This paper was presented at ISPIM Connects Athens – The Role of Innovation: Past, Present, Future, on 28-30 November 2022. Event Proceedings: LUT Scientific and Expertise Publications: ISBN 978-952-335-691-7. Order number in series 110.

Increasing circularity of high-tech products by multi-stakeholder value optimisation

Mona Arnold*

VTT Technical Research Centre of Finland ltd, P. O. Box 1000 02044 VTT Finland.
E-mail: mona.arnold@vtt.fi

Päivi Kivikytö-Reponen

VTT Technical Research Centre of Finland ltd, P. O. Box 1300 33101 Tampere Finland.
E-mail: paivi.kivikyto-reponen@vtt.fi

Maria Antikainen

VTT Technical Research Centre of Finland ltd, P. O. Box 1300 33101 Tampere Finland.
E-mail: maria.antikainen@vtt.fi

* Corresponding author

Abstract: Countries are increasingly seeking access to reliable, secure and resilient supplies of the critical minerals they need. High technology products including EU critical raw materials (CRMs) are not efficiently recycled and their lifetime can be relatively short.

This paper explores new sustainable value creation models in cities for increasing the circularity of selected high technology products containing CRMs. The focus in this paper is on CRMs in smart buildings and their renewable energy solutions.

The aim is to provide insights for improving the resilience of critical raw materials and to generate proposals for sustainable value for involved private and public stakeholders. It includes mapping the value chains of selected CRMs containing products and based on the 9R framework (Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle and Recover), we create an understanding on the value optimization and operationalization of the chosen R strategies involving public, private organisations and consumers.

Keywords: critical raw materials; circularity; circular economy; value creation; value chain; circular business model; smart buildings

This paper was presented at ISPIM Connects Athens – The Role of Innovation: Past, Present, Future, on 28-30 November 2022. Event Proceedings: LUT Scientific and Expertise Publications: ISBN 978-952-65069-1-3.

1 Introduction

The circular economy (CE) aims to offer solutions to major sustainability challenges we are facing, such as resource scarcity (Peck et al., 2015) and growing waste streams (MacArthur, 2013). Circularity is especially essential for critical raw materials, the supply of which is considered far from risk-free. Secured provision of many of these elements is essential for important functions of the society green transition, such as electrification (batteries, magnets) and renewable energy (photovoltaics, magnets). Today, the use of critical raw materials in the EU economy is far from being fully circular (Mathieux et al., 2017) and there is a need to find efficient and innovative solutions on how to keep these critical materials in the economy.

The study focuses on the circular economy of critical raw materials with collaborative value creation models in increasingly smart cities. This requires technological development but likewise innovations in business models and partnerships. In this aspect, the role of city actors and the citizen are imperative and their collaboration with businesses.

This paper concentrates on the application area smart buildings, which through increasing use of sensors and control applications is becoming a significant destiny for many critical raw materials (CRM) containing digital products. Moreover, through photovoltaic energy production and associated batteries and connection to smart grids, constructions are becoming virtual power plants with control algorithms for the buildings' demand and response of energy.

The main research questions in the study are how in this specific segment - smart buildings - sustainable business models can be built for higher circularity of CRMs and to explore what kind value is created by which party - looking broadly at both social, economic and sustainability impacts and the role of cities in design and implementation of circular economy. We are especially interested in the role of a city and how this public party can support higher circularity and circular business models.

2 Methodology

2.1 Case description

Based on expert interviews on smart buildings, related hardware and their lifecycle, intelligent energy management together with local renewable energy production was chosen as a specific application in this segment. The concept includes an intelligent microgrid which can become part of the wider national or regional energy system. The property can both produce its own energy with the help of solar panels and automatically regulate its energy consumption by purchasing, storing and consuming energy according to the current need (Figure 1). For the property, it is part of the strategy for sustainable construction and to utilise new energy sources as efficiently as possible.

