead to two outcomes in CE practices: First, the absence of information about supply and demand of circulating material objects entirely prohibits markets to find the optimal allocation of secondary resources (i.e., no transaction takes place). Second, available poor-quality information prohibits secondary resource markets in the long-term, as their inefficient cost structures are not competitive with the cost structures of alternative primary resource markets.

4.3.2 Actor-related Information Flows

Actor-related information flows concern structured data about **location**, **availability**, and **behaviour of an actor** involved in a flow network. This class of information is especially relevant for CE practices that rely on an actor's physical participation, either in transportation, transformation, or utilization of material objects.

We observed the importance of the information in our sample for *rethink* and *reuse* practices in peer-to-peer flow networks as well as in *repair* practices in peer-to-business flow networks. For instance, *Style Lend*, a peer-to-peer sharing platform for female designer fashion, requires the lending actor (or an organised deputy) to be physically available for pick-up of the shared material object (i.e., clothing) by the borrowing actor. Another example is *kaputt.de*, a mobile phone repair platform, that relays repair services of repair professionals to end consumers with defective mobile phones. These CE practices would fail because no agreement on the spatial and temporal terms of the physical settlement would be achieved in the absence of location (i.e., spatial), availability (i.e., temporal), and behaviour (i.e., service quality) information on involved actors.

The above-mentioned examples represent a recurrent pattern implying that deficient actor-related information increase **ex-post transaction costs**. The uncertainties resulting from actors' physical participation in the flow network drive **handling costs** (e.g., transportation), **adjustments costs** (e.g., changing temporal availability of involved actors), and **control costs** (e.g., quality assurance) (Kirchherr et al., 2018). Especially in the observed peer-to-peer (e.g., *Airbnb*) or peer-to-business (e.g., *kaputt.de*) flow networks, where the utilization (e.g., housing) or transformation (e.g., repairing) of material objects (e.g., flats or mobile phones) requires the active involvement of actors (e.g., house lenders or repairers), the presence of actor-related information is critical for the entire CE practice.

4.3.3 Material Object-related Information Flows

Material object-related information flows concern structured data about **properties**, **utilization**, **location** or **condition of material objects**. Like market-related information flows, this class is prevalent among various CE practices. However, during the empirical analysis of our real-world sample, we identify a more heterogenous set of enablement patterns of object-related information in CE practices.

First, the critical information about **properties of material objects** affects all CE practices. To name a few, information on dimensional properties (e.g., size) enable CE practices relying on transportation of material objects (e.g., *reuse*). Furthermore, information on material properties (e.g., ingredients) is crucial in (a) *refuse* and *reduce* practices educating private actors (i.e., consumers) to achieve pro-environmental consumption behaviour change (e.g., *Evocco*) and (b) *remanufacturing* and *refurbishing* practices guiding institutional actors (i.e., business) to transform material objects and extend their lifespan.

Second, information about the **utilization of material objects** support *rethink* practices where the core principle of shared resource utilization, essentially, relies on information-based and real-time coordination. For instance, *Car2Go* coordinates the shared utilization of its material objects (i.e., cars) based on information about future (i.e., reservation), current (i.e., rental), and past (i.e., rental history) utilization by actors.

Third, information about the **location of material objects** is especially important for the application of any CE practices that involve the movement of material objects. These practices comprise *rethink* (i.e., sharing) scenarios relying on spatial information for utilization of products (e.g., *Readymade Furniture*) and *reuse*, *repair*, *refurbish*, *remanufacture*, *recycle*, and *recover* scenarios relying on spatial information for transportation of products (e.g., *Patagonia*), components (e.g., *Twindis*), or raw materials (e.g., *Scrap Connection*).

Fourth, information about the **condition of material objects** is enabling CE practices that include a change of ownership of a material object or a dependence of an actor on the proper utilization of a material object's functionality. A change of ownership increases the financial risk involved in the transaction and incurs opportunity costs due to forgoing primary market alternatives. Among our set of CE practices, *reuse*, *repair*, *refurbish*, *remanufacture*, *recycle*, and *recover* represent scenarios with ownership changes, either on product (e.g., *Loop Rocks*), component (e.g., *RICOH*), or raw material (e.g., waste-to-energy cases) level. If a CE practice (e.g., *Drivy*) involves the utilization of a material object (e.g., driving), the utilizing actor expects the functionalities provided by the material object (e.g., breaking) to be in a proper and working condition.

