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Is Life Cycle Assessment enough to address unintended side effects from Circular Economy initiatives?

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Abstract: Despite the spread of policy and business initiatives aiming at transitioning to a Circular Economy (CE), the concept is criticized in the scientific literature for its lack of emphasis on social contexts. Implementing CE initiatives to production systems can indeed lead to "unintended side effects", i.e. both rebound effects and other indirect shifts in consumption patterns. In this forum article we address the question: "*How to make the unintended side effects of implementing CE initiatives knowable and actionable?*" We argue that the ability of Life Cycle Assessment (LCA) to address unintended side effects from CE initiatives is limited, as LCA can model how different product systems interact with each other, but without attending to the socio-technical dynamics taking place within and across different life cycle phases. To extend the potential of LCA in supporting decision making, our suggestion is to complement LCA with other types of analytical approaches, such as Practice Theory (PT) and Actor-Network Theory (ANT), which can qualify our understanding of the unintended side effects of CE initiatives. These theories consider societal dynamics as socio-technical and focus on the processes and practices through which production- and consumption dynamics change. Thus, they can provide analyses of whether and how CE initiatives are capable of realizing novel relations within/among socio-technical systems. Ultimately, they can provide explanations on why things end up the way they do, thus supporting LCA in the investigation of more ´real´ rather than ideal scenarios.

1. INTRODUCTION

The transition to a more circular economy has become a key issue for government and business. It is currently being promoted by the European Union (EC 2015, 2020), many national governments, e.g. Denmark (Ministry of Environment and Food 2018), Sweden (Swedish Research and Innovation 2012) and the Netherlands (Government of Netherlands 2016), and an increasing number of business companies have embraced the concept as a means for business development (e.g. EMF 2013a; Stewart and Niero 2018).

Circular Economy (CE) is an "umbrella concept", i.e. "*an emergent framing around waste and resource management that aims to offer an alternative to prevalent linear take-make-dispose practices by promoting the notion of waste and resource cycling*" (Blomsma and Brennan, 2017, p.603). CE is often associated with three activities (Bocken et al. 2016): closing loops (recycling), narrowing loops (increasing resource efficiency) and slowing loops (extending product life). It is however also a contested concept (Korhonen et al. 2018b), subject to critiques in the scientific literature (e.g. Korhonen et al. 2018a; Millar et al. 2019; Blomsma and Brennan 2017; Schröder et al. 2019), for among other things its lack of social considerations (Kirchherr et al. 2017) and social context (Moreau et al. 2017). This is confirmed by Merli et al.´s (2018) systematic review of the academic literature on CE. They conclude that even though CE is often framed within the triple bottom line of sustainability, insufficient consideration is given to social implications. Fratini et al. (2019) argue that CE research pays relatively little attention to the active role actors can play in CE, highlighting the need to conceptualize CE as co-produced in and by the social, spatial, material and organizational processes. Korhonen et al. (2018a) argue that the most important question for CE in terms of long-term sustainable development is how the saved resources and money generated by the CE ideally can be directed to sustainable consumption practices. Most studies on CE focus on the production side, paying limited attention to how consumers and consumption are affected by CE (Camacho-Otero et al. 2018). However, implementing alternative CE initiatives to production systems can have unintended consequences or side effects due to shifts in both production and consumption.

In the context of this paper, the term "unintended side effects" refers both to what is coined 'rebound effects' (RE) and 'other indirect shifts in consumption patterns'. The RE is usually associated with situations in which efficiency improvements give rise to counteracting effects so the improvements are reduced or even reversed (Sonnberger and Gross 2018). Originally conceived within the energy economics field (see Wallenborn (2018) for an overview of RE research), this notion has recently been extended also to the CE debate. Zink and Geyer (2017) argue that while energy rebound occurs when increases in use-phase efficiency are offset by increased use, CE rebound occurs when increases in production or consumption efficiency are offset by increased levels of production and consumption. In their analysis, Figge and Thorpe (2019) conceptually explored the RE, and how it has been historically understood as a concept applied to linear systems. By investigating resource flow within a circular system, as well as within a producer-producer rather than producer-consumer type of relationship, they identify and define a new type of RE, termed 'symbiotic rebound'. The symbiotic rebound is "*the foregone benefit compared to the expected benefit caused by changes in circular resource flow*" (Figge and Thorpe, 2019, p.63). They argue that the choice of reusing or recycling a resource at a given point of time is binary, and the value created from doing one comes at the cost of not doing the

other. The symbiotic rebound can be differentiated from other forms of RE on the basis of its main driver – opportunity costs, which can lead to a greater use of resources in a CE than expected. As economies become increasingly circular and resource flows become increasingly interconnected, decisions regarding resource use increasingly create opportunity costs. Thus, they demonstrate how rebounds can significantly impact the eco-efficiency of circularity measures and that economic activities´ increased interconnectedness might increase the circularity of resource flows, but simultaneously lead to symbiotic rebounds that counteract the desirable effect of increased circularity (Figge and Thorpe 2019). This calls for the use of analytical frameworks that are able to uncover the interconnected relations between different production and consumption systems.

