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Approach for developing implementation strategies for circular economy in global production networks

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ABSTRACT

Due to excess of resource consumption, circular economy (CE) aims to return products to the production life cycle in an economically and ecologically reasonable way.

Yet, few approaches focus on the strategic and network level of CE. First, existing approaches regarding the configuration of CE networks and the development of appropriate business models are reviewed. Second, an approach on how to integrate both aspects is presented. By integrating these aspects, implementation strategies for CE in global production networks shall be developed facilitating strategic decisions.

The approach is planned to be demonstrated in a German company supplying the automotive sector.

1. Introduction

Up to the year 2030, an increase in world population up to 9 billion people is expected. The resulting challenges to meet customer demand thus increase the pressure on the natural limited resources. Without rethinking how society uses raw material in the linear value chain, many of the industry's key elements could be exhausted already in the upcoming years. (Forum, 2014) Even today, volatile raw materials availability and prices are posing major challenges for manufacturing companies (Kranert, 2017; Soleimani and Govindan, 2014).

The circular economy (CE) takes up these challenges and aims at returning products, components and materials back to the product and production life cycle multiple times (Tolio et al., 2017). Thus, its goal is to recover as much of the economic and environmental value as economically reasonable in order to reduce the use of naturally limited resources (Thierry et al., 1995).

Recent studies already show the potentials of a CE: Regarding resource and energy consumption, a reduction of up to 80–90% is possible compared to the production of the same products in the linear economy. Thus, reductions in material and energy cost of 25–30% are possible. Moreover, it is expected that more and more companies aim to develop and produce more durable products. (Tolio et al., 2017) According to a study conducted by the Ellen MacArthur Foundation, the European economy could generate annual benefits of up to 0.9€ billion until 2030, when transforming its traditional linear economy to a new CE (MacArthur et al., 2015).

Although the benefits from transforming its business to a CE are clear, only few companies have adapted the new, sustainable economy completely so far. However, even nowadays, CE has a broad field of application. One example for this is the automotive aftermarket. Here, spare parts are required over a long-term horizon, even after the series production of the vehicle was already terminated. Thus, e.g. remanufacturing is used to upgrade end-of-life parts and components to an "as-new" condition and sell them at lower prices and over a longer time horizon compared to the production of new parts. Nowadays, more and more companies from other sectors try to introduce CE for some product families as well (Fasko, 2015), but most of them lack a structured and analytical approach in doing so. Moreover, a closer analysis of these attempts reveals that many companies are heading more towards a "2-way-linear" system rather than a real CE where separate network and production structures are build up for the supply of new parts and the supply of remanufactured products.

Transforming its business model from a linear value chain to a CE poses great challenges on companies. This is due to the strategic, long-term decisions which have to be taken and are only reversible at great expense. Moreover, uncertain environmental conditions over these long time horizons enhance these challenges. (Abele et al., 2008) In the context of the CE, another crucial challenge is posed: the so-called "lock-in effect" describes the fact, that

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many organizations nowadays align their processes and structures to the linear economy in a very efficient way. Thus, transforming their business to a CE is associated with a high organizational and monetary effort. (MacArthur et al., 2015)

The aim of this paper is to develop an approach to support strategic decision makers in companies with introducing CE and implementing respective global production network structures (Lanza et al., 2019) and business models. Thus, strategic decisions are made on the foundation of a methodologically profound analysis. The proposed method is a combination of a traditional optimisation model and a simulation model. By doing so, the financial effort for transforming the business shall be distributed over the period of time and, thus, be more manageable in each period. For this purpose, it is reasonable to start introducing CE for single products or product families first and later enlarge this program to the whole range of products.

The structure of the remaining paper is as follows: Chapter 2 presents the state of the art regarding CE business models and the configuration of CE production networks deriving the research gap. Chapter 3 briefly presents the aim of the work in more detail. Thereafter, Chapter 4 presents a framework for developing implementation strategies for CE as well as the expected results and an exemplary use case. Chapter 5 concludes the article with an outlook on the upcoming research steps.

2. State of the art

The following chapter presents the state of the art regarding CE business models and the configuration of CE production networks.