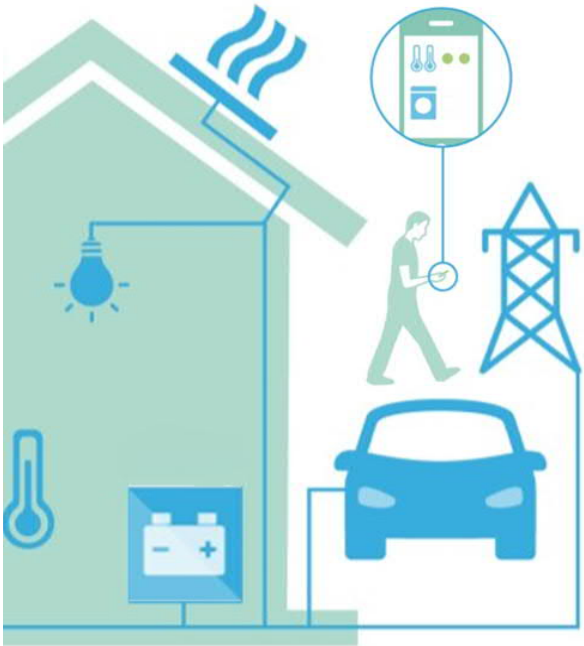

Figure 1 The Smart Building concept. Modified from Ketomäki 2022.

The property acquires the required hardware (PC panels, batteries) sometimes under a leasing contract also including the installation and maintenance of the system and software for smart control. Due to the financial terms the client ultimately normally redeems the equipment after a certain period and uses it until the end of its practical use life. Thus, the end of life management is fully in the hand of the property. With respect to circularity, the business ecosystem which can evolve around such concept includes maintenance and repair services, waste management and recycling, facilitation of refurbishment (e.g., end of use product tracking, second hand market brokerage) etc.

2.2 Data collection and analysis

Data was gathered through interviews of industrial actors representing the construction and IT/energy industry. Moreover, interviewees included public actors (city representatives) and academia. Altogether twelve interviews were conducted for this particular segment, which included six company interviews, four interviews with the academic actors and two with cities (Espoo and Helsinki).

We used a semi-structured interview guide that was modified based on the interviewee's position and background. Interviewee's represented different positions such as company CEOs, energy experts, city officers. Interviews lasted from 20 minutes to 70 minutes, were conducted on-line and partly recorded. The analysis was done by iterative round in which we categorised and re-categorised the results.

This paper was presented at ISPIM Connects Athens – The Role of Innovation: Past, Present, Future, on 28-30 November 2022. Event Proceedings: LUT Scientific and Expertise Publications: ISBN 978-952-65069-1-3.

Interviews were complemented with professional and academic literature and expert knowledge on the occurrence of CRMs in various products and potential circular processes involving these products.
The analysis of the studied case was done using Brehmer et al.'s perspective on how value is created and captured across organizational boundaries, by investigating the value transfers between the focal organization and the external network of business model actors. It incorporates environmental and social sustainability established in the content, structure, and governance of the business models (Brehmer et al., 2018).

3 Theoretical background and framing

3.1 Circular business models (CBM) from boundary spanning perspective

Business model innovation is a key factor for organizations to achieve their social and environmental goals by utilizing environmentally, socially and economically efficient technologies and solutions (Boons and Lüdeke-Freund, 2013; Geissdoerfer et al., 2016; Rashid et al., 2013). Companies using circular economy business models can improve their economic, social and environmental performance (Nidumolu et al., 2009; Porter and Kramer, 2011) and protect themselves from environmental risks (Evans et al., 2009; Freeman, 2017).
Based on the extensive literature on circular business model innovation and circular business models, Geissdoerfer et al. (2020) define CBMs in the following way*:* "business models that are cycling, extending, intensifying, and/or dematerialising material and energy loops to reduce the resource inputs into and the waste and emission leaking out of an organisational system. This comprises recycling measures (cycling), use phase extensions (extending), a more intense use phase (intensifying), and the substitution of products by service and software solutions (dematerialising).
The circular economy requires cross-border cooperation between actors (Boons and Lüdeke-Freund, 2013), and a cross-border perspective on the business model offers analytical power to study such interaction (Zott et al., 2011). To better understand value creation and capture from a circular economy perspective, we choose a cross-border perspective on BM that focuses on value transfers (i.e., transactions) between the target organization and actors outside its value network (Zott et al., 2011, Amit & Zott, 2012).
In this study, business models are evaluated utilising the framework presented by Brehmer et al 2018. They demonstrated that analysing the environmental and social sustainability of organizations using the boundary-spanning perspective on business models provides complementary insights to the traditional component-based view of the business model. This perspective focuses on how value is created and captured across organizational boundaries, by investigating the value transfers between the focal organization and the external network of business model actors and public entities.