In addition to CE rebounds, CE initiatives can also cause other types of shifts in consumption patterns (Jensen et al. 2019). If, for instance, a CE policy assumes that the reduction of single use plastic waste is a matter of individual choice, then policy is likely to assign responsibility to the individual consumer. However, the individual consumer's actions may not lead to the desired outcome, because the individual`s actions have little or no influence on the production of single use plastic. As a consequence, if the use of single use plastics in, for instance, household cutlery is not challenged, end users may end up buying other types of single use materials instead (e.g. straws/plates made from coated paper or metals rather than plastic) that generate other types of (unwanted) waste and induced environmental impacts. If the policy instead facilitated a space within which a deliberation of whether or not single use plastics in households cutlery are actually needed, a different type of output can be expected. Indeed, intended as well as unintended consequences are linked to the problem framing upon which a policy is built (Jensen et al. 2019), and unintended consequences are consequences that happen because of the scope and focus of the policy.

The number of studies seeking to quantify unintended side effects induced by CE initiatives is limited and most address REs (Scheepens et al. 2016; Zink and Geyer 2017). To our knowledge only one study offers quantitative estimates of the rebound´s magnitude. It is a study of smartphone reuse (Makov and Font Vivanco 2018), and it combines Life Cycle Assessment (LCA), sales statistics, consumer surveying, consumer demand modeling, and environmentally-extended input-output analysis (EE-IO). LCA is an established method in the Industrial Ecology (IE) field to assess the environmental performance of product systems based on the eco-efficiency concept (Bjørn and Hauschild 2013). Although LCA has historically been used to highlight the role of different actors, such as designers, manufacturers and distributors in improving the overall environmental performance of products (Graedel and Allenby 1995), it is now the dominant method to quantitatively assess CE initiatives (Elia et al. 2017; Saidani et al. 2019; Petit-Boix and Leipold 2018). While LCA can certainly be used to address two requirements for a CE initiative to lead to absolute resource decoupling (Kjaer et al. 2018), i.e. ensuring net resource reduction and avoiding burden shifting between life cycle stages, it struggles with meeting the *third requirement, i.e. mitigating RE*. This has to do with the fact that LCA focuses narrowly on the product, and only to a limited degree on the systems in which it is embedded and which facilitate certain usages. RE can to some extent be quantified by consequential LCA (CLCA) (Hertwich 2005; Font Vivanco and van der Voet 2014), which is a sophisticated modelling technique seeking to assess the environmental consequences of an

action/decision by including *market mechanisms* in the analysis (Zamagni et al. 2012). The fact that CLCA bases the life cycle modelling on changes in marginal demand, explains why it is used mainly to model RE (Font Vivanco and van der Voet 2014), mostly in combination with EE-IO tables, which integrate consumer spending data in LCA (Thiesen et al., 2008). This enables the use of behavioral science in the context of LCA both for measuring spending behavior and for assessing potentials and means for changing consumer behavior (Polizzi di Sorrentino et al. 2016). However, spending behaviors are only a small fraction of behaviors associated to the usage and disposal of a product.

LCA is a method which aims to model how different product systems interact with one another in terms of exchanges between technosphere and ecosphere, but it does not attend to the socio-technical dynamics taking place within and across different phases of the product life cycle. Thus, its ability to address unintended side effects from CE initiatives is limited. A crucial question remains unanswered: "*How to make the unintended side effects of implementing CE initiatives knowable and actionable?*" We argue that in order to fully exploit LCA's potential as a decision support tool, it can be complemented with other analytical approaches that can qualify our understanding of the side effects of CE initiatives. We suggest using theories such as Practice Theory (PT) (Nicolini 2012) and Actor-Network Theory (ANT) (Law 2008). Both theories emphasize analyzing products as part of socio-technical systems, i.e. as mutually constituted by technological developments, stakeholder influences and social norms. Both PT and ANT can – despite their differences, highlighted in the last section – be characterized as process theories. Both focus on the processes and practices through which changes in behaviors emerge (or do not emerge). They are, therefore, useful in analyzing whether and how CE initiatives are capable of realizing novel relations among socio-technical systems. Both can provide valuable insights that can improve our understanding of the unintended side effects of CE initiatives.

