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Originally published in:
NachhaltigkeitsManagementForum,
27 (2019), 1-9
DOI: 10.1007/s00550-018-0468-9

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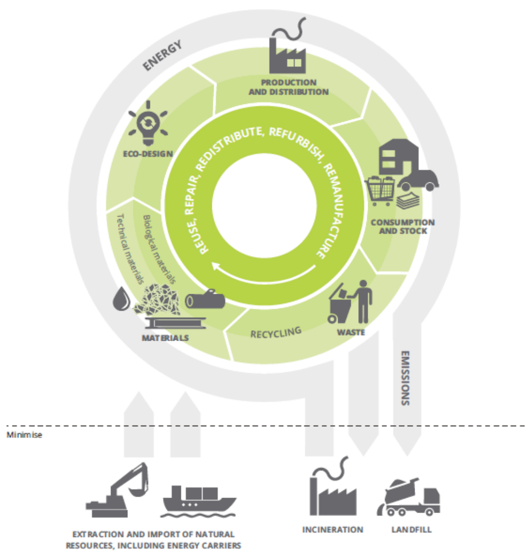
Abstract
Digital platforms may yield a host of advantages in putting circular economy into effect. This paper analyses the related chances and discusses requirements of digital platforms for the realization of a circular economy. It specifically points to potential solutions offered by digital platforms for existing barriers. From there it identifies issues that need specific attendance to create economically and ecologically functional platforms. Three economically relevant perspectives are discussed for this: a management perspective, a legislative perspective and a social/systems perspective.

Deutscher Titel und Zusammenfassung:
Voraussetzungen und Herausforderungen für Digitale Plattformen als Marktplätze der Kreislaufwirtschaft
Digitale Plattformen können zahlreiche Vorteile für die Realisierung einer Kreislaufwirtschaft aufweisen. Dieser Beitrag analysiert diese Chancen und diskutiert die zu schaffenden Voraussetzungen. Er weist dabei besonders auf potentielle Lösungen für bestehende Barrieren hin, die aus Sicht der Autoren durch digitale Lösungen besonders gut überwunden werden können. Sodann wird aufgezeigt, dass noch zahlreiche Bedingungen erfüllt werden müssen, damit diese Vorteile auch ausschöpfbar sind. Dabei werden drei ökonomisch besonders relevante Perspektiven behandelt: die Perspektive des Plattform-managements, eine regulatorisch-legislative Perspektive und die Einflüsse auf der sozialen bzw. Systemebene.

1. *Introduction*

Currently, economies worldwide are pursuing a mostly linear model of production. This means extraction, processing, utilization and then disposal through incineration or landfill ("take, make, waste"; Lacy and Rutqvist 2015). Such material is then no longer available for use within economic processes. The results are hence massive material losses, dependency on geopolitically instable states and volatile markets for primary resources. A circular economy, on the contrary, seeks to counter this approach. It can be defined as "an industrial economy that is restorative or regenerative by intention and design" (MacArthur 2013). The circular economy's goal is therefore to "preserve the value of utilised resources and materials as long as possible, to use them as frequently as possible, and to produce as little waste as possible (ideally none at all). The concept covers all aspects of economic activity, from resource extraction through production, storage and consumption, ending with disposal or ideally recycling." (Wilts 2016). It is therefore associated with alternatives that work against linear processing (EEA 2015, see also Figure 1). Most prominent among these are instruments that allow a form of re-utilization for products that have somehow reached the end of their use. Such instruments are for example: Repairing goods, so they be used longer; reuse or redistribution of used goods or materials (e.g. used cars can be sold to other users or parts that are still operable can be disassembled and resold.); remanufacturing and refurbishment where a core of a used product is restored to be sold again (recapturing the value added), recycling where materials (e.g. plastics) are regained from products (e.g. bottles) to be put to use in production processes. An important ingredient to permit such practices is product and service design that ensures that goods are suitable for being repaired, remanufactured, recycled, etc (EEA 2017).

Figure 1: The circular economy concept



Source: EEA 2016.