3.2 9R-Strategies

For increased circularity we followed the 9R conceptual framework, which concerns the role of innovation in circular economy transitions in product chains (Potting et al. 2017). 9Rs stands for Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle and Recover that presents the material and product circularity strategies. These strategies are grouped and put in order of preference in Fig 2. Each group involves different type of actors and applicable business models.

The first group, *Smarter product design, manufacture and use* strives to achieve lower material input and lower consumption through multifunctionality, which requires product innovation and is basically in the hands of material producers, product manufacturers and (eco)designers. The second group deals with *Extended lifespan of products and its parts,* enabled by innovations in product design and socio-institutional changes. Lastly developing -*closed loop and recycling solutions for materials and energy* avoiding down-cycling.

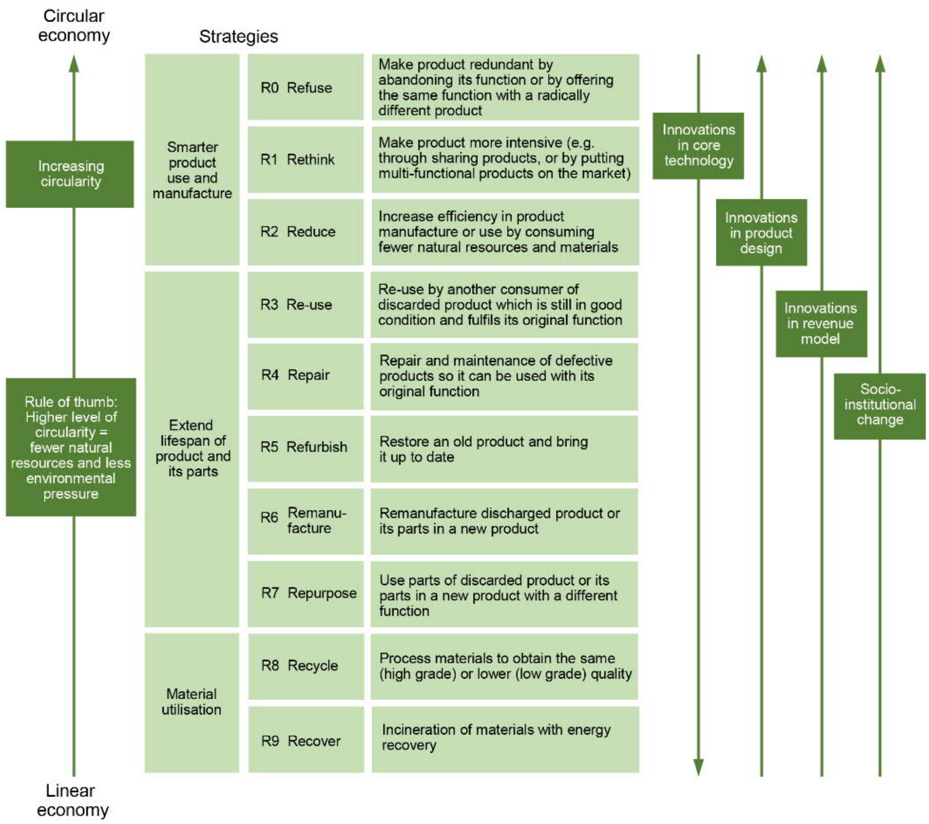

Figure 2 Circularity strategies within a production chain, in order of priority. Adapted from **Potting et al. 2017.**

3.3 Critical materials in smart buildings

While there is no agreed academic definition of a smart building (Buckman et al. 2014) it is commonly appraised as a structure that uses automated processes to automatically control the building's operations including heating, ventilation, air conditioning, lighting, security and other systems, maximizing user comfort while minimizing energy consumption. This includes a wealth of sensors embedded or applied in the building, together with analysis and control which can be either physically in the building or in a cloud. Although many sensors can include critical materials and CRMs. the amount per sensor is infinitesimal, and very dispersed around the building. Common practice does not include the recovery or reuse of such items after their end of life, but they are left at their place when replaced with updated peers (interviews).

Buildings taking active part of the smart grid is an evolving system innovative approach that can entail using the building as a power generation unit by applying solar panels and/or small scale windmills feeding into the grid when not used for own purposes or storing surplus energy temporarily with batteries and using the power when the economically beneficial, depending on the spot price of electricity. Such systems normally come with automatic control and linked to the grid owner. Especially applications, which comprises also a set of batteries, contain already noticeable amount of CRM.