The paper proceeds as follows. First, we briefly introduce PT (section 2) and ANT (section 3), and how they can contribute to our understanding of unintended side effects from CE initiatives and help in qualifying the ways in which these issues can be addressed. Then, we present an illustrative case within packaging (section 4) to clarify the types of questions PT (section 4.1) and ANT (section 4.2) can help answering when assessing the impact of CE initiatives. Section 4.3 outlines the main implications of a complementary use of PT and ANT with LCA. Finally, we highlight the type of knowledge about this case and in general that PT and ANT can provide (section 5).

2. PRACTICE THEORY

Practice theory (PT) is an umbrella term for multiple theories seeking to understand 'what people do'. Originating within sociology, PT argues that social practice(s) rather than technology, actors or individual behavior should take center stage analytically. PT is based on a flat ontology, which is at odds with the commonplace understanding of social phenomenon taking place at different levels (micro, meso and macro levels). Social phenomena are considered as a web of inter-mingled practices, in which there are no given hierarchies between practices nor between the actors that undertake them (Reckwitz 2002; Shove et al. 2012; Schatzki 2002).

PT emphasizes the social dimensions of what people do, particularly exploring how social norms and ideas about normality evolve through the reproduction of social practices. Reckwitz (2002, p. 250) defines a practice as "*a routinized way in which bodies are moved, objects are handled, subjects are treated, things are described, and the world is understood*". The work of Shove (2010), Røpke (2009), Shove et al. (2012) and Warde (2005) focuses on consumption patterns as results of practice dynamics. In light of this, unintended side effects can also be understood as outcomes from the interconnectedness of practices constituting everyday life (Shove 2018; Sonnberger and Gross 2018). To give an example: Mylan et al. (2016) used the everyday experience of domestic food provisioning to highlight the importance of everyday interactions between routine activities, mundane technologies and cultural meanings in (re)producing patterns of consumption. They recommended a "*shift from the conceptualization of consumers as 'users' of particular products and services to imagining them as 'doers' of particular activities during which resources are consumed"* (Mylan et al. 2016, pp.11). Their example illustrates that people do not 'use', 'reuse' or 'recycle' food, but rather they 'do' activities that constitute daily life (such as looking after family, working, socializing with friends), while incorporating food as part of these activities. On the same line, Revilla and Salet (2018) use PT to analyze the social meaning behind the practice of discarding food and the role that household food rituals play in both shaping the social meaning of food and in spreading the knowledge about food waste (and ultimately reducing the amount of food wasted). From a PT perspective (Shove et al. 2012), it is important to explore the interconnectedness of meanings (e.g. ideas about a good meal), materials (e.g. food) and skills (e.g. how to prepare a good meal) when studying practices that generate consumption dynamics.

Essentially, PT's approach to studying unintended side effects of CE initiatives would be to consider how particular interventions in material aspects may influence the social and vice versa. Revisiting the household cutlery example from the introduction, a PT approach would question why single use plastics in households cutlery are needed in the first place, and whether interventions could be made to change skills or meanings related to social events that would not require the use of cutlery (the 'material') altogether, cutting down the need for material supplements, and thus eliminating certain resource loops entirely, instead of just slowing or narrowing them. A PT approach would thus study why people feel a (practical as well as emotional) need to use disposable tableware instead of reusable tableware, and then seek to make it practically viable to use reusable tableware instead.

3. ACTOR-NETWORK THEORY

Actor-Network Theory (ANT) is – despite its name – not a coherent theory but a family of conceptual and methodological approaches that grew out of French and British studies in the sociology of science and technology from the late 1970s (Farías et al. 2020). Cast in general terms, ANT is concerned with how 'things' – be they scientific facts, specific technologies, CE or other forms of societal order – come into being, i.e., are generated and stabilized (or not) to become (or not become) taken-for-granted features of society.

