From requirements to a research agenda for governments governing reuse of critical raw materials in the circular economy

van Engelenburg, S.H.; Rukanova, B.D.; Ubacht, J.; Tan, F.S.; Tan, Y.; Janssen, M.F.W.H.A.

DOI
10.1145/3543434.3543645

Publication date
2022

Document Version
Final published version

Published in
Proceedings of the 23rd Annual International Conference on Digital Government Research

From requirements to a research agenda for governments governing reuse of critical raw materials in the circular economy

Selinde Van Engelenburg
Delft University of Technology
S.H.vanEngelenburg@tudelft.nl

Boriana Rukanova
Delft University of Technology
B.D.Rukanova@tudelft.nl

Jolien Ubacht
Delft University of Technology
J.Ubacht@tudelft.nl

Siu Lie Tan
Circular Symbiosis
siulie.tan@circularsymbiosis.com

Yao-Hua Tan
Delft University of Technology
Y.Tan@tudelft.nl

Marijn Janssen
Delft University of Technology
M.F.W.H.A.Janssen@tudelft.nl

ABSTRACT

Governmental organisations use a diversity of policy instruments for sustainability goals. In the field of materials, they aim to advance the reuse of materials on the one hand. On the other hand, they also want to control critical raw materials (CRMs) to protect society against scarcity. Information sharing is required to monitor for both objectives. Research into information sharing for the circular economy mainly focuses on using ICT to follow entire products, such as digital product passports. However, research into information sharing for reuse flows and monitoring at the level of materials is limited so far. Therefore, in this paper, we derive the following requirements for information sharing to support the monitoring of materials and CRMs in particular: 1) businesses and government organisations should have access to the complete history of materials; 2) businesses should be able to share information on materials between different supply chains and industries; 3) information on materials should be reliable and tamper-resistant; 4) governments should be able to obtain a complete overview of the pool of CRMs in circulation and of who is responsible for them; 5) the system supporting the information sharing on materials should be highly robust and should not have a single locus of control. Based on this overview of requirements, we present a research agenda in which we identify challenges and related future research questions.

CCS CONCEPTS

• **Applied computing** → Computers in other domains; Computing in government; E-government; Operations research; Industry and manufacturing; Supply chain management; • **Information systems**;

KEYWORDS

Circular Economy, Interorganisational Information Systems, Business-to-Government Information Sharing, Critical Raw Materials

dg.o 2022, June 15–17, 2022, Virtual Event, Republic of Korea

ACM ISBN 978-1-4503-9749-0/22/06.
https://doi.org/10.1145/3543434.3543645

ACM Reference Format:
Selinde Van Engelenburg, Boriana Rukanova, Jolien Ubacht, Siu Lie Tan, Yao-Hua Tan, and Marijn Janssen. 2022. From requirements to a research agenda for governments governing reuse of critical raw materials in the circular economy. In *DG.O 2022: The 23rd Annual International Conference on Digital Government Research (dg.o 2022), June 15–17, 2022, Virtual Event, Republic of Korea.* ACM, New York, NY, USA, 6 pages. https://doi.org/10.1145/3543434.3543645

1 INTRODUCTION

Governmental organisations often monitor compliance in supply chains by following entire products (see, e.g., [30]). Yet, monitoring materials from which these products are made in a circular economy (CE) is also vital for governmental organisations [25, 26]. Without the proper monitoring of materials, policy measures to stimulate circularity and protect safety may be subject to abuse and thus fail to achieve their intended goals. A lack of information for government and businesses can harm the safety of recycling and reuse processes and resulting materials and make it more challenging to maintain their value [28]. Monitoring of materials is particularly important for *Critical Raw Materials* (CRMs) that are essential for the functioning of society while, at the same time, are at risk of becoming scarce [33]. Monitoring can support the prevention of scarcity or inform the choice and deployment of strategies to address scarcity.

Digital technologies are vital for creating visibility in a CE for businesses and government, but research in this area is limited [40]. Information systems often align with the structure of linear (i.e., non-circular) supply chains. As such, information sharing starts at the producer and is enriched by different parties in the supply chain involved in the production or transportation of the product (see, e.g., [15, 18]). Usually, information sharing ends when the product arrives at the consumer. Likewise, public monitoring usually follows the same model, starting with the producer and ending with the consumer.