Summarizing the previously mentioned examples, we state that material object-related information deficits (a) increase the **ex-ante transaction costs** (i.e., initiation costs), (b) increase **ex-post transaction costs** (i.e., handling costs, adjustment costs, and control costs), and (c) hinder **transaction-free and material flow-free CE practices** (i.e., *refuse* and *reduce*), thereby, decreasing the probability of stimulating pro-environmental behaviour change (e.g., foregoing consumption).

4.3.4 Activity-related Information Flows

Activity-related information flows concern structured data about **instructions on using and transforming material objects**. We consider this class of information flows separately from the other classes as it does not directly enable market (cf., Section 4.2.1) or flow network-related (cf., Section 4.2.2 and Section 4.2.3) mechanisms in a CE practice. Instead, it is crucial in practices that induce actors to act on material objects directly.

Some practices aim to alter the **use of material objects** to spur eco-effective (i.e., *refuse*) or eco-efficient (i.e., *reduce*) consumption behaviour. Here, real-world objects in our sample (e.g., *Evocco* or *Nest Mobile*) provide actors (i.e., consumers) with specific information on how to change for the environmental better (e.g., consumption of alternative products or adapted heating behaviour).

Other practices require active participation of actors **transforming material objects** to extend their lifespan (i.e., *repair*, *refurbish*, *remanufacture*) or extract value from their end-of-life (i.e., *recycle*, or *recover*). All transformations require information on how to achieve this, for instance, repair and dismantling instructions for a material object or a list of required tools.

Abstracting from our sample of real-world objects, we state that activity-related information generates knowledge that enables (a) individuals to develop pro-environmental consumption behaviour through transaction-free and material flow-free CE practices and (b) organizations to establish business operations that transform material objects in a sustainable manner.

5 Discussion

5.1 Summary of Findings

We developed a taxonomy of information flows that enable CE practices. We see that all physical components (cf., Sections 4.1 and 4.2) are themselves important information carriers that might play a crucial role in the successful application of CE practices (cf., Section 4.3). To summarise, the taxonomy highlights that information about:

- Supply and demand of material objects is relevant in CE practices that intend to exchange material objects across the boundaries of two actors;
- Location and availability of actors is relevant in CE practices that require a personal involvement of actors in exchanging material objects;
- Properties and condition of material objects are relevant input for all CE practices;
- Location of material objects is relevant in CE practices that involve moving material objects;
- Utilization of material objects is relevant for CE practices that involve sharing material objects;
- Instructions on using material objects is relevant in CE practices that aim to achieve a change in actors' consumption behaviour; and
- Instructions on transforming material objects is relevant in CE practices that require actors' active involvement in changing the properties and the condition of material objects.

Considering "information as a resource" in a CE context, our analysis specified *what* classes of information affect which CE principles and where this information arises from. This contributes a basis to speculate *how* IS should collect, process, and disseminate the data and information for CE practices.

5.2 Potential Roles of Information Systems in a Circular Economy

We discuss the implications of our taxonomy development in terms of three potential roles that IS can assume to enable the application of CE principles. To stimulate future research on these roles, we provide initial starting points in existing IS research.

5.2.1 Information Systems for Sensemaking

A **sensemaking information system** (SMIS) for CE practices supports individual or organizational actors in comprehending, explaining, and predicting (Seidel et al., 2013; Starbuck and Milliken, 2006; Weick et al., 2005) their current consumption or sourcing, production, and distribution behaviour, respectively.

Successfully involving consumers in CE practices remains to be a challenging endeavour. Environmental Sciences' literature on barriers to sustainable consumption practices collectively reports on missing consumers' awareness and acceptance (Camacho-Otero et al., 2018; Kirchherr et al., 2018; European Commission, 2014). Consequently, a SMIS for individual sustainable consumption practices should act as **educator**, **motivator**, **persuader**, and **decision supporter** enabling actors to make sense of smarter use and lifespan extension of material objects. Our taxonomy points out, that the SMIS, therefore, will rely on information about the **properties** (e.g., hazardous materials) and **conditions** (e.g., historical information about supply chain activities) of material objects and present (i.e., disseminate) it to the right actor in the right moment.