Creating a circular economy is closely linked with achieving a number of benefits both ecological and economic. Most importantly this relates to decoupling economic growth and resource use so as to enable sustainable growth (European Commission 2014).
However, while recycling rates are improving, they are still far below desirable values or

economic efficiency (see. e.g. UNEP 2011 for metals and World Economic Forum 2016, Plastics Europe 2016 for plastics). Even when material is collected this does not automatically imply that proper reuse, remanufacturing or recycling can take place: So far, several factors have hindered the emergence of a widespread circular economy. These factors were summarized by the OECD (2005, 2007, see also UNEP 2011) and are denoted in Table 1. It becomes apparent that at least the first four points refer directly to information deficits. Lack of information on supply, quality and availability paired with missing knowledge on suitability and feasibility lead to failure with regard to uptake. use and substitution. This results in a (false) preference for virgin material, effectively blocking the emergence of circular economy solutions.

Table 1: Deficits of resource supply markets for circular economy uptake. Own depiction based on OECD 2005, 2007, UNEP 2011.

Market Failure (transaction and search costs)	• Higher transaction costs for secondary material (e.g. through negotiation costs because of heterogeneity) • Problems of price discovery through absence of information • Search costs are high because of “ad hoc” nature of secondary markets (markets are spatially diffuse and temporally irregular)
Information Failure	• Missing information on qualities of secondary materials (e.g. regarding admixtures, contaminants) and material flows make use of secondary material more complicated and expensive • Low information quality may lead to “lemon markets”[1] (adverse selection) and thus further discourage recycling, etc. • Secondary material may not be directed to highest potential value-added catering for value loss
Customer externalities	• (Cognitive) Misconceptions on quality and suitability of secondary materials lead to preference for virgin material • Unawareness of substitutability • Risk aversion leads to clinging to status quo
Technological externalities	• Recyclability provides no competitive advantage as there is no immediate return for producers • Flawed design increases (downstream) costs of recycling • Missing markets for externalities (true prices or for littering) lead to unheeded externalities in the primary market
Market power and vertical integration (not further discussed here)	

Today, as the Digital Transformation has considerably progressed, digital technologies may offer solutions to solve or mitigate these problems e.g. by reducing information asymmetries or by improving information standards and market transparency. Thus, they can be important ingredients to create a circular economy (Lacy and Rutqvist 2015).
A special role may be taken here by digital platforms which we understand as networked market and exchange structures (MacAffee and Brnjolfsson 2017, Atos 2016). Markets and economies for secondary materials and recyclates could be created and actors could be connected on such platforms For example, Neligan and Schmitz (2017) argue that digital integration in cooperative networks could create stable product qualities and reduce uncertainties for planning and may enable new business models. Lacy and Rutqvist (2016) show how start-up “Rent the Runway” has succeeded in a circular business model (ReUse of Clothing) through data analytics and a dedicated logistics platform. World Economic Forum (2016, 34) proposes the “*Physical Internet’ — a logistics system based on standardised, modularised, shared assets. Transitioning to the ‘Physical Internet’ could unlock significant economic value — estimated to be USD 100 billion and a 33% reduction in CO2 emissions annually in the United States alone*.”

[1] The notion of “lemon markets“ was developed by Nobel Prize-winning economist George Akerlof (1970) and relates to the markets for used cars. In the US, cars that are defective but still sold on are known as “lemons”. Lemon markets then describes the problem that buyers of cars do not know whether a vehicle will keep working for a few more years, or if it is only fit for scrap. In effect, used car are in a general suspicion of being “lemons”, so that cars that are still in good shape tend to be sold below their real value which again. Suppliers of good quality used cars are thus deterred from selling which then disables the emergence of a proper reuse market.

However, until today full-fledged digital platforms that utilize the Digital Transformation to its full effect (see below) for circular markets and/or across supply chains or supply webs are non-existent. Current approaches in that regard represent exchange platforms on a “seek/offer”-basis. That is suppliers of e.g. recyclable material announce their goods or customers express a certain demand. However, such approaches offer little assistance in overcoming the problems mentioned above. While search costs may be lowered. e.g. information asymmetries and customer externalities persist. First exemption are companies who offer advanced logistics based on apps, or who include pre-chekcs on reliability and solvency. Such models lower search or transaction costs at least to some extent.

From the perspective of a circular economy, digital platforms demand enhanced understanding specifically with regard to the realization of economic benefits and the role of industrial actors (Lieder and Rashid 2016). This paper seeks to make a contribution in closing this gap. It points towards the potential of digital platforms in addressing the aforementioned information deficits and points towards the requirements regarding their management and installation.

In the following chapter we provide a characterisation of such platforms. We also delineate their potential contribution to solving the aforementioned problems associated with creating a circular economy. Chapter 3 will then identify requirements concerning their functionality for a circular economy based on three dimensions: Platform management, security of participants and data, and externalities as macro effects. In the concluding section we discuss our findings and hint towards required support for the realization of digital platforms for circular economy markets.