For renewable energy applications, commonly applied batteries are lithium iron phosphate ($LiFePO_4$) (e.g., Fortune Business Insight 2022). $LiFePO_4$ act as the cathode material alongside a graphite carbon electrode with a metallic backing as the anode. Lithium, natural graphite and phosphate rock are listed as critical materials for Europe's economy (European Commission 2020). In a large commercial building, the battery is made of blocks which, in total, can make the size of a commercial container (interview).

While the major materials in a PV panel are glass and aluminium, it also contains some metals and semiconductors (~ 5%). Here, indium and gallium can be found in the semiconductors (Ebin, 2021). Moreover, Silicon metal, listed as an EU Critical raw material is needed for solar cell raw material. Silicon solar cells are the most common cells used in commercially available solar panels (Lees and Fugmann 2021).

4 Results

Figure 3 depicts the business ecosystem around the smart building concept with indication of the local public sector's role in promoting increased circularity of the products used in the concept. The scheme follows the framework presented by Brehmer et al (2018) and depicts the current state and is based on interviews related to the case of a large commercial building housing a shopping mall.

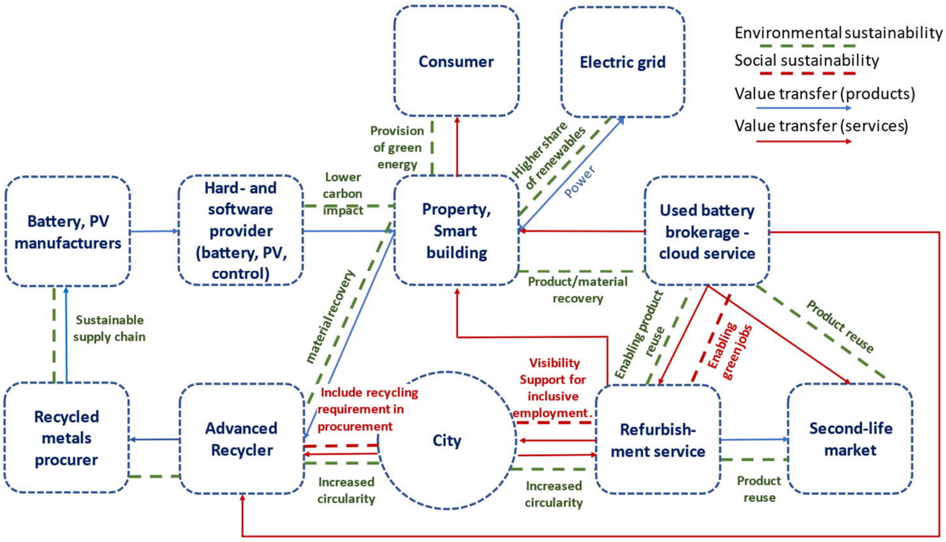

Figure 3 Business ecosystem including sustainability value creation. Case: Smart building as part of the local renewable energy system.

As depicted in Figure 3, value transfer is in many cases combined with economic and/or social sustainability. Environmental sustainability is connected to both product and service based value transfer, whilst social sustainability was seen to link primarily to public actors' activities and also to a certain degree to private services, which can support the generation of new green jobs.

Though direct business operations by public entity is, by law, constrained, the cities can take numerous active roles in enhancing the circularity of critical materials in the society. Based on interviews of two cities in Finland, currently the circular economy targets of the cities as public bodies are more focused end-of-life recycling of municipal waste, and in general recycling instead on lifetime extension strategies of goods and other waste preventive actions. The significant power a city has to support circularity is not well acknowledge across the organisation. As large procurers they have the power to set high standards for the supplier on the circularity of goods and services the city is purchasing and also set examples with their own activities e.g., in this case, energy management in their own buildings. This can give a good market push towards more sustainable business strategies of the suppliers, something which would not necessarily take place, based solely at economic terms. Moreover, as a large procurer, the city can play a role in generating economy of scale, when it comes to generating critical mass for advanced recycling, aiming at the recovery of target critical elements or enabling repair or refurbishment services for a certain product containing critical materials, in this case batteries or photovoltaics.

5 Discussion and Outlook

The study revealed limited efforts and business models around increasing circularity of critical materials in the application in question. This can be partly because of the novelty of the concept, and/or the fact that as such there is little economic incentives to keep critical materials in the loop, due to very dispersed amounts in the products in question.