Future research can tap into two types of already existing Green IS research streams, dealing with individual behaviour change enabled through IS: First, the well-established concept of **IS-enabled sensemaking** (cf., Baber et al. (2016), Sandberg and Tsoukas (2015), Klein and Moon (2006), Boland Jr. (1984)), nowadays, functions as robust theoretical foundation in Green IS research as well (Seidel et al., 2018; Seidel et al., 2013). The process-oriented nature of this concept (Weick et al., 2005) supports IS research in designing and developing IS for sensemaking of environmental phenomena on the individual and organizational level. Second, scholars have paired theoretical knowledge from the Psychology discipline on pro-environmental behaviour (Steg and Vlek, 2009; Bamberg and Möser, 2007) with IS research on the design of persuasive technology (Oinas-Kukkonen and Harjumaa, 2009) to investigate **persuasive environmental sustainability systems** (Brauer et al., 2016; Dahlinger and Wortmann, 2016; Shevchuk and Oinas-Kukkonen, 2016; Mustaquim and Nyström, 2014). Knowledge from this research could essentially also inform design principles for SMISs for CE practices.

5.2.2 Information Systems for Matchmaking

A **matchmaking information system** (MMIS) for CE practices supports individual and organizational actors in (a) searching and comparing supply and demand of material objects and (b) negotiating and contracting terms and conditions of the intended transaction. Such an information system is valuable for CE practices that include a change of ownership or the shared utilization of material objects.

Exchanging material objects in secondary or shared markets is challenging as supply and demand are spatially scattered and temporally asynchronous, irregular, and discrete (Berg and Wilts, 2018; Camacho-Otero et al., 2018). In such a context, an MMIS acts as **transparency creator**, **complexity reducer**, **trust builder**, and **legal advisor**. It, therefore, organises information about the involved **actors' behaviour** (e.g., previous transaction fulfilment reliability rating) and the **properties** and **conditions** (e.g., quality, size, ingredients) of the exchanged or shared material objects (cf., Table 2).

Future research on MMIS can draw on valuable knowledge from the **Energy Informatics** research stream (cf., Slavova and Constantinides (2017), Ketter et al. (2016), Goel (2015), Goebel et al. (2014). Its central objective is to analyse, design, and implement "systems to increase the efficiency of energy demand and supply systems […] [based on the] collection and analysis of energy data" (Watson et al., 2010, p. 24). However, this knowledge reference should be established with caution as there exist some crucial differences between **primary commodity resource markets** (e.g., electric energy market) and **secondary material markets** (e.g., market for reused construction materials): Commodity resource demand and supply systems for primary markets trade homogeneous material objects (e.g., oil, electric energy) in high, continuous frequencies and handle the fulfilment in established, specialised technical infrastructure systems (e.g., oil pipelines or transmission grids). Demand and supply systems for secondary markets, instead, trade heterogeneous material objects (e.g., second-hand windows or mortar) in low, discrete frequencies and handle the fulfilment in ad-hoc sociotechnical infrastructure systems (e.g., individual motorised transportation systems).

These differences come with implications for the design of MMIS for CE practices that are not entirely clear, yet. Future research should evaluate what we can learn from the established Energy Informatics research stream, what must be adapted to the CE context, and what requires completely new approaches.

5.2.3 Information Systems for Task Support

A **task-supporting information system** (TSIS) for CE practices enables individual and organizational actors in transforming a material object to extend its lifespan or the lifespan of its components and raw materials. CE practices that include material object transformation expect an active involvement of actors in complex and cognitively challenging tasks, for instance, repairing a smartphone or recycling production waste.

Drawing on empirical observations from our sample of real-world objects, we suggest conceptualizing the underlying tasks of transformational CE practices as a process chain. To illustrate this, a repair scenario (e.g., *kaputt.de*, *ifixit*, *Fairphone*) would consist of (a) defect identification (e.g., defective charger socket), (b) solution alternatives selection (e.g., repair-it-yourself, professional repair service, replacement/disposal), and (c) selected alternative execution. In such a context, the TSIS acts as **motivator**, **complexity reducer**, **decision supporter**, and **procedural instructor**. Considering our taxonomy of information flows, a TSIS organises and provides **activity-related** information, such as repair and dismantling instructions, cost estimation, or a list of required tools.