2. Circular economy through Digital Platforms

So far recycling markets are often characterized by high transaction costs leading to lower recovery rates as desirable from an economic or environmental point of view: Recyclers often have only limited information about specific needs of the demand side so that they don´t invest in high quality recycling processes (OECD 2005). Waste incineration on the other hand has become the dominant technology for many waste streams because the necessary information on the composition of waste streams is very low (Wilts 2012).

Digital platforms

Against this background, aiming at a circular economy with closed material loops, we envision digital platforms as digital-based market places where discarded products, components or recyclable fractions, etc. can be exchanged between companies in a value creation network to enable Reuse, Remanufacturing, Recycling or proper waste treatment. We see these platforms as business-to-business market places where companies in different places of the circular supply chain, for example producers of raw material, companies in manufacturing, waste management, and so on, interact to exchange material, goods, etc. for applications such as recycling, obtainment of goods for remanufacturing or redistribution, or purchase of recyclate to use in production. In principle different forms of platforms are conceivable. These could be industry focused (e.g. electronics – electronic waste), but also multi-sided, bringing together playersfrom different industries and fields as some recyclates or material may find various applications (e.g. metals).

Digital platform technologies receive increasing interest regarding solutions for distributive and organizational problems. For example McAfee and Brynjolfsson (2017) show how web-based platforms as online-to-online and online-to-offline constructs imply new forms of business and economies based on new digital possibilities that stem forma a reduction of information asymmetries. Gawer and Cusumano (2014) show how platforms also enable knowledge exchange both within companies and networks resulting in different kinds of innovation as well as in efficiency gains. We concentrate here on platforms of the first kind, whose main function is to enable trade through digital linking of suppliers and customers, thereby eventually removing barriers and lowering search costs. However, the analytical capabilities of Data Science e.g. through “Fast Data” or “Big Data” can also be utilized to create leverage points for a value added that make exchange feasible and profitable: Platforms could not only provide means for trade exchange but could also provide valuable information for circular economy markets. Means of “Fast Data” – real time data analysis –, and “Big Data” – analysis of a large amount of historical data – can help to monitor, evaluate and understand emerging resource and value streams (Reuter et al. 2015). These approaches make it possible to keep track of deals, material and value flows so as to understand which material streams exist and where they head thus also enabling innovation and efficiency to platform in the sense of Gawer and Cusumano (2014). Data to be provided on a platform should thus include information on inter alia purity of a material, or quality/status of a good on offer, name potential additives or hazardous ingredients, provide amount of supply or demand, and clarify time of supply or demand. Another ingredient specific to such platforms is that these exchanges can be automatized, controlled and improved through dedicated algorithms enabling automatized markets at least theoretically. Through this, digital platforms should be able to allow for more effective allocation e.g. through reversed logistics, the closing of loops, reduction of material loss, thereby potentially also reducing dependency on scarce primary resources from volatile or unsafe markets.

Through this both the suppliers and consumers of circular material would benefit. Suppliers can realize prices that are in conformity with the quality of their products, thus stop suffering from consumer externalities. On the other hand businesses on the consuming side achieve clarity and certainty with regard to the material and goods they obtain for reuse. For some this may even enable becoming part of a circular economy in the first place.

How digital circular platforms may enable circular economy by mitigating or eliminating the deficiencies listed in Table 1 will be discussed in the next section.

Enabling a Circular Economies through the Employment of Digital Platforms

Mitigating *market failure* can be the most important contribution of the aforementioned algorithms. Through these exchange, effectiveness and efficiency for the economic and environmental perspectives can be evaluated. The arising "intelligence" of digital networks and computers in recombining information for innovative solutions can be employed to this avail (Brynjolfsson and McAfee 2016). This can also result in novel business models e.g. through arbitrage or outsourcing models (see also Charter 2016). Moreover, such platforms can provide and apply a host of legal, technical and scientific knowledge, so as to support different aspects of deal making concerning waste material therefore effectively reducing transaction and search costs further.[2]

Information failure can be addressed through the digital tracking and provision of information collected over the value chain and the (re-)production process e.g by means of Cyber Physical Systems which store both product and process information. With transparency on material composition and origin it will be easier to direct it to its most effective utilization. Provision of such data would grant important insight into secondary materials' qualities and thereby reduce information asymmetries further and significantly diminish the risk of creating lemon markets. In this way *customer externalities* in the form of prejudice and reservations towards secondary material can be lowered, as the underlying data becomes reliable, trustworthy and traceable eventually eliminating reservations to the use of secondary materials as e.g. quality guarantees can be made and kept. Through this risk adverse customers can be persuaded to e.g. use recyclates.