This linear information sharing and supervision model is suitable for following products downstream from the producer to the consumer. Yet, in a CE, materials remain in circulation such that nature tolerates the throughput flow [19]. Therefore, products' components and materials need to be repaired, remanufactured, reused, recycled, or upcycled at the end of their life cycle. Subsequently, they re-enter the economy in an upstream materials flow. Supply chains in a CE are thus structurally different from those in a linear economy. The linear model of information sharing and supervision leaves out of sight the upstream processes and does not support a robust way of following materials through several cycles. Hence, our research objective is to explore how information sharing on raw materials flows needs to be (re)designed to support the circularity of raw materials and to monitor the scarcity of CRMs. We do so by discussing the requirements for information sharing on raw materials in a CE in section 2. Next, discuss the challenges to meeting these requirements in section 3. In section 5, we present our research agenda.

2 REQUIREMENTS FOR MONITORING MATERIALS IN A CIRCULAR ECONOMY

Information sharing for tracing goods in a CE is essential (see, e.g. [1, 12, 20]). Information sharing is necessary for several objectives and stakeholders, which calls for a diversity of requirements for the information sharing process. In this section, we present these objectives and based on them, we formulate requirements.

We did not perform a complete, systematic literature review for this study, as our paper aims to develop an initial research agenda. Our perspective was to identify important examples of requirements in literature and policy reports giving rise to new challenges that need addressing. To this end, we used the referenced sources in this section. Hence, we do not claim to be exhaustive but rather present an initial holistic overview of challenges to which other perspectives can be added.

Materials can deteriorate over time, and contamination negatively influences materials' quality and value [23]. Whether reuse of materials is possible in certain products (e.g., food packaging) depends on their quality and history. Therefore, information on the history of the actual use is necessary to enable reuse and recycling, as it supports sorting and harvesting and helps to understand potential hazards and contamination [20, 32]. For the government, ensuring compliance with laws and regulations for promoting and ensuring safe circular processes also requires such a history. Furthermore, information is necessary to evaluate the effectiveness of policies like extended producer responsibility schemes promoting the uptake of secondary raw materials in production processes [5]. In some cases, relevant properties of materials (e.g., purity) can be measured. However, loss of history makes it challenging to act when new insights arise on harmful effects of materials later (e.g., in the case of PFAS) [2]. Therefore, *the first requirement is that businesses and government organisations should have access to the complete history of materials.*

In upstream processes, materials from a product can end up in the same or a different supply chain of other products or even in other industries. For example, metal from machinery can be reused in the construction of buildings [10]. When materials can cross the boundaries of industries, the options for reuse increase, which extends their market and thus market value. Furthermore, the prices of upstream processes can be reduced by creating economies of scale [22]. Therefore, *the second requirement is that businesses should be able to share information on materials between different supply chains and industries.*

To protect against (artificially created) scarcity and ensure safe reuse and recycling, governmental organisations need to detect potentially fraudulent behaviour, such as exporting materials to evade regulations and so-called 'greenwashing'. Ensuring compliance is especially important when recycling costs are high and the quality and price of recycled materials low [26, 27]. *The third requirement is thus that the information on materials should be reliable and tamper-resistant.*

Establishing a CE is necessary to protect against resource scarcity and price volatility for CRMs [31, 33]. Monitoring these materials is vital to prohibit undue dependency for their supply on other regions, countries, or sources where, e.g., the fair treatment of workers or sustainability is not guaranteed [33]. Furthermore, it needs to be ensured that no artificial scarcity is created to increase prices, e.g., due to geopolitical conflicts or private business objectives. Both government and businesses need to be able to anticipate scarcity. When it is known that a CRM is scarce, businesses can eco-design with substitutes, and governments can introduce extra taxes to discourage their use [33]. In addition, governments may need to prioritise the application of CRMs with higher social value. For example, suppose a shortage of batteries arises due to the scarcity of its components. Then, the government might want to prioritise their use in life-saving medical systems over gaming computers. Detecting scarcity and the ability to act upon it can be facilitated by an overview of the materials in circulation and parties to be held accountable when materials disappear or are reused inefficiently. However, data on the quantity and whereabouts of materials are often unstructured and scattered amongst various institutions and industries [14]. Therefore, as a *fourth requirement, governments should be able to obtain a complete overview of the pool of CRMs in circulation and of who is responsible for them.*