ANT is based on three key tenets – symmetry, heterogeneity and performativity (Babri et al. 2018). *Symmetry* refers to the epistemological stance of not assuming – a priori – that either people or the things (non-humans) surrounding them determine the character of change and

stability (Law 1992, p.383). The second tenet, *heterogeneity*, concerns the many different actors, both human and non-human, entangled in shaping science, technologies, and CE, etc. ANT does not make an analytical distinction between human and non-human actors. Both can 'do' things, and agency, understood as the ability to act, is therefore considered distributed. Accordingly, when it comes to CE's unintended side effects, ANT inspired analyses would, similar to PT inspired analyses, seek to avoid deterministic accounts that ascribe the side effects to *either* the social, e.g. people's mind-set and/or behavior, *or* the material, e.g. the particular raw materials and technologies involved. The third tenet, *performativity*, is tied to ANT's focus on how things come into being, and refers to how scientific statements are "*not outside the world(s) to which they refer, but are actively engaged in the constitution of the reality that they describe*" (Callon 2007. p.316). Key to these endeavors are the tools, e.g. visualizations, models and calculative devices used to render things visible, knowable and actionable. To exemplify, an ANT study on reducing the use of households cutlery would analyze the actor-network supporting households cutlery consumption to identify the weak and strong links enabling this consumption pattern in order to propose strategies for transforming this actor-network into one in which cutlery is no longer needed/wanted. Furthermore, viewed from this perspective, LCA could be an 'interessement device'(Akrich et al. 2002) that can be used to persuade actors to stop using and/or producing households cutlery.

Viewed from an ANT perspective, both CE initiatives and their unintended side effects would be considered outcomes of the network of people and materials involved. CE initiatives can be seen as a particular framing, while the unintended side effects are considered as overflows (Callon 1998), i.e. something that exceeds the framing – or definition – of what the CE initiatives are supposed to achieve. Accordingly, ANT seeks to avoid ascribing the unintended side effects of CE, such as RE, to consumer behavior alone. Instead, emphasis is given to how CE initiatives are framed and defined, and how the involved consumers, producers, suppliers, calculations, raw materials, and technologies become aligned (or not) in developing these initiatives. From an ANT perspective, overflows are pervasive, because aligning actors' interests is a precarious achievement that is likely to be subject to contention. Thus, the unintended side effects of CE initiatives are to be expected. This insight will be further developed in connection with the following illustrative case.

4. AN ILLUSTRATIVE CASE: PACKAGING

Packaging is part of our everyday life and involved in many different socio-technical systems (and practices): e.g. food and beverage provision (shopping, dining) and personal care (laundering, showering). The processes of accelerated everyday life, enabled by technological innovations, result in more and more practices being squeezed into a given period of time (Sonnberger and Gross 2018), accompanied by an increasing amount of packaging waste and related environmental impacts. Most packaging on the market is single use and, thus, an exemplar of the 'take-make-use and throw away' of the linear economy. Although measures are being taken to change this, e.g. the ban of certain single-use plastics by 2021 (EC 2019) and measures aiming at food waste prevention that could privilege use of bio-based biodegradable packaging (Dilkes-Hoffman et al. 2018), such initiatives will only be effective in reducing pressures on environment if the alternatives are better from an environmental point of view.

LCA has proven to be a very valuable tool in driving more environmentally preferable food and beverage packaging solutions (UNEP & SETAC 2013). However, even if LCA has been used to move packaging production towards CE initiatives (e.g. Niero et al. 2017; Pauer et al. 2019), the LCA modelling of the use and end of life stages of packaging mainly relies on assumptions, e.g. on the number of uses and disposal options (Gallego-Schmid et al. 2018; Tsiliyannis 2005). Current applications of LCA risk providing scenarios that do not adequately take consumer behaviour (and underpinning practices and socio-technical systems) into account. This is problematic for a method that is used as a decision support tool in policy making (Hellweg and Canals 2014), and can be misleading for consumers, who base their perception of the environmental sustainability of packaging on the origin of material and what they can do at the disposal stage (Boesen et al. 2019; Steenis et al. 2017). A key issue with LCA of packaging systems is that it cannot univocally be determined which is the best option from an environmental point of view (Boesen et al. 2019), as the selection depends on the situation and its context. This can be analysed in different ways by exploring the different practices and actor-networks involved.

Here we consider an illustrative case of a company producing liquid soap for hygiene purposes, packed in a single-use plastic packaging. As part of its sustainability strategy, the company aims to become more circular by either recycling or reuse. The conventional approach would be to apply LCA to assess the potential environmental impacts of different CE initiatives in order to identify which option is the best from an environmental point of view.