We suggest, future IS research on TSIS to start with existing knowledge on **persuasive systems design (PSD)** (cf., Oinas-Kukkonen and Harjumaa (2009)) and **mobile cyber-physical systems (CPS)** (cf., Khaitan and McCalley (2015), Hu et al. (2013), Wu et al. (2011)): we consider (a) PSD as relevant, as the main objective of TSIS, essentially, comprises the goal-oriented and computer-aided execution of complex tasks (e.g., repair), and (b) CPS as relevant, as at the core of these tasks is a physical object (e.g., smartphone) carrying activity-related information (e.g., defect information) itself.

5.3 Limitations

Our work is beset with limitations that should not be ignored:

First, we based our taxonomy development on a purposive sample of real-world objects, which does not entail all objects potentially part of CE-driven business models or initiatives. Moreover, our sample exhibits a bias towards small to medium-sized enterprises and service providers and lacks cases from large, established manufacturing enterprises (except for *Patagonia*), thereby limiting the generalisability of our taxonomy. Reasons for this bias are twofold: it might be (a) grounded in a bias of the public databases we used to collect the CE cases from, whilst (b) correctly reflecting a possible population bias (i.e., large manufacturing enterprises are less inclined to participate in a CE). We followed the guidelines for making our taxonomy adaptable (Nickerson et al., 2013), so that it can in future research be applied to a larger dataset that specifically considers established enterprises. Another outstanding activity is theory-testing qualitative empirical research (e.g., case studies) to challenge and refine the current taxonomy.

Second, we did not detail the role of third-party platform providers and collectors in our taxonomy. Both seem to contribute what could be labelled a coordinating function to a CE: the collector as physical and the platform provider as digital broker. It remains unclear, how these powerful functions enable or hinder the development of CE practices and how IS can support these functions.

Third, we did not yet assess the potentials of digital technologies for the collection and processing of data (e.g., internet of things, machine learning). What classes of information (cf., Section 4.3) can be collected via which sensor types? How does the level of IS-automation affect the CE practice? Our taxonomy provides a good starting point to theorise about these potentials for the three IS roles in a CE.

Fourth, deconstructing the CE practices into flow networks and material objects and identifying relevant information flows applies a technical lens to the phenomenon. Recent conversations in established CE discourses, however, demand the inclusion of social elements and business perspectives in CE-related research (Reike et al., 2018; Bocken et al., 2017). As our taxonomy essentially classifies CE-driven business models and initiatives, we see an opportunity to further this research trajectory by linking our findings to the social business context.

6 Conclusion

The purpose of our paper was to identify and categorize relevant information flows that enable nine CE practices forming the core of the CE paradigm. Based on this analysis, we discussed an initial set of IS roles in a CE. We contribute a taxonomy that supports the classification and analysis of CE business models and initiatives and the identification of relevant information flows underlying these practices.

Our taxonomy allows deconstructing the complexity of the nine CE practices to two constituent components of the physical world: flow networks (i.e., spatially distributed actors with demand and supply requirements) and material objects (i.e., physical artefacts, whose life and use are extended and intensified by CE practices). Both constituent components carry important information classes (i.e., market, material object, actor, or activity-related information) that enable the CE practices differently.

Our taxonomy is deliberately situated at a general, abstract level to facilitate wide applicability in future solution-oriented IS research for environmentally sustainable production and consumption practices. It allows both the Green IS and IS design science communities to (a) better structure and analyse the problem and requirements space of CE practices and (b) better design suitable and impactful solution-oriented artifacts for sustainable production and consumption practices (Venable, 2006).

Another goal of our work was to introduce the concepts of sustainable production and consumption and CE into the scholarly conversation of the IS community. Both are timely and intensely debated ideas in other fields that have not yet really entered our own discourse yet. We believe, and expanded on this belief, that IS theory and artefacts can play a focal role in both areas, which in turn allows solution-oriented IS research to become a referent discipline to the emerging discourse in other academic fields.

References

Baber, C., S. Attfield, G. Conway, C. Rooney and N. Kodagoda (2016). "Collaborative sense-making during simulated Intelligence Analysis Exercises" *International Journal of Human-Computer Studies* 86, 94–108.