If a system supporting information sharing on materials fails, this could severely impact upstream processes and government supervision. We thus need to avoid a single point of failure or a single point of attack. Simultaneously, considering the scale of such a system, it is unlikely that stakeholders will accept a dominant stakeholder having extensive power over the system. *The fifth requirement is thus that the system supporting the information sharing on materials should be highly robust and should not have a single locus of control.*

Information sharing at the level of products is still necessary for a CE; this is at least as necessary as for a linear economy. However, existing solutions, such as digital product passports, focus only on the level of products or a particular industry (see, e.g., [4, 6, 24, 39]). When materials are tracked, it is typically only in the first part of the downstream process until they end up in a product (see, e.g., [38, 41]). As such, they do not meet the requirements formulated. Thus, alternatives for information sharing supporting the monitoring of materials in a CE are required.

3 CHALLENGES FOR MONITORING MATERIALS IN THE CIRCULAR ECONOMY

Based on the requirements in section 2, we created an overview of challenges for monitoring materials in the CE (see Table 1). Section 4 translates these challenges into research questions for which answering it would contribute to solving them to formulate a research agenda. In the remainder of this section, we discuss each challenge in more detail. This overview is not intended to be exhaustive but

Table 1: Challenges for monitoring materials in the CE, based on the requirements

Related Requirements (R)	Challenges (C)
R1. Businesses and government organisations should have access to the complete history of materials.	C1. Making the information necessary for supporting circular processes and monitoring materials available for a long period of time (at least decades).
R1. Businesses and government organisations should have access to the complete history of materials. R3. The information on materials should be reliable and tamper-resistant.	C2. Tagging and identifying materials so that the tags cannot be tampered with and do not harm the environment, and such that materials can be followed through different cycles, in various states and when mixed and converted.
R1. Businesses and government organisations should have access to the complete history of materials. R2. Businesses should be able to share information on materials between supply chains and industries. R3. The information on materials should be reliable and tamper-resistant.	C3. Identifying incentives for businesses to share reliable and up-to-date information on materials with all businesses and government organisations needed to support circular processes and monitoring.
R1. Businesses and government organisations should have access to the complete history of materials. R2. Businesses should be able to share information on materials between supply chains and industries.	C4. Appropriately balancing the risks of information sharing for businesses with the benefits of information sharing for supporting circular processes and monitoring.
R4. Governments should be able to obtain a complete overview of the pool of CRMs in circulation and who is responsible for them	C5. Determining the appropriate granularity of batches of materials for assigning IDs
R1. Businesses and government organisations should have access to the complete history of materials. R2. Businesses should be able to share information on materials between supply chains and industries. R5. The system supporting information sharing on materials should be highly robust and should not have a single locus of control.	C6. Appropriately balancing the scalability of the information sharing with the information sharing needs of businesses and government.
R1. Businesses and government organisations should have access to the complete history of materials. R2. Businesses should be able to share information on materials between supply chains and industries. R5. The system supporting information sharing on materials should be highly robust and should not have a single locus of control.	C7. Creating a governance model for the information systems supporting the monitoring of materials.

rather to initiate a discussion and stimulate research to address the challenges or extend this initial overview.

Several challenges are associated with making the complete history of materials accessible (R1). Materials might be in many different cycles, especially when recycling technology improves. Furthermore, some products need to be recycled even after decades (e.g., building materials). However, making information available, even after decades, is difficult as a lot might change over time. The parties making information available might stop doing so. For example, a producer making available information on materials in their products might go bankrupt. Another difficulty is that data formats, information systems, and even the required content might change over time due to new developments. Therefore, *challenge 1 is to make the information necessary for supporting circular processes and monitoring materials available for a long period of time (at least decades).*

Following materials through different cycles to create a history (R1) requires identifying them. For products, this can be done by assigning an ID and tagging them (e.g., using barcodes). However, for materials, this is more difficult. Different materials, e.g., powders and liquids, have different physical properties creating varying (tagging) requirements. Furthermore, materials can be in different states (e.g., window glass, culets/shards), divided, (irreversibly) mixed with other materials (e.g., composites in blades of windmills) or converted into others. This requires flexible tagging and representation. To make matters more complex, tagging methods should not harm the environment. Furthermore, tags need to be tamper-resistant (R3) to connect information and materials securely. Therefore, *challenge 2 is to tag and ID materials so that the tags cannot be tampered with and do not harm the environment, and such that materials can be followed through different cycles, in various states and even when mixed and converted.*