4.1. PRACTICE THEORY AND PACKAGING

According to PT, consumption does not happen as something intentional and meaningful in itself, but is rather an outcome of several habitual and routinized practices that are meaningful to keeping up comfort and cleanliness as part of everyday life (Shove 2003). This implies that rather than treating packaging related to the use of personal hygiene products such as shampoos and soaps as a matter of individual preference and choice, PT would consider the *study of personal hygiene practices* to understand the implications different forms of packaging can have on people practices. For example, exploring and challenging showering as a social practice means exploring the meanings, skills and materiality that go into the performance of showering, including the purposes and frequency with which we shower, and how the type of package of the used products affects or is being affected by that practice. If it is generally accepted, and maybe expected, that people shower every day and use products to minimize body odors, then using many packaged products become less of a matter of personal preference and more of a matter of keeping up a normalized way of keeping clean and presentable. Unfolding the *practice of showering* would mean looking at: i) *meaning*: ideas about cleanliness, comfort and freshness, maybe also related to a ´wellness' feeling and that products should look nice; ii) *skills:* skills and knowledge related to how to keep oneself clean and iii) *materials*: shampoo, running water, shower niche, showerhead, etc.

From a PT perspective, the crucial questions related to unintended side effects then become what causes the spread, diversification and intensification of particular, resource intensive practices

over time, thereby framing unanticipated side effects as part of the way everyday life unfolds (Sonnberger and Gross 2018). Thus, when studying unintended side effects in relation to the application of a CE initiative, we find that PT can be instrumental in showing how changes from linear to CE require changes in systems of practices (Watson 2012; Jensen 2017), and that changes in some practices lead to changes in other practices that, too, can have undesired side effects. To exemplify, the practice of showering is linked to the purchasing of soap and shampoo that are typically packaged in single use packaging. Changing the way, as well as the frequency, with which we shower may change the way we engage with packaged personal hygiene products. PT would direct attention to the practices targeted by CE initiatives and to how they are bundled together and thus affect each other. For example, the choice of a reusable packaging could imply that the user has to go to the shop to refill the empty packaging. Accordingly, shop availability/proximity becomes essential. In case of recyclable packaging, the empty product needs to be disposed in the proper bin at the end of its life. If less product is used, then package recycling is also slowed. Essentially, PT can help us shed light on the need for i) dismantling and/or ii) enabling practices needed for circularity to take place. For instance, it helps to identify what types of changes are needed in systems of practices (professional as well as everyday life practices), such as showering, shopping and commuting.

4.2. ACTOR-NETWORK THEORY AND PACKAGING

In analyzing company CE initiatives, ANT would focus on who and what is involved in framing, negotiating and influencing the necessary changes to the packaging, e.g. ranging from the choice of materials to manufacturing, marketing, use and disposal processes. Making the necessary changes may not be straightforward, as this is likely to run counter to existing framings, i.e. linear modes of thinking and ways of working. Therefore, moving towards more circular packaging is likely to be subject to competing concerns and diverging interests, necessitating the mobilization of a host of things, including LCA scenarios, to persuade and enroll others into accepting that the production and use of e.g. a reusable packaging is worthwhile. The success of a CE initiative depends on the actors' abilities in aligning and stabilizing interests. For example, some actors in manufacturing might see packaging as essential for protecting their goods, while others in the energy sector may see packaging merely as an energy source and/or a source of CO_2 emissions. The ways in which actors see packaging and the investments they have made will, however, influence whether or not they will be interested in CE initiatives. Packaging is a proposition that becomes sensible through various discourses, business models, and assessment methods (like LCA). Whether packaging is waste or a resource is thus something that comes into being through cultural, economic, and political work (Korhonen et al. 2018a).

By proactively mapping the actor-networks of specific packaging systems involved in CE initiatives, ANT can contribute by identifying the controversies involved and how barriers and drivers for the CE initiatives are created and addressed (Blomsma et al. 2019; Pedersen and Clausen 2018; Babri et al. 2018). In the abovementioned example regarding the packaging of personal hygiene products, ANT asks how actors' interests become aligned so as to prompt or prevent people from changing their way of treating packaging. For many consumers packaging is simply necessary to contain the product, and something to be disposed of in existing waste facilities (e.g. landfills or incineration). Whether it will be possible to close or slow the packaging materials through (respectively) recycling and reuse will depend on a host of things.