Bailey, K. D. (1994). *Typologies and taxonomies*. *An introduction to classification techniques*. Thousand Oaks, Calif.: SAGE.

Bamberg, S. and G. Möser (2007). "Twenty Years After Hines, Hungerford, and Tomera: A new Meta-analysis of Psycho-social Determinants of Pro-environmental Behaviour" *Journal of Environmental Psychology* 27 (1), 14–25.

Bapna, R. (2004). "User heterogeneity and its impact on electronic auction market design: An empirical exploration" *MIS Quarterly* 28 (1), 21–43.

Benedict, M., L. Kosmol and W. Esswein (2018). "Designing Industrial Symbiosis Platforms – from Platform Ecosystems to Industrial Ecosystems" *PACIS (Pacific Asia Conference on Information Systems (PACIS) 2018 Proceedings)*.

Berg, H. and H. Wilts (2018). "Digital platforms as market places for the circular economy—requirements and challenges" *NachhaltigkeitsManagementForum | Sustainability Management Forum*, 1–9.

Bocken, N. M. P., E. A. Olivetti, J. M. Cullen, J. Potting and R. Lifset (2017). "Taking the Circularity to the Next Level: A Special Issue on the Circular Economy" *Journal of Industrial Ecology* 21 (3), 476–482.

Boland Jr., R. J. (1984). "Sense-Making of Accounting Data as a Technique of Organizational Diagnosis" *Management Science* 30 (7), 868–882.

Boritz, J. E. (2004). *Managing enterprise information integrity*. *Security, control, and audit issues*. Rolling Meadows, Ill.: IT Governance Institute.

Bovee, M. W. (2004). *Information quality: a conceptual framework and empirical validation*. *PhD thesis:* University of Kansas.

Boyden, S. and S. Dovers (1992). "Natural-Resource Consumption and Its Environmental Impacts in the Western World. Impacts of Increasing per Capita Consumption" *Ambio* 21 (1), 63–69.

Brauer, B., C. Ebermann and L. Kolbe (2016). "An Acceptance Model for User-Centric Persuasive Environmental Sustainable IS" *International Conference on Information Systems (ICIS) 2016 Proceedings*.

Brendel, A. B., S. Lichtenberg, I. Nastjuk and L. Kolbe (2017). "Adapting Carsharing Vehicle Relocation Strategies for Shared Autonomous Electric Vehicle Services" *International Conference on Information Systems (ICIS) 2017 Proceedings*.

Camacho-Otero, J., C. Boks and I. Pettersen (2018). "Consumption in the Circular Economy: A Literature Review" *Sustainability* 10 (8), 2758–2782.

Corbett, J. (2013). "Designing and Using Carbon Management Systems to Promote Ecologically Responsible Behaviors" *Journal of the Association for Information Systems* 14 (7), 339–378.

Dahlinger, A. and F. Wortmann (2016). "Fostering Pro-Environmental Behavior with Green Consumer IS: The Effects of IS-Induced Construal and General IS Usage Motivations" *European Conference on Information Systems (ECIS) 2016 Proceedings*.

Davis, S. J. and K. Caldeira (2010). "Consumption-based accounting of CO2 emissions" *Proceedings of the National Academy of Sciences of the United States of America* 107 (12), 5687–5692.

Degirmenci, K. and J. Recker (2016). "Boosting Green Behaviors through IS that Enable Environmental Sensemaking" *International Conference on Information Systems (ICIS) 2016 Proceedings*.

Doty, D. H. and W. H. Glick (1994). "Typologies as a Unique Form of Theory Building: Toward Improved Understanding and Modeling" *Academy of Management Review* 19 (2), 230–251.

Earl, M. (2001). "Knowledge Management Strategies: Toward a Taxonomy." *Journal of Management Information Systems* 18 (1), 215–233.

Eldredge, N. and J. Cracraft (1980). *Phylogenetic patterns and the evolutionary process.* New York: Columbia University Press.

Elliot, S. and J. Webster (2017). "Editorial: Special issue on empirical research on information systems addressing the challenges of environmental sustainability: an imperative for urgent action" *Information Systems Journal* 27 (4), 367–378.