As discussed, sharing information on materials can benefit society. However, obtaining information is also in the direct interest of some businesses. For example, a recycler can use instructions from producers to recycle materials more efficiently, determine their value and weigh this against recycling costs. Sharing can also benefit businesses. For example, a recycler who wants to sell materials finds more buyers if they share reliable information about their qualities. Yet, even in linear supply chains, aligning the incentives for different businesses is often difficult [21]. There is no reason to not expect such misalignment in a CE in which many different supply chains get entangled as materials get from one to the other. This means that there will be cases in which businesses might not perceive a direct benefit of sharing the history of materials (R1) with the government and businesses in other supply chains or industries (R2). Especially businesses downstream the value chain, such as manufacturers, micro, small and medium enterprises, might not directly benefit from recuperating materials from secondary sources in the upstream value chain, let alone other supply chains or industries. Therefore, they might not be incentivised to contribute to this process. Consequently, governmental organisations cannot use their data. Additionally, facilitating information sharing entails investments for companies into their ICT infrastructure and thus raises their administrative costs. Without a direct benefit, businesses have little incentive to make these investments. Furthermore, without an incentive, they might not be inclined to ensure the quality of information, which harms its reliability (R3). Therefore, *challenge 3 is identifying incentives for businesses to share reliable and up-to-date information on materials with all businesses and government organisations needed to support circular processes and monitoring.*

Even if businesses have incentives to share information, they might still perceive risks. According to the literature, businesses view autonomous control over data and sharing arrangements as key to their competitive position [11, 16, 35, 36]. Businesses may fear that if they open up information, they will be more vulnerable to misuse of the data or opportunism by others, and that sensitive information is not kept confidential [9, 13, 17, 29, 37]. We expect that this fear will be no different in a CE. In fact, it might be worse as additional information sharing is required with a broader set of parties (R1, R2).

Some solutions for keeping information confidential and access control include using encryption or only sharing aggregated information or links to information. However, these measures each have their disadvantages. For example, encrypting data or sharing links harms transparency and means that we need additional processes for sharing keys or the actual information that is linked [7]. On the one hand, aggregated data can be perceived as less sensitive in some cases, making it more challenging to identify a particular business or shipment. However, on the other hand, the possibility of data aggregation might be perceived as a threat, e.g., when data analytics can be applied to it [8]. It is thus imperative to find ways of information sharing that strike an appropriate balance between the risks perceived by businesses and the need for information sharing to support circular processes and monitoring.

There are still a lot of unknowns that make it difficult to find this appropriate balance. For example, it is unclear what information on materials businesses perceive as sensitive and to whom. This information might reveal trade secrets from a commercial perspective, even if it does not reveal how to create the complete product. Businesses might perceive similar businesses in different supply chains as competitors; in contrast, this may not be the case for businesses in different industries. Nevertheless, as they are not involved with these businesses, they might not know them and not trust that they will not share their information with others. From a public perspective, in the case society could be severely harmed by the scarcity of a CRM, one could argue that the prevention of scarcity in the interest of society should prevail over the commercial interests of specific businesses. These are just a few considerations that can play a role and need further investigation. Therefore, *challenge 4 is to appropriately balance the risks of information sharing for businesses with the benefits of information sharing for supporting circular processes and monitoring.*

For the government to have a complete overview of a CRM (R4), information on such a CRM should be stored in a single system, or government should have access to all systems where the information is stored. To discern different (batches of) materials, they will need an ID. However, an issue here is the granularity of assigning these IDs. If IDs are only assigned to large batches, it becomes impossible to identify small quantities used in products. But assigning IDs to small batches can create scalability problems. To illustrate, storing a unique ID for each gram of titanium consumed yearly in the European Union (EU) would require almost 77 Terabytes[1]. This is a lot, especially considering the same needs to be done for all other CRMs and considering that these are only the IDs, not the information about the materials. This makes choosing the appropriate granularity and efficiency of the representation and compression methods of paramount importance. The work on determining granularity is limited and does not address the particular properties of materials [3]. Therefore, *challenge 5 is determining the appropriate granularity of batches of materials for assigning IDs.*

A complete history will need to be shared (R1), which entails a huge volume of information that also threatens scalability. Furthermore, the number and variety of parties involved are large as data must be shared between supply chains and industries (R2). As the information sharing should be highly robust and not rely on a single locus of control (R5) and be tamper-resistant, a centralised system will likely not offer a solution. An obvious solution would be storing the data in multiple places (e.g., using blockchain technology). Consequently, the volume of information stored and shared can become even more considerable, creating more scalability problems.