For example, when it comes to recycling, problems in sorting plastic packaging may be attributed to 'bad' design and/or to the costs of sorting, cleaning, etc. Efforts must be put into changing packaging manufacturers functional view of packaging as a solely means of containment and transport and as a marketing platform to enable them to see the packaging waste as a resource to be valued (Dorland et al. 2014). In the case of reuse, the network of actors involved and their interests in the establishment of a refill and take-back system needs to be investigated. CE (and the promises it is said to bring) has also agency in these networks as a way to re-frame the economic potential of packaging materials.

ANT is useful for depicting and understanding how actors, in practice, negotiate what CE in packaging entails. However, as mentioned, aligning interests is a precarious endeavor; one that is likely to be subject to contestation and, perhaps, even resistance from actors not the least bit interested in promoting CE. The extent of their influence will depend on the materials, discourses, organizations, people, technologies, and different calculative devices involved in framing the CE initiatives as desirable as well as the drivers and barriers for advancing CE. ANT directs attention to how issues of power can influence CE initiatives. These initiatives are, however, likely to have some unintended side effects that concomitantly need to be addressed. Although an ANT approach precludes wide-ranging conclusions as to what will promote CE or prompt unintended side effects (as this will be a matter of how the involved actors act and interact), it directs attention to 'following the actors' in unearthing who and what is involved in framing, enacting, and enrolling others in creating circular systems and in clarifying how those specific CE configurations might potentially create unintended side effects.

4.3. IMPLICATIONS FOR LCA

From a methodological standpoint, our idea is that first a PT and ANT study can be conducted to later inform the LCA study. The main modifications of the LCA methodology refer to the scope definition, namely the function definition (i.e. showering practice) and system boundaries definition (i.e. including also all inputs and outputs needed to fulfill the function). Also, the interpretation phase of the LCA will be indirectly affected by scenario analysis, which necessarily will be used to quantify the qualitative information provided by PT and ANT analyses.

The starting point for a combined PT-ANT-LCA analysis (as for a standalone LCA) is the definition of the baseline scenario (see Figure 1a), i.e. the current situation that includes the use of a certain type of plastic packaging with a defined end-of-life (EoL) scenario. In LCA the EoL is usually defined using the average (plastic) EoL management in the country-region under investigation, typically including a fraction of recycling and incineration and/or landfill disposal, see e.g. Gallego-Schmid et al. (2018). A second step is the definition of alternative scenarios, describing the two CE initiatives under investigation, i.e. the "recycling" scenario (see Figure 1b) and the "reuse" scenario (see Figure 1c).

[Figure 1 around here]