2.1. Business models for the circular economy

If companies intend to implement CE, the corresponding business model for realizing the plan is of utmost importance. Business models that are specially adapted to CE can sustainably secure various aspects that are relevant for the companies concerned. On the one hand, the profitability of a company in CE can be ensured by a correspondingly optimised business model so that the company's activities are profitable and sustainable. (Sundin et al., 2016) Furthermore, a corresponding business model can ensure the return flow of products after their use. This is shown in different industrial examples (Fasko, 2015, Sundin et al., 2016). It is also possible to collect data from customers during the use of the product, which may be useful in CE processes, as evidenced by discussions with industry. Amongst other things data could be collected while using the products to simplify remanufacturing work.

Basically, a distinction is made between product-orientated and service-orientated business models. In product-orientated business models, the product itself is sold to customers, which gives companies the incentive to maximise the number of products sold. In service-orientated business models, companies earn money by being paid for a service they offer. Products used for the service are cost factors since they retain in possession of the company. This gives companies an incentive to use the products as long and intensively as possible. (Tukker, 2015) In addition, there are hybrid forms such as Product Service Systems (PSS), in which a mixture of tangible products and intangible services are combined to optimally meet the customers' needs. In particular service-orientated business models and PSS seem to be most attractive for the implementation of CE.

There are numerous business models that are suitable for implementing CE. Appropriate business models for the development of CE are based, amongst others, on the principles of the ReSOLVE framework of the Ellen MacArthur Foundation. (MacArthur et al., 2015) ReSOLVE is composed of the principles regenerate, share, optimise, loop, virtualize and exchange. Regenerate focuses on a shift towards renewable materials and sources of energy. Share refers on the one hand to the possibility of a shared utilisation of goods (e.g. CarSharing) and on the other hand to the maximization of resource use along the product life cycle through for instance reuse and increased durability (e.g. lease and hire). Optimise stands for high efficient products and processes. Loop means closing production loops via returning technical materials to use (e.g. repair, remanufacturing, recycling). Virtualize is the possibility of delivering utility without a physical product (e.g. online music). At last exchange relies on the use of innovative technologies and materials. (Angelis, 2018) Business models that can be assigned to the principles of the ReSOLVE framework are fundamentally suitable for implementing a CE.

There are numerous examples of successfully implementing a CE using various business models (Angelis, 2018). In the automotive industry, for example, the ATP Group implements remanufacturing. The value chain operates in different steps. The OEM collects the parts from the end-users and sends them to ATP for remanufacturing as contractually agreed. The remanufactured products will be sent back to the OEM and the OEM will give them back to the end-users with surcharge to ensure the cores returning for remanufacturing in future. “Cores” are the used products returning from customers to the company. The benefits are the lower costs for the OEM and the lower price for the customer. Furthermore, there are less raw materials needed. (Sundin et al., 2016) Another example is the so called „circular lighting“ of Philips. They provide guaranteed lighting performance with regard to energy, light level and uptime, while owning the reuse, refurbishing or recycling loop to ensure you get maximum value from the lighting system you pay for. (Philips, 2018)

Besides the previously presented supply perspective of circular business models, the demand perspective for circular products must be considered. Given the increasing world population and thus increasing demand, as well as the price elasticity in many relevant markets, a reduction in the price (i.e. remanufactured products can be sold at a lower price than new products) will automatically increase demand, given that the quality remains stable. (MacArthur et al., 2015) What still might remain a challenge for CE is the increase of acceptance of circular products at the customer side. However, due to increasing social popularity for more sustainability, this challenge could come off on its own.

2.2. Configuration of circular economy production networks

When planning the production network for a CE, a so-called closed-loop supply chain (CLSC), an integrated view on the forward and reverse logistics is necessary. In addition to the classical challenges of forward logistics, such as cost optimal facility location and fulfilment of demand, new challenges caused by the reverse logistics, arise. Next to the location of new facilities for the reverse logistics and the resulting costs and changes in organization, uncertain backflows of used products and the quality of these have to be considered in network design and optimisation. In literature, there are several approaches, which use e.g. mixed-integer linear programming (MILP), for planning and optimising such networks.

Fleischmann et al. (2001) present a multi-echelon, single-product, single period and un-capacitated model for a closed-loop supply chain and implement it as a mixed-integer linear program. The objective of the model is to minimise the total costs caused by facility location decisions and transportation. The quality of collected cores is considered with a minimum disposal fraction. There are several extensions for the model presented to bring the model closer to reality. Except for the remanufacturing of cores, products can be produced completely new and it is possible to introduce penalty costs for non-collected cores (Fleischmann et al., 2001).