Strategies for reducing scalability problems have downsides harming the information sharing process. For example, sharing links to information instead of the information itself can reduce the volume of shared information. However, it might harm transparency and robustness and reduce protection against tampering. Therefore, *challenge 6 is to appropriately balance the scalability of the information sharing with the information sharing needs of businesses and government.*

Avoiding a single locus of control is not just a technological problem (R5). It is also about which parties determine the standards and processes. The need for monitoring does not stop at a country's border or the border of industries or supply chains (R1, R2). There are many companies involved, having all kinds of systems. There is a need for governance to involve these parties and standardise data and processes. To this end, there are many options ranging from top-down to bottom-up approaches. Likely, this depends on the context, type of material, actors involved, installed systems, investments needed, etc. Which type of governance is most effective

[1] The average yearly consumption of titanium of the European Union (EU) between 2012 and 2016 is 1,509 kt [34]. 1, 509 kt is 1,509,000,000,000 grams. Uniquely identifying each gram, requires assigning them a string of 7 alphanumeric characters, as this allows for $62^7 = 3, 521, 614, 606, 208$ unique strings. Storing a character in ASCII is 8 bytes. Storing the IDs for all grams, thus requires 84,504,000,000,000 bytes of space, which is 76.8559 Terabytes.

is unknown and needs further research. Therefore, *challenge 7 is to create a governance model for the information systems supporting the monitoring of materials.*The following section formulates research questions based on these challenges and offers a reflection on our proposal for this research agenda.

4 RESEARCH AGENDA AND REFLECTION

Based on the challenges in section 3, we present the research questions as a foundation for a research agenda into the role of information sharing for monitoring materials in a CE, particularly CRMs. Our premise is that information sharing between business and government is necessary to monitor scarcity and develop policy measures to stimulate reuse. The numbering of the research questions corresponds to the numbering of the challenges in Table 1:

RQ1. How can the information necessary to support circular processes and monitoring materials in a CE be made available for a very long time (at least decades)?

RQ2. How can materials be tagged and identified so that the tags cannot be tampered with and do not harm the environment, and materials can be followed through different cycles, in various states, and when mixed and converted?

RQ3. What are incentives for businesses to share reliable and up-to-date information on materials with all businesses and government organisations needed to support circular processes and monitoring of materials?

RQ4. What is an appropriate balance between the risks of information sharing for businesses and the benefits of information sharing for supporting circular processes and monitoring of materials?

RQ5. What is the appropriate granularity of batches of materials for assigning IDs?

RQ6. What is the appropriate balance between the scalability of information sharing with the information sharing needs of businesses and government for supporting circular processes and monitoring materials?

RQ7. What governance model is suitable for information systems supporting the monitoring of materials?

This overview is not exhaustive but is meant as a starting point for discussion and additional research from other perspectives. Some of the questions proposed are generic for business and government information sharing, and others are specific to a CE. To illustrate the needed contribution from other perspectives, we can mention the privacy risks of the data related to the phase in which citizens use products/materials before they are returned for recycling. Another example is the required sustainability of the information sharing itself. With this discussion paper, we want to inspire other researchers to address the current challenges and uncertainties in the transition toward a CE and how digital technologies/information sharing can be designed to support this transition.

5 CONCLUSIONS AND FURTHER RESEARCH

This discussion paper presents a research agenda for monitoring materials, particularly CRMs in a CE. First, we discussed the need for monitoring materials in a CE and its requirements. Next, we analysed the requirements. Based on these, we identified the challenges. For each of these challenges, we formulated a research question. These research questions can serve as a foundation for a research agenda for information sharing between businesses and governments to monitor the CE's reuse of critical raw materials.

The list of requirements, challenges, and related research questions presented in this work is a starting point. It is meant to start a discussion and additional research on this topic. Further research should focus on refining and extending them based on further in-depth analysis of literature and reports and discussions with experts and policymakers involved in implementing a CE in practice. And from taking other perspectives than a systems requirements perspective into account.