However, following the three categories of the 9R strategy (Figure 2), the following circular options can be applied, with possible involvement of new actors (Table 1):

Table 1 Potential R strategies for distributed renewable energy production in smart buildings.

Strategies for enhanced circularity	*Possible routes*
Smarter product use and manufacture	Substitution of lithium with less critical elements with a higher circularity. Modulised manufacturing enable easy exchange of module.
Extend lifespan of the product and its parts	Refurbish and remanufacturing. Collaboration with battery technology experts and brokerage services such as Nortical. Reapplied in less demanding environment and sold on second-life markets e.g. to consumers. Repair of broken panels. Improving product durability with material choices, to slow down aging,
Useful application of materials	Recovery of critical raw materials (Li) and other critical elements from the recycled material. Requires collaboration with recyclers and development of advanced recycling systems. Recovered material can be used for the manufacturing of new batteries.

In principle, also reuse of batteries is possible. However, in this case, the equipment is planned to be used in until its end of life (15-2 years). The lifespan of a stationary battery is ca 15 years (Pirhonen 2022)., In case of demolition, refurbishment and/or remanufacturing would in principle be the preferably strategy for value capture compared to material recycling. However, the long lifespan of a building (30-50 years) and that of batteries (ca 15 years) means that the technology is outdated and recovered batteries would need to after refurbishment, be applied in other, less demanding applications.

Recycling and recovery of critical material or elements has been seen as an important step to increase the resilience of the supply chain of products containing critical raw materials. However, within the circularity strategies, recycling (R8, Fig 2) is generally a less preferable option and strategies further up in the hierarchy should be considered (e.g. Potting et al., 2016). Reducing (R2) the use of critical material would in this case mean substituting the component with less critical material content in the products still delivering the same function. Such option, e.g. organic batteries, is yet not commercially available and requires long-sighted further technology development (Kim et al. 2022). Still the substitution can be considered widely, instead of element to element substitution, material to material, function to alternative function or alternative product or service substitution may be an option.

Refurbishment and remanufacturing and succeeding reuse (R5-R6) of batteries and panels would require modular construction practices, enabling easy assembly and disassembly of the products. In principle this option is possible, and there is an opportunity for the establishment of such services combined with repair and maintenance services. The fact that the new technologies are developing fast, thus rather replaced with new products than maintained for extended lifecycles, is in practice seen as an obstacle to the evolvement of models supporting higher product circularity. Therefore, the product design to support upgradability during the coming years could be more carefully taken into consideration.

One often mentioned strategy for increased reuse would be to establish a service oriented model (see for instance, Bocken et al. (2016)), i.e. the leasing of a PV system with adherent control demand response systems. Such system enables economy of scale when the system provider operates several similar entities and can make an impact down the value chain. This model also potentially encourages the maintenance of products and offers users lower risk and easy solution. Examining current practices gives that such models require careful pricing and incentive for the properties to allow take back of the system when approaching its end of life (Vuola 2022). However, in practice, the rather long life spans of the components in the photovoltaics and battery system (+15 years) do not easily support such business models. In the short-term perspective, enabling increased recycling of batteries and solar panels can have the largest impacts on circularity.

To ensure increased circularity in the future, other options, such as leasing combined with takeback systems, reuse, maintenance, repair and refurbishment, other sharing models should be considered for optimal resource use, and lifespan extension for critical materials. Cities can take a considerable stronger role in promoting such strategies, notably by, firstly, applying them on public buildings and construction and generally incorporating circularity criteria more strongly in their procurement.

6 Areas for feedback &development

We would like to receive feedback on the following topics:

- General feedback on the paper (relevancy, topic)
- How do you see the public sector promote circular businesses as efficiently as possibly?
- What other useful frameworks for evolving circular business models can be used?

References and Notes

Amit, R., & Zott, C. (2012) Creating value through business model innovation. *MIT Sloan Management Review* 53. Available at: http://marketing.mitsmr.com/PDF/STR0715-Top-10-Strategy.pdf#page=38

Antikainen, M., Valkokari, K. (2016). A Framework for Sustainable Circular Business Model Innovation, Technology Innovation Management Review. Carleton University. Vol. 6 (2016) No: 7, 5-12.