Salema et al. (2007) use the basic model of Fleischmann et al. (2001) and extend it successively by lower and upper limits for capacities, the possibility of processing multiple products and the possibility of coping with uncertainty in demand and return flows. The same authors present an approach for simultaneous tactical and strategical planning in a multi-product, multi-period, multi-echelon network which is modelled as a mixed-integer program. The different planning dimensions are realized with two interconnected time-scales. (Salema et al., 2009) Moreover, an approach to model the network as graph-based network to reach a more generic, more flexible model, in which different supply chain structures can be easily modelled, is presented (Salema et al., 2010).

Soleimani and Kannan (2015) present a mixed integer linear program for a multi-product, multi-echelon, multi-period closed-loop supply chain. A complex network structure with several different connections between supply-chain echelons, depending on the underlying real-world network, is considered. Because the solution of a mixed-integer linear program for a closed-loop supply chain is NP-hard, a hybrid algorithm consisting of a genetic algorithm and particle swarm optimisation is proposed to cope with this complexity, especially for large-scale problems.

Amin and Baki (2017) create a mixed-integer linear program for a multi-product, multi-echelon, multi-period closed-loop supply chain with uncertain demand. The objectives of the model are the profit maximization and the maximization of the on-time delivery. The global impact factors exchange rates and custom duties are considered and a solution approach based on fuzzy programming is presented.

In addition to simple cost minimization or profit maximization, there are approaches with multiple objectives. These approaches mostly consider multi-echelon, multi-product, multi-period mixed integer formulations for a closed-loop supply chain with three objectives. The objectives are often the profit maximization, the maximization of the social responsibility and the maximization of environmental reliability (Govindan et al., 2016) or customer satisfaction (Soleimani et al., 2017). Other approaches also consider the customer fill rate and the satisfaction level of the stakeholders (Özkir and Basligil, 2013).

In addition to these approaches based on the warehouse location problem there exist some approaches which consider the network to be given and unchangeable and are only concerned with the optimisation of the collection process and the produced and transported quantities of goods. Two of these approaches are briefly summarized in the following.

Kim et al. (2006) focus on the optimisation of the cost saving achieved by remanufacturing. To this end, the quantities of collected and remanufactured or disposed products, as well as multiple products and multiple periods are considered. Remanufacturing can be performed in own facilities or by a subcontractor. In the own remanufacturing process, set up operations between different products are taken into account.

Denizel et al. (2010) use stochastic programming for developing a model for the tactical planning of remanufacturing in production. The underlying network is considered given and unchangeable, so that the focus is on the profit-optimised production plan. For this reason, the produced and remanufactured product quantities are considered, taking into account the stochastic quality of the cores. To realize the stochastic quality, several scenarios for different quality levels are created and weighted with their probability of occurrence.

2.3. Research gap and implications

When researching business models in CE, it is striking that so far there are only few approaches dealing with the simulation of a business model in the CE, through which possible outcomes of the effects are investigated, e.g. (Lieder et al., 2017; Panarotto et al., 2017; Asif et al., 2016). The most detailed and relevant simulation study is provided by Lieder et al. (2017), because it incorporates characteristics and decisions of individual customers regarding circular products over a certain period of time. However, this approach lacks the possibility to derive implications for the production strategy of global CE operations. Therefore, it needs further investigation in this regard.

Regarding the production network configuration all approaches in the literature consider a greenfield network. The approach at hand, however, considers the complete network as a brownfield, which means that every type of facility can have existing locations which can be closed and can have potential locations which can be opened during the run time of the optimisation.

Furthermore, the relationship between production network planning and the configuration of the associated business models in CE is not examined in detail yet. Only few authors (e.g. (Tolio et al., 2017; Mont et al., 2006)) mention the need for network configuration when adjusting CE business models. They also lack a systematic approach to investigate which impact different network configurations have on the choice of an appropriate business model and vice versa. The article at hand aims to close this research gap by presenting a framework for the integrated production network and business model configuration for implementing CE.

3. Aim of the work

The aim of this work is to develop a framework for the integrated analysis and optimisation of business models and the corresponding network configuration for implementing a global CE. This framework supports decision makers in their strategic decisions due to the fact that these are taken with a long-term horizon and are thus only reversible at great expense (Abele et al., 2008). The framework for developing implementation strategies for CE in global production networks is realized by conducting an integrated simulation and optimisation of the current as well as potential future business models and the production network configuration. By integrating these two methods, it is possible to derive implications of action and improvement measures. This will be performed by backwards induction and the identification of migrations paths. The framework is presented in detail in the next chapter.