REFERENCES

[1] Antikainen, M. *et al.* 2018. Digitalisation as an Enabler of Circular Economy. *Procedia CIRP.* 73, (2018), 45–49. DOI:https://doi.org/10.1016/j.procir.2018.04.027.

[2] Beekman, M. *et al.* 2020. Coping with Substances of Concern in a Circular Economy. *National Institute for Public Health and the Environment of the Netherlands.*

[3] Dasaklis, T.K. *et al.* 2019. Defining granularity levels for supply chain traceability based on IoT and blockchain. *COINS* (2019).

[4] Debacker, W. and Manshoven, S. 2016. Key barriers and opportunities for Materials Passports and Reversible Building Design in the current system. *Buildings as Material Banks Project.*

[5] Dimitropoulos, A. *et al.* 2021. Extended Producer Responsibility: Design, Functioning and Effects. *Netherlands Environmental Assessment Agency and CPB Netherlands Bureau for Economic Policy Analysis.*

[6] Dounas, T. *et al.* 2021. Topology generated non-fungible tokens: Blockchain as infrastructurefor a circular economy in architectural design. *Projections - Proceedings of the 26th International Conference of the Association for Computer-Aided Architectural Design Research in Asia, CAADRIA 2021* (2021), 151–160.

[7] van Engelenburg, S. *et al.* 2018. A Blockchain Architecture for Reducing the Bullwhip Effect. *BMSD 2018, LNBIP 319* (2018), 69–82.

[8] van Engelenburg, S. 2019. Designing context-aware architectures for business-to-government information sharing. *Dissertation.*

[9] Fawcett, S.E. *et al.* 2007. Information sharing and supply chain performance: the role of connectivity and willingness. *Supply Chain Management: An International Journal.* 12, 5 (2007), 358–368. DOI:https://doi.org/10.1108/13598540710776935.

[10] Finding and utilising "waste" materials for construction purposes: 2021. https://www.ellenmacarthurfoundation.org/case-studies/finding-and-utilising-waste-materials-for-construction-purposes. Accessed: 2021-07-18.

[11] Gawer, A. and Cusumano, M. 2013. Industry Platforms and Ecosystem Innovation. *Journal of Product Innovation Management.* 31, 3 (Oct. 2013). DOI:https://doi.org/10.1111/jpim.12105.

[12] Gupta, S. *et al.* 2018. Circular economy and big data analytics: A stakeholder perspective. *Technological Forecasting & Social Change.* June (2018). DOI:https://doi.org/10.1016/j.techfore.2018.06.030.

[13] Hart, P. and Saunders, C. 1997. Power and Trust: Critical Factors in the Adoption and Use of Electronic Data Interchange. *Organization Science.* 8, 1 (Feb. 1997), 23–42. DOI:https://doi.org/10.1287/orsc.8.1.23.

[14] Huisman, J. *et al.* 2017. Prospecting Secondary Raw Materials in the Urban Mine and mining wastes (ProSUM) - Final Report.

[15] Jensen, T. and Tan, Y.-H. 2015. Key Design Properties for Shipping Information Pipeline. *Open and Big Data Management and Innovation.* (2015).

[16] Johnston, H.R. and Vitale, M.R. 1988. Creating Competitive Advantage With Interorganizational Information Systems. *Management Information Systems Quarterly.* 12, 2 (1988), 153–165.

[17] Klievink, B. *et al.* 2012. A Stakeholder Analysis of Business-to-Government Information Sharing: the Governance of a Public-Private Platform. *International Journal of Electronic Government Research.* 8, 4 (2012), 54. DOI:https://doi.org/10.4018/jegr.2012100104.

[18] Klievink, B. *et al.* 2012. Enhancing Visibility in International Supply Chains: The Data Pipeline Concept. *International Journal of Electronic Government Research (IJEGR).* 8, 4 (2012), 14–33. DOI:https://doi.org/10.4018/jegr.2012100102.

[19] Korhonen, J. *et al.* 2018. Circular Economy: The Concept and its Limitations. *Ecological Economics.* 143, (2018), 37–46. DOI:https://doi.org/10.1016/j.ecolecon.2017.06.041.

[20] Laubscher, M. and Marinelli, T. 2014. Integration of Circular Economy in Business. *Proceedings of the Conference: Going Green–Care Innovation* (2014).