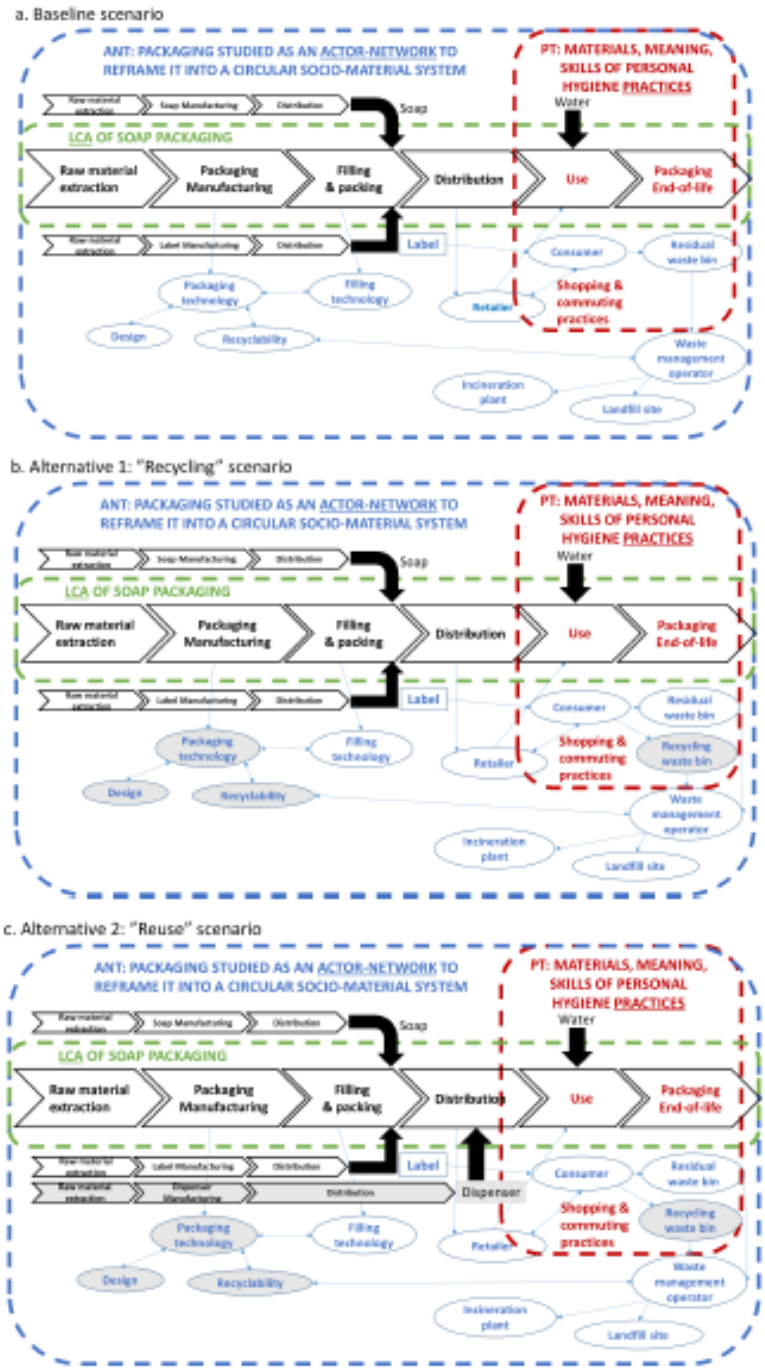

Figure 1 Indication of different research focuses of Life Cycle Assessment (LCA, green), Actor-Network Theory (ANT, blue), Practice Theory (PT, red) when studying packaging and representation of the scenarios considered in the hypothetical case: a) baseline scenario, b) recycling scenario, c) reuse scenario. The main differences with the baseline scenario are highlighted in grey. The arrows indicate the one-way or two-ways link among actors.

PT can contribute with knowledge about practices that generate particular consumption patterns, and which may then inform consumption related assumptions used in LCA modelling for CE, e.g., the number of times reusable packaging is reused or the disposal option is chosen by the consumer. This is done by considering the broader range of practices connected with showering, such as commuting and shopping. A PT analysis would focus on the practice of showering and not use of plastic packaging. Thus, for all scenarios knowing the consumers´ frequency of showering, the amount of liquid soap used in different seasons and their shopping practices (e.g. in discount stores) would allow one to identify different sub-scenarios based on real world information. For example, for the recycling scenario (see Figure 1b) the choice of how to dispose of the plastic packaging could be investigated by considering the motivations that move consumers to opt for either the recycling bin or the one for residual waste. For the reuse scenario (see Figure 1c), changes in practices would be needed for the CE initiative to be successful, e.g. the availability of refills in retail shops or as direct supply at the household, which from a life cycle perspective would require including other types of packaging to transport the liquid soap and further transportation from home to shop. From a design perspective, alternative materials could be more suited to increase packaging durability, but consideration should also be given to consumers´ attachment to specific types of packaging (and their aesthetics).

An ANT analysis would map the actors involved and consider what materials and tools they use to persuade other actors to either recycle or reuse plastic packaging. In this regard, LCA is likely to be an important "calculative tool" through which the definition of functional unit, life cycle inventory, choice of impact assessment measures and metrics, and assorted calculations together render the environmental performance of the packaging knowable, calculable, and actionable for actors seeking to develop more circular packaging. Viewed from this perspective, LCA not only documents impacts along the life cycle, it also intervenes in the development processes by identifying which impacts are the important and/or legitimate to address. The definition of the baseline scenario allows to direct efforts towards a more circular initiative, by showing where the hotspots are, both in terms of life cycle stages and life cycle impact categories. Different human (e.g. waste management operators) and non-human actors (e.g. different types of plastics and manufacturing technologies needed to process the different materials) are responsible for change to happen, and a decision in one life cycle stage has implications for the feasibility of different solutions, see Figure 1b and 1c. Unlike many IE studies, an ANT approach is also useful for documenting how issues are framed and problematized (by whom and with what tools), and how the development and stabilization of specific socio-technical networks occur. This includes analyzing the limitations of LCA in representing the full complexity of the system supporting a product's life-cycle, and, therefore, exemplifying how and to what extent some side effects fall outside its unit of analysis.