4. Framework for developing implementation strategies for circular economy

Fig. 1 shows the framework for developing implementation strategies for a global CE. It consists of two main aspects, i.e. the *simulation module* and the *optimisation module*. Regarding the *simulation module*, the business models are simulated with a special focus on the individual behaviour of each customer, which is a crucial factor with regards to the success of a CE (Lieder et al., 2017). Due to the fact that it is a difficult task to gather such data, different methods and assumptions shall be used to realise the simulation. First of all, a differentiation between (many) individual customers and (few) key accounts might help. Focusing on key accounts, e.g. contracted workshops, will facilitate the detailed simulation. Moreover, a clustering of different customer groups seems reasonable and feasible. At last, stochastic modelling tools can be used to consider uncertain parameters based on well-grounded distribution assumptions. Moreover, the production network is simulated including all network objects of a traditional linear economy (e.g. suppliers, production sites, and distribution centres) and objects of a CE (e.g. collection centres, remanufacturing sites, and disposal locations). Moreover, the links between network

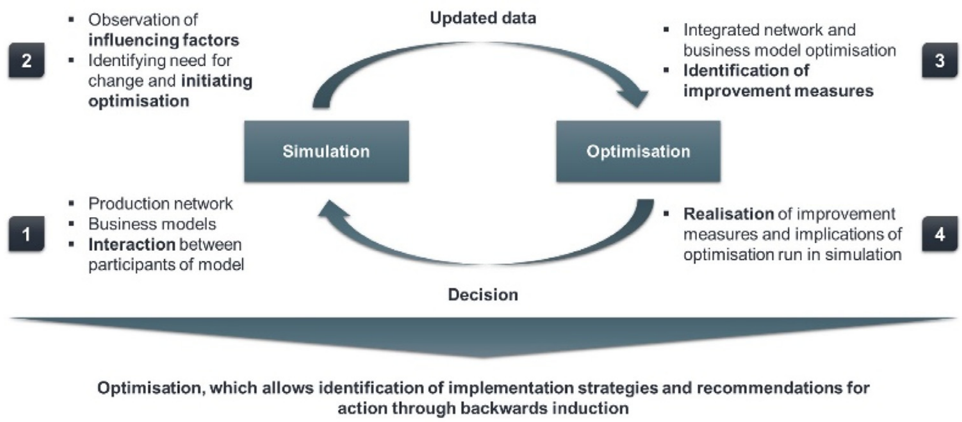

Fig. 1. Framework for developing implementation strategies for circular economy in global production networks.

objects in terms of transport connections of various transportation modes are modelled. Within the *optimisation module* of the framework, all aspects regarding business models (e.g. selection and scaling) as well as the network objects (e.g. opening/closing of locations, change of transport connections) are considered and analysed and define the solution space of the optimisation itself. As stated by März et al. (2011) combining simulation and optimisation methods leads to exploiting the advantages of both methods. In general, one differentiates between hierarchical and sequential combination of simulation and optimisation, depending on the time sequence of calculations and their interdependencies. In the approach at hand, the optimisation is integrated within the simulation and the whole approach is repeated iteratively. In this case, the simulation is more or less used as a forecasting function (März et al., 2011). Thus, the whole approach is repeated several times and over a long-term, strategic time horizon. The intermediate and final results of the approach can then be used to derive generally valid migration paths for implementing CE.

4.1. Approach for implementing circular economy by integrating optimisation and simulation

In the following, a typical and exemplarily run through the framework shown in Fig. 1 is explained.

The approach starts with simulating the current status of the production network, business models and especially the interaction between the participants of the model. Moreover, the overall environment of the company is simulated. Thus, the simulation here acts as a forecasting function of influence factors, individual behaviours and aspects like product returns of remanufacturing products. If the considered company does not have any business models or processes regarding CE, then this aspects is firstly blanked out completely and will be introduced by decisions taken in the optimisation model.