European Commission (2014). *Scoping Study to Identify Potential Circular Economy Actions, Priority Sectors, Material Flows & Value Chains*. *Final Report.* European Union.

Fiedler, K. D., V. Grover and J. T.C. Teng (1996). "An Empirically Derived Taxonomy of Information Technology Structure and Its Relationship to Organizational Structure" *Journal of Management Information Systems* 13 (1), 9–34.

Fleurbaey, M., S. Kartha, S. Bolwig, Y. L. Chee, Y. Chen, E. Corbera, F. Lecocq, W. Lutz, M. S. Muylaert, R. B. Norgaard, C. Okereke and A. Sagar (2014). "Sustainable development and equity" *Climate Change 2014: Mitigation of Climate Change. IPCC Working Group III Contribution to AR5*, 283–350.

French, A. M. and J. P. Shim (2016). "The Digital Revolution. Internet of Things, 5G and Beyond" *Communications of the Association for Information Systems* 38, 840–850.

Geissdoerfer, M., P. Savaget, N. M.P. Bocken and E. J. Hultink (2017). "The Circular Economy – A new Sustainability Paradigm?" *Journal of Cleaner Production* 143, 757–768.

Ghisellini, P., C. Cialani and S. Ulgiati (2016). "A Review on Circular Economy. The Expected Transition to a Balanced Interplay of Environmental and Economic Systems" *Journal of Cleaner Production* 114, 11–32.

Goebel, C., H.-A. Jacobsen, V. del Razo, C. Doblander, J. Rivera, J. Ilg, C. Flath, H. Schmeck, C. Weinhardt, D. Pathmaperuma, H.-J. Appelrath, M. Sonnenschein, S. Lehnhoff, O. Kramer, T. Staake, E. Fleisch, D. Neumann, J. Strüker, K. Erek, R. Zarnekow, H. Ziekow and J. Lässig (2014). "Energy Informatics. Current and Future Research Directions" *Business & Information Systems Engineering* 6 (1), 25–31.

Goel, S. (2015). "Anonymity vs. Security: The Right Balance for the Smart Grid" *Communications of the Association for Information Systems* 36 (1), 23–32.

Gregor, S. (2006). "The nature of theory in information systems" *MIS Quarterly* 30 (3), 611–642.

Hu, X., T. H. S. Chu, H. C. B. Chan and V. C. M. Leung (2013). "Vita: A Crowdsensing-Oriented Mobile Cyber-Physical System" *IEEE Transactions on Emerging Topics in Computing* 1 (1), 148–165.

Irani, Z., J. Jimenez, H. Lee, A. Martin, V. Molendini, R. Rascazzo, N. Savino and U. Sivarajah (2015). "A Decision Support System for Fostering Smart Energy Efficient Districts" *Americas Conference on Information Systems (AMCIS) 2015 Proceedings*.

Ketter, W., M. Peters, J. Collins and A. Gupta (2016). "A Multiagent Competitive Gaming Platform to Address Societal Challenges" *MIS Quarterly* 40 (2), 447–460.

Khaitan, S. K. and J. D. McCalley (2015). "Design Techniques and Applications of Cyberphysical Systems: A Survey" *IEEE Systems Journal* 9 (2), 350–365.

King, A. M., S. C. Burgess, W. Ijomah and C. A. McMahon (2006). "Reducing Waste. Repair, Recondition, Remanufacture or Recycle?" *Sustainable Development* 14 (4), 257–267.

Kirchherr, J., L. Piscicelli, R. Bour, E. Kostense-Smit, J. Muller, A. Huibrechtse-Truijens and M. Hekkert (2018). "Barriers to the Circular Economy: Evidence from the European Union (EU)" *Ecological Economics* 150, 264–272.

Kirchherr, J., D. Reike and M. Hekkert (2017). "Conceptualizing the Circular Economy. An Analysis of 114 Definitions" *Resources, Conservation and Recycling* 127, 221–232.

Klein, G. and B. Moon (2006). "Making sense of sensemaking 1: Alternative perspectives" *IEEE Intelligent Systems* 21 (4), 70–73.

Klör, B., M. Monhof, D. Beverungen and S. Braäer (2018). "Design and evaluation of a model-driven decision support system for repurposing electric vehicle batteries" *European Journal of Information Systems* 27 (2), 171–188.