In the specific case of the liquid soap manufacturer aiming at implementing a more circular initiative, there could be unintended side effects from implementing the CE strategy that could be qualitatively identified by a PT and/or ANT analyses and possibly quantified in the definition of alternative LCA scenarios. The target audience of a combined PT-ANT-LCA analysis are design engineers seeking to identify the best option among alternative CE initiatives from an environmental point of view. Complementing LCA with PT-ANT analyses allows for considering not only material aspects in the development process, but also the social implications

that can favor (or not favor) the CE initiative's success. Importantly, combining LCA with PT-ANT analyses directs attention to the problem-framings, various problematizations and power-relations along the value chain. Potential users of such combined analyses could be policy makers that need to take the rebound issue into account in the development and assessment of CE policies, as outlined by Font Vivanco et al. (2018).

5. CONCLUDING REMARKS

The transition from linear to CE approaches is seldom as straightforward and easy as much of the literature appears to assume. Such transitions might require fundamental changes in both production and consumption systems, and in the way they meet social and ecological livelihood and well-being. However, the implementation of CE initiatives to production and consumption systems can have unintended side effects due to shifts in both production and consumption. The quantification of such unintended side effects has thus far been limited; mostly based on quantitative LCA studies. LCA is primarily used to support decision making; in most cases through the definition of alternative scenarios. We argue that to further exploit LCA's potential in supporting CE policy, there is a need to develop an understanding of `how things work`. This first requires understanding 'how things work' in practice, both present practices and new CE-inspired practices. Thus, *to make the unintended side effects of implementing CE initiatives knowable and actionable,* PT and ANT can be instrumental, as they provide explanations of why things end up the way they do, and both move away from abstract, decontextualized, hypothetical analyses of existing and possible practices.

Both PT and ANT can deliver on the critique of the underlying assumptions regarding behavior, i.e. that it is based on rational decision making. The way behavior is conceptualized has implications for recommendations on how ´behavioral (and other) problems´ should be addressed. Both PT and ANT focus on the processes through which things, such as a CE initiative, come into being, i.e. 'compete' against the existing ways of doing things. PT directs attention to the social practices (the interplay between meanings, materials, and skills) and their maintenance, whereas ANT has a stronger emphasis on the role of actors and tools in framing possible CE initiatives. PT has practices as unit of analysis, whereas ANT focuses more broadly on problematizations of the existing systems, how action is generated through interactions, representations, performance, and the enrolment of others. Both emphasize that what is in focus in CE initiatives and what is unintended derives from actors' meanings, practices, or actions rather than abstract (generalized) definitions.

The illustrative case in this article focused on packaging where reusing and recycling often is in focus as CE initiative. Within other product areas like clothing, furniture and electronics, slowing and narrowing of resource flows through longer product life time and different type of sharing schemes are very relevant (Jørgensen and Remmen 2018). Within such product areas, PT and ANT can contribute with analyses of different types of product obsolescence and how they shape consumption patterns and product life time, e.g. technical obsolescence of products due to limited quality of components and psychological or social obsolescence due to frequent launching of new products (Bocken et al. 2016; Jørgensen and Jensen 2012). A combination of LCA and ANT can analyze the actual recycling of resources from obsolete products compared to

what is claimed, based on an ideal understanding of CE as being able to change production and consumption systems into "creating closed-loop processes in which waste serves as an input" (EMF 2013b). Such analyses can show the importance of a stronger focus on prolonged lifetime and sharing schemes, but also whether and how such systems might gain support from businesses, civil society, and public agencies, etc.

Within CE research, there is a need for interdisciplinary research to synthesize insights from the natural and technical sciences as well from sociology, geography, and political science, to expand our understanding and to provide more robust recommendations on how and in which conditions CE initiatives can contribute to sustainability transitions. This article is a call for the IE community to be open to experiment with analytical tools and theories from Science and Technology Studies, which study the social construction of technology and aim at contributing with a symmetric approach describing people, technology, and objects in the same terms to prevent presupposed differences (Edge 1995). In particular we encourage further research which combines LCA with ANT and/or PT in the development and assessment of CE initiatives implemented by business, civil society and public authorities. PT and ANT can complement LCA by developing assumptions about existing and future social practices and related infrastructural systems (production, distribution, consumption, waste management, etc.) and thereby support the development of more ´real´ rather than ideal scenarios for assessment of environmental consequences of a CE initiative. Further studies considering real case LCAs are thus encouraged. The traditional IE tools and approaches focus on the material aspects, but given the potentials of ANT and PT in addressing the socio-technical aspects of CE initiatives, we believe that these theories could improve the assessment of social impacts of CE initiatives, thus ultimately supporting LCA in the investigation of more ´real´ rather than ideal scenarios.

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