In the second step, the simulation model permanently reviews and checks the influence factors and other indicators, which are relevant for the corresponding company and indicate a need for change. This might be the development of new markets, competitors entering the markets, significant changes in any kind of cost and other aspects. As soon as a certain criteria is met, the simulation model will initiate the start of the optimisation phase. A first implementation of a basic, discrete event simulation model of a global production network including CE aspects is already completed. In further industry workshops, this simulation model will be extend by relevant factors and change indicators will be defined.

The third phase is the actual integrated production network and business model optimisation. This optimisation run is initialised with the updated data of the current network configuration transferred from the simulation model. As mentioned previously, the optimisation is formulated as a mixed-integer linear program which aims to review and improve all network objects (locations, transport modes, production volumes etc.) and all aspects regarding the business models (selection, scaling, etc.). The results of this optimisation run is the identification of actual improvement measures regarding both aspects, the production network configuration and the corresponding business model. The objective function of the integrated optimisation model thereby includes sustainability aspects, e.g. as presented by Bhinge et al. (2015), who develop objectives for each of the three sustainability dimensions, i.e. economical, ecological and social sustainability. First pre-studies show that the implementation and evaluation of the optimisation program has the potential to reveal several improvement potentials. Therefore, a multi-period, multi-stage and multi-product optimisation program was modelled and implemented. The corresponding optimisation program follows the usual value stream of circular products, i.e. production - use - collection and identification - storage - cleaning and determination of second life strategy (e.g. reuse, remanufacturing, recycling) - second use. It incorporates first basic, strategic decisions like transportation connections between different stages, the opening or closing of facilities as well as different technologies or capabilities within the facilities and the determination of a second life strategy based on the categorisation of returned products in different quality classes. The modelling and implementation of specific, circular business models, their scaling and other control parameters as well as the influence of these business models to the return rate, price, and quality remains yet to be completed.

In the fourth step, these improvement measures and implications identified by the integrated optimisation model are realised in the simulation model. These pose an external decision for the simulated production network and business model, which are then again simulated over a long-term, strategic time horizon. Thus, the approach starts over at step 1, but with a new, improved state of the production network and business model configuration. The approach is continued until the end of the strategic planning horizon or the period of observation is reached.

Overall, the combination of a simulation and an optimisation allows for the identification of generally verified implementation strategies for CE and derives actual recommendations for action through backwards induction.

4.2. Expected results

The target group of the above presented approach are strategic decision makers in manufacturing companies, who manage global production networks and the overall business strategy. Additionally, these decision makers are interested in the implementation and use of CE methods, but lack a thorough understanding and methodological and structured approach for the purpose of implementing CE.

The expected benefits of the presented approach are the step-by-step and secured implementation of CE with a manageable invest in each time period. Thus, the lock-in effect of manufacturing companies can be overcome and the potentials of CE can be realized.

Moreover, the presented approach supports the understanding of interconnections and interdependencies between the configuration of the production network and the selection and configuration of matching business models. Thus, a key research gap as presented by Tolio et al. (2017) will be closed.

4.3. Exemplary use cases for the framework

A crucial factor for the successful validation and demonstration of the presented approach is the availability and integrity of detailed data, which is up to now rarely the case. For this reason, a close relationship and joint development with industry partners is ensured within different research projects. For the case that the gathered data over the whole project period might not be enough, stochastic assumptions have to be used.

The approach is planned to be validated and demonstrated in a German company supplying the automotive sector and at a German special machine manufacturer. In both cases, the companies already started a basic CE approach, i.e. by repairing or remanufacturing a small, selected share of their product programme. Building up these approaches was mainly customer and thus market driven. However, they lack the possibility of a structured decision support tool to optimise their current CE operations or identify potentials and starting points for other products to remanufacture.

Thus, within two research projects, the validation and demonstration of the presented approach will be realized by using company data and thus showing the potentials of the approach.

5. Next steps and need for further research

The next steps regarding the presented approach are (i) to continue implementing the approach including the simulation and optimisation module as well as the interfaces between them, (ii) to validate this approach using real world data of the involved companies, and (iii) to conduct research studies and derive implications for action for the corresponding companies. Furthermore, an abstraction of the results leads to the possibility to derive more general statements about an appropriate implementation strategy for CE and thus create a scientific benefit as well.

Further research might include to extend the approach to even further aspects relevant for CE. These might be the assessment and optimisation of the individual product design, IT-related support regarding cross-company and cross-sectorial collaborative platforms facilitating CE, and further aspects which might have an essential impact on the strategic implementation of CE.

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