Lazarevic, D. and H. Valve (2017). "Narrating expectations for the circular economy: Towards a common and contested European transition" *Energy Research & Social Science* 31, 60–69.

Lee, Y. W., D. M. Strong, B. K. Kahn and R. Y. Wang (2002). "AIMQ: A methodology for information quality assessment" *Information & Management* 40 (2), 133–146.

Lin, D., L. Hanscom, A. Murthy, A. Galli, M. Evans, E. Neill, M. Mancini, J. Martindill, F.-Z. Medouar, S. Huang and M. Wackernagel (2018). “Ecological Footprint Accounting for Countries: Updates and Results of the National Footprint Accounts, 2012–2018” *Resources* 7 (3), 58–79.

Marett, K., R. F. Otondo and G. S. Taylor (2013). “Assessing the Effects of Benefits and Institutional Influences on the Continued Use of Environmentally Munificent Bypass Systems in Long-Haul Trucking” *MIS Quarterly* 37 (4), 1301–1312.

Melville, N. P. (2010). “Information Systems Innovation for Environmental Sustainability” *MIS Quarterly* 34 (1), 1–21.

Mustaquim, M. and T. Nyström (2014). “Designing Persuasive Systems for Sustainability - A Cognitive Dissonance Model” *European Conference on Information Systems (ECIS) 2014 Proceedings*.

Nickerson, R. C., U. Varshney and J. Muntermann (2013). “A method for taxonomy development and its application in information systems” *European Journal of Information Systems* 22 (3), 336–359.

Oberländer, A. M., M. Röglinger, M. Rosemann and A. Kees (2018). “Conceptualizing business-to-thing interactions – A sociomaterial perspective on the Internet of Things” *European Journal of Information Systems* 27 (4), 486–502.

Oinas-Kukkonen, H. and M. Harjumaa (2009). “Persuasive Systems Design: Key Issues, Process Model, and System Features” *Communications of the Association for Information Systems* 24 (1), 485–500.

Potting, J., M. Hekkert, E. Worrell and A. Hanemaaijer (2016). *Circular Economy: Measuring Innovation in Product Chains.* The Hague: PBL Netherlands Environmental Assessment Agency.

Prat, N., I. Comyn-Wattiau and J. Akoka (2015). “A Taxonomy of Evaluation Methods for Information Systems Artifacts” *Journal of Management Information Systems* 32 (3), 229–267.

Reike, D., W. J.V. Vermeulen and S. Witjes (2018). “The circular economy: New or Refurbished as CE 3.0? — Exploring Controversies in the Conceptualization of the Circular Economy through a Focus on History and Resource Value Retention Options” *Resources, Conservation and Recycling* 135, 246–264.

Sabherwal, R. and W. R. King (1995). “An Empirical Taxonomy of the Decision-Making Processes Concerning Strategic Applications of Information Systems” *Journal of Management Information Systems* 11 (4), 177–214.

Sandberg, J. and H. Tsoukas (2015). “Making sense of the sensemaking perspective: Its constituents, limitations, and opportunities for further development” *Journal of Organizational Behavior* 36, 6-32.

Schoormann, T., D. Behrens and R. Knackstedt (2018). “The Noblest Way to Learn Wisdom is by Reflection: Designing Software Tools for Reflecting Sustainability in Business Models” *ICIS (International Conference on Information Systems (ICIS) 2018 Proceedings)*.

Schrödl, H. and P. Simkin (2014). “Bridging Economy and Ecology: A Circular Economy Approach to Sustainable Supply Chain Management” *International Conference on Information Systems (ICIS) 2014 Proceedings*.

Sedera, D., S. Lokuge, B. Tushi and F. Tan (2017). “Multi-disciplinary Green IT Archival Analysis: A Pathway for Future Studies” *Communications of the Association for Information Systems* 41 (1), 674–733.

Seidel, S., P. Bharati, G. Fridgen, R. Watson, A. Albizri, M.-C. Boudreau, T. Butler, L. Kruse, I. Guzman, H. Karsten, H. Lee, N. Melville, D. Rush, J. Toland and S. Watts (2017). “The Sustainability Imperative in Information Systems Research” *Communications of the Association for Information Systems* 40 (1), 40–52.