Bocken, N.M.P., de Pauw, I., Bakker, C., van der Grinten, B., 2016. Product design and business model strategies for a circular economy. J. Ind. Prod. Eng. https://doi.org/10.1080/21681015.2016.1172124

Boons, F., & Lüdeke-Freund, F. (2013) Business models for sustainable innovation: state-of-the-art and steps towards a research agenda. *Journal of Cleaner production*, *45*, 9-19.

Brehmer, M., Podoynitsyna, K., & Langerak, F. (2018) Sustainable business models as boundary-spanning systems of value transfers. *J. of Cleaner Production*, 172, 4514-4531.

Buckman A., Mayfield M and Beck B. (2014) What is a Smart Building? Smart and Sustainable Built Environment, Vol. 3 (2) 2 pp. 92 – 109.

Geissdoerfer, M., Pieroni, M. P., Pigosso, D. C., & Soufani, K. (2020) Circular business models: A review. Journal of Cleaner Production, 277, 123741.

Ebin, B. (2021) Critical Raw Material Circularity for Solar Cell Technologies and Material Recycling Options. Presentation at the Circular Materials Conference 2021. Sweden.

Evans, S., Gregory, M., Ryan, C., Bergendahl, M., Tan, A., 2009. Towards a sustainable industrial system: With recommendations for education, research, industry and policy (18) (PDF) The Circular Economy – A new sustainability paradigm?. Available from: https://www.researchgate.net/publication/311776801_The_Circular_Economy_-_A_new_sustainability_paradigm [accessed Nov 04 2022].

Fortune Business Insight (2022) Lithium iron battery market. Market report. Abstract available at: https://www.fortunebusinessinsights.com/lithium-ion-li-ion-phosphate-batteries-market-102152.

Freeman, R. & Dmytriyev, S. (2017) Corporate social responsibility and stakeholder theory: Learning from each other. Symphonya. Emerging Issues in Management, (1), 7-15.

Ketomäki J. (2022) Rakennusten älyindikaattori. Smart readiness indicator (SRI). Presentation at the Motiva Building maintenance days 19.3. 2022. Helsinki.

Kim, J., Kim, Y., Yoo, J. et al. (2022) Organic batteries for a greener rechargeable world. *Nat Rev Mater*. https://doi.org/10.1038/s41578-022-00478-1

Lees E. and Fugmann U. (2021) What you need to know about polysilicon and its role in solar modules. BNP Viepoint Highlights. Available at: https://viewpoint.bnpparibas-am.com/what-you-need-to-know-about-polysilicon-and-its-role-in-solar-modules/

MacArthur, E. (2013) Towards the circular economy. *J. of Industrial Ecology* 2(1), 23-44.

Mathieux, F., Ardente, F., Bobba, S., Nuss, P., Blengini, G., Alves Dias, P., Blagoeva, D., Torres De Matos, C., Wittmer, D., Pavel, C., Hamor, T., Saveyn, H., Gawlik, B., Orveillon, G., Huygens, D., Garbarino, E., Tzimas, E., Bouraoui, F. and Solar, S., (2017) Critical Raw Materials and the Circular Economy – Background report, EUR 28832 EN, Publications Office of the European Union, Luxembourg.

Nidumolu, R., Prahalad, C. K., & Rangaswami, M. R. (2009). Why sustainability is now the key driver of innovation. *Harvard business review*, *87*(9), 56-64.

Peck, D., Kandachar, P. and Tempelman E. (2018) Critical materials from a product design perspective, Mater. Des., 65 (2015), pp. 147-159, 10.1016/j.matdes.2014.08.042

Pirhonen V. (2022) Pirhonen V. Vibeco ltd, CEO. Personal communication. April 2022

Porter, M. E., & Kramer, M. R. (2011). Creating shared value: Redefining capitalism and the role of the corporation in society. *Harvard Business Review*, *89*(1/2), 62-77.

Potting, J., Hekkert, M., Worrell, E., Hanemaaijer, A. (2017) Circular Economy: Measuring Innovation in Product Chains. The Hague. *PBL Publications* 2544

Rashid, A., Asif, F. M., Krajnik, P., & Nicolescu, C. M. (2013) Resource conservative manufacturing: An essential change in business and technology paradigm for sustainable manufacturing. *Journal of Cleaner production*, *57*, 166-177

Zott, C., Amit, R., & Massa, L. (2011) The business model: recent developments and future research. *Journal of Management*, *37*(4), 1019-1042.

Vuola A-P. (2022) Vuola A-P. Siemens Financial Service, Regional Director. Personal communication. October 2022.