[21] Lee, H.L. and Whang, S. 2000. Information sharing in a supply chain. *International Journal of Manufacturing Technology.* 1, 1 (2000), 79–93. DOI:https://doi.org/10.1504/IJMTM.2000.001329.

[22] Llanquileo-Melgarejo, P. and Molinos-Senante, M. 2021. Evaluation of economies of scale in eco-efficiency of municipal waste management: an empirical approach for Chile. *Environmental Science and Pollution Research*. 28, 22 (2021), 28337–28348. DOI:https://doi.org/10.1007/s11356-021-12529-1.

[23] Nishida, H. 2011. Development of materials and technologies for control of polymer recycling. *Polymer Journal*. January (2011), 435–447. DOI:https://doi.org/10.1038/pj.2011.16.

[24] Portillo-Barco, C. and Charnley, F. 2015. Data requirements and assessment of technologies enabling a product passport within products exposed to harsh environments: a case study of a high pressure nozzle guide vane. *International Journal of Product Lifecycle Management*. 8, 3 (2015), 253–282.

[25] Rukanova, B. *et al.* 2021. Digital Infrastructures for Governance of Circular Economy: A Research Agenda. *Proceedings of Ongoing Research, Practitioners, Workshops, Posters, and Projects of the International Conference EGOV-CeDEM-ePart 2021* (2021).

[26] Rukanova, B. *et al.* 2021. Extended Data Pipeline for Circular Economy Monitoring. *DG.O2021: The 22nd Annual International Conference on Digital Government Research* (Jun. 2021), 551–553.

[27] Salmon, D. *et al.* 2021. A framework for modeling fraud in E-waste management. *Resources, Conservation and Recycling*. 171, December 2020 (2021). DOI:https://doi.org/10.1016/j.resconrec.2021.105613.

[28] SITRA Studies 2021. *The Winning Recipe for a Circular Economy*.

[29] Stijn, E. Van *et al.* 2011. Innovative ICT solutions for monitoring and facilitating international trade. *Network Industries Quarterly*. 13, 3 (2011), 26–29.

[30] Tan, Y.-H. *et al.* 2019. Developing Large Scale B2B Blockchain Architectures for Global Trade Lane. *6th Innovation in information infrastructures (III) workshop* (2019).

[31] The European Commission 2015. Closing the loop - An EU action plan for the Circular Economy. *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions*. (2015).

[32] The European Commission 2018. Communication on the implementation of the circular economy package: options to address the interface between chemical, product and waste legislation.

[33] The European Commission 2018. *Report on Critical Raw Materials and the Circular Economy*.

[34] The European Commission 2020. *Study on the EU's list of Critical Raw Materials*.

[35] Tilson, D. *et al.* 2010. Digital infrastructures: The missing IS research agenda. *Information Systems Research*. 21, 4 (2010), 748–759. DOI:https://doi.org/10.1287/isre.1100.0318.

[36] Tiwana, A. *et al.* 2010. Platform evolution: Coevolution of platform architecture, governance, and environmental dynamics. *Information Systems Research*. 21, 4 (Dec. 2010), 675–687. DOI:https://doi.org/10.1287/isre.1100.0323.

[37] Urciuoli, L. *et al.* 2013. Drivers and barriers affecting usage of e-Customs - A global survey with customs administrations using multivariate analysis techniques. *Government Information Quarterly*. 30, 4 (Oct. 2013), 473–485. DOI:https://doi.org/10.1016/j.giq.2013.06.001.

[38] Wan, J. *et al.* 2016. Software-Defined Industrial Internet of Things in the Context of Industry 4.0. *IEEE Sensors Journal*. 16, 20 (2016), 7373–7380. DOI:https://doi.org/10.1109/JSEN.2016.2565621.

[39] World Economic Forum 2014. Towards the Circular Economy: Accelerating the scale-up across global supply chains.

[40] Zeiss, R. *et al.* 2021. Mobilising information systems scholarship for a circular economy: Review, synthesis, and directions for future research. *Information Systems Journal*. 31, 1 (2021), 148–183. DOI:https://doi.org/10.1111/isj.12305.

[41] Zheng, T. *et al.* 2021. The applications of Industry 4.0 technologies in manufacturing context: a systematic literature review. *International Journal of Production Research*. 59, 6 (2021), 1922–1954. DOI:https://doi.org/10.1080/00207543.2020.1824085.