Seidel, S., L. Chandra Kruse, N. Székely, M. Gau and D. Stieger (2018). “Design principles for sensemaking support systems in environmental sustainability transformations” *European Journal of Information Systems* 27 (2), 221–247.

Seidel, S., J. Recker and J. vom Brocke (2013). “Sensemaking and Sustainable Practicing. Functional Affordances of IS in Green Transformations” *MIS Quarterly* 37 (4), 1275–1299.

Shevchuk, N. and H. Oinas-Kukkonen (2016). “Exploring Green Information Systems and Technologies as Persuasive Systems: A Systematic Review of Applications in Published Research” *International Conference on Information Systems (ICIS) 2016 Proceedings*.

Sihvonen, S. and T. Ritola (2015). "Conceptualizing ReX for Aggregating End-of-life Strategies in Product Development" *Procedia CIRP* 29, 639–644.

Slavova, M. and P. Constantinides (2017). "Digital Infrastructures as Platforms: The Case of Smart Electricity Grids" *European Conference on Information Systems (ECIS) 2017 Proceedings*, 1217–1231.

Sneath, P. H. A. (1995). "Thirty Years of Numerical Taxonomy" *Systematic Biology* 44 (3), 281–298.

Sonneberg, M., K. Kuehne and M. Breitner (2015). "A DSS for the Optimization of Electric Car Sharing Stations" *International Conference on Information Systems (ICIS) 2015 Proceedings*.

Stål, H. I. and H. Corvellec (2018). "A decoupling perspective on circular business model implementation: Illustrations from Swedish apparel" *Journal of Cleaner Production* 171, 630–643.

Starbuck, W. H. and F. J. Milliken (2006). "Executives' perceptual filters: what they notice and how they make sense" *Organizational Realities*, 209–232.

Steg, L. and C. Vlek (2009). "Encouraging Pro-environmental Behaviour: An Integrative Review and Research Agenda" *Journal of Environmental Psychology* 29 (3), 309–317.

van Buren, N., M. Demmers, R. van der Heijden and F. Witlox (2016). "Towards a Circular Economy. The Role of Dutch Logistics Industries and Governments" *Sustainability* 8 (7), 647–663.

Venable, J. (2006). "The Role of Theory and Theorising in DSR" *International Conference on Design Science Research in Information Systems and Technology (DESRIST) 2006 Proceedings*.

Wackernagel, M., N. B. Schulz, D. Deumling, A. C. Linares, M. Jenkins, V. Kapos, C. Monfreda, J. Loh, N. Myers, R. Norgaard and J. Randers (2002). "Tracking the ecological overshoot of the human economy" *Proceedings of the National Academy of Sciences of the United States of America* 99 (14), 9266–9271.

Wagner, S., T. Brandt and D. Neumann (2013). "Beyond Mobility - An Energy Informatics Business Model for Vehicles in the Electric Age" *European Conference on Information Systems (ECIS) 2013 Proceedings*.

Wang, R. Y. and D. M. Strong (1996). "Beyond Accuracy: What Data Quality Means to Data Consumers" *Journal of Management Information Systems* 12 (4), 5–33.

Watson, R. T., M.-C. Boudreau, A. Chen and M. Huber (2008). "Green IS: Building Sustainable Business Practices". In R. T. Watson (ed.) *The Global Text Project*, pp. 1–17.

Watson, R. T., M.-C. Boudreau and A. J. Chen (2010). "Information Systems and Environmentally Sustainable Development: Energy Informatics and New Directions for the IS Community" *MIS Quarterly* 34 (1), 23–38.

Weick, K. E., K. M. Sutcliffe and D. Obstfeld (2005). "Organizing and the Process of Sensemaking" *Organization Science* 16 (4), 409–421.

Wilts, H. and H. Berg (2017). "The Digital Circular Economy: Can the Digital Transformation Pave the Way for Resource-Efficient Materials Cycles?" *International Journal of Environmental Sciences and Natural Resources* 7 (5).

Wu, F.-J., Y.-F. Kao and Y.-C. Tseng (2011). "From wireless sensor networks towards cyber physical systems" *Pervasive and Mobile Computing* 7 (4), 397–413.