Improved transparency or automation of trade would also reduce unawareness as potential customers would either be pointed towards potential secondary substitutes or automated exchange would eliminate this issue.

Furthermore, the problem of *technological externalities* could be mitigated when information regarding a product's composition also holds information for disassembly. Through such information, end-of-life products could then be automatically traded on a platform and find their best price and/or allocation e.g. based on their most valuable ingredients combined with information on recycling or reuse qualities. Improved retail chances for recyclates would then also motivate for recycling friendly design.

3. *Requirements and challenges for digital circular platforms*

The foregoing chapter discussed the potential of digital platforms for the creation of a circular economy. In this section we will now analyse solutions needed for digital platforms to operate effectively.

Digital circular platforms will have to meet a host of requirements and challenges that have to be solved to bring them into reality. Existing models like Rubicon Global that mostly rely on manually entered data via an app or as advertisements, so far they mostly concentrate on improving existing market constellations with little or no impact on improved resource conservation or resource efficiency. They are therefore still far away from the potentials which may come with Industry 4.0 technologies, especially the information richness of Cyber Physical Systems. Hence, despite the promises of Industry 4.0, Cyber Physical Systems and the Internet of Things, more digitally integrated and automated platforms still need to be realized. A major reason for this is the aforementioned

[2] Such applications are already taking place in other areas. The most notable and informative stemming from cancer treatment. Here, the ability of digital networks to analyse and process the vast bulk of latest research allows to effectively identifying the most promising treatment for individual patients (Brynjolfsson and McAfee 2016).

absence of a dedicated value creation network between industry, waste management companies, and digital service providers. Moreover, especially among small and medium-sized companies (SMEs), "digital readiness" is yet too low (Roland Berger 2016). The question therefore remains which measures have to be taken to put digital circular platforms into effect. We suggest that these relate to at least three perspectives: the perspective of managing such a platform (administrative perspective), security requirements (legal perspective), and system legitimacy as well as effectiveness (social and macro perspective).

A platform management perspective

A preliminary requirement is that a functional platform has to provide profitable business cases. For this, economies and pay-offs need to be clarified. Profitable business cases require that relevant industries have to be joined in a value creation net to allow for meaningful exchange of material. For this, inter alia, the benefit-size trade-off needs to be solved: Platforms require a certain critical mass to ensure meaningful, profitable business and to create sufficient legitimacy, i.e. to create benefits for the participants. The importance of this was illustrated e.g. by many failed attempts to establish construction and demolition waste exchange platforms in Germany that never reached this critical mass (see Wilts 2016b). At the same time the participants will only join – and thus generate size – when the accrued benefits are promising enough. This creates a conundrum for platform and market emergence: As long as participants are missing, sufficient amounts cannot be realized; as long as amounts are low, participants will be reluctant to join.
Before digital platforms can start to effectively enable circular solutions, several preconditions need to be established. Specifically the information supposed to be collected and processed needs to be created. For this, materials need to be identifiable and traceable. This is already possible by means of Cyber Physical Systems in which products – and potentially material – carry the information of their use and employment through the production process.
To solve information asymmetries and reduce transaction as well as search costs for circular purposes, detailed information on material composition needs to be included as well. Ideally, this will not only concern economic returns but also include ecological factors as resource efficiency. Such information is important as in some cases where e.g. recycling has a very high demand on energy or resources, other, non-materially circular solutions such as incineration may prove to be more friendly to the environment. Hence, harmful rebound effects need to be avoided (Berkhout et al. 2000, Binswanger 2001). Such rebounds can also emerge from the technological requirements of digital platforms themselves. When the technologies require more material and energy than is actually saved, no advantages in terms of a resource efficient circular economy are created. The need for this task has already been addressed but still needs more effort, specifically from an environmental perspective (see e.g. von Geibler et al. 2015).
Moreover, data quality needs to be ensured so that processes become reliable and meaningful. This requires standards and procedures that make information comprehensible, transferable and ensures that information is being created and processed at all relevant places. Also, dependencies on other aspects of value chains need to be clarified for smooth processing such as timing of waste production. From a technological perspective this implies the establishment of standards and interfaces that guarantee compatibility and efficient trading processes. The relevance of data quality and compatibility for platforms in the field of circular economy is amplified by deficiencies in the current nomenclature: The official declaration system for waste is designed in a way that aims at the avoidance of any waste being disposed without proper treatment. For this, especially non-hazardous waste is subsumed under very general categories, e.g. "01 05 05 oil-containing drilling muds and wastes". For any industrial company that considers this waste as a secondary raw material, it would, of course, be crucial to know the exact share and quality of oil that contaminated the drilling mud.
Lastly, as algorithms can be subject to errors especially in early analytical phases the system needs learning capacity and error tolerance. At the same time the likeliness and potential sources of errors through correlation should be made clear for risk assessment and error identification (see Ross 2016). This would again reduce information asymmetry and enable further learning. It also implies to foresee test-beds and beta-versions so as to only implement platforms that are truly working.

Data analytics vs. user protection: Solving safety and legal issues for participant protection

The first perspective has shown how important the provision of dedicated data is for platforms to operate. However, since data use also bears the danger of abuse in different ways, precautions, both legal and otherwise have to be taken, so that a digital circular platform can

operate effectively. Specifically so, as the fear of data piracy, violation or loss of property rights, and threats like viruses are among the major barriers to platform uptake. With regard to secondary material, the potential need to disclose information on product composition on the side of manufacturers surely is another challenge. Also, platforms tend to develop standards for exchange but also for products e.g. in terms of specific qualities (McAfee & Brynjolfsson 2017) which the industry or recyclers might be unwilling to accept. Some important issues regarding this point are discussed here.
For transaction costs to be reduced, contract and deal execution require a solid procedural basis, i.e. processes that ensure that trade can actually happen (North 1984). A platform thus needs to be designed to either establish trustworthy routines for deal making and execution, e.g. through tracking deals and materials and by evaluating participants, or it has to find ways to make trust less important.[3]
As a necessary precondition fort this, data protection needs to be ensured. This regards the deals themselves, as users should have a guarantee on conducting business safely and on their respective terms. However, it is also important to protect against intrusion e.g. from cyber crime and espionage, as such a platform – as any other web-based activity – may provide loopholes to access a company's data and trade as well as technological secrets.
Secondly, user protection needs to be guaranteed. This would entail proper contract enforcement procedures so that exchanges are legally protected and participants' rights can be imposed. User accounts need to be secure so that they cannot be taken over or abused by a third party. And it has to be warranted that any algorithms applied guarantee a high "deal quality", i.e. operate in a way that ensures profitability in the aforementioned dimensions to the highest degree conceivable.
Thirdly, property rights need to be safeguarded. Providing precise information about material employed, involved products and processes, as well as specific amounts of components, etc. would be extremely useful in realizing a more circular economy. However, this may also mean unveiling critical information on company secrets or technologies employed, even if the products concerned are subject to property rights. It is thus necessary to create a degree of safety in which property rights cannot be violated and where data required for meaningful matchmaking does not lead to a corruption of privileged information. Guaranteeing confidentiality and use of encryption mechanisms to this avail may be a special competitive advantage of digital platforms to realize circular economy markets. Recent developments have shown that various approaches can be used for this based on e.g. technical solutions such as the block chain technology for contract documentation and enforcement as well as for information encryption in order to create solutions that are ideally commensurable with functioning markets. Moreover, legislative approaches such as dedicated property rights, laws and economic incentives come to mind. Obviously, combinations of these three types of interference are also conceivable.

Generation of legitimacy and system effectiveness

Implying a high level of automation, platforms as market places in a digital circular economy are likely to have far reaching impacts on the specific markets, but also beyond their immediate reach. Specifically, the exponential nature of the digital transformation and many digital markets (Brynjolfsson/McAfee 2016) bear the potential of fast lock-in generation and market concentration, thus lending market power to a very limited number of players. In such a case novel and potentially more effective circular economy solutions created after a lock-in could be omitted because of faulty market structures. Several factors should thus be observed to prevent harmful structural effects from emerging.
It is of interest in this regard, that the idea of reducing transaction costs, search costs and information asymmetry advocates the emergence of standards for reporting and deal making. While this makes absolute sense from an administrative perspective, these standards are also prone to enforce lock-ins and therefore preclude innovation too early. It may therefore become a public task to monitor and adapt such standards, especially to make sure that they do not distort the emerging markets. One instance of solving this may be a multitude of interlinked competing platforms for different markets and products.
Moreover, securing access to the platforms for all relevant actors will be important. There is a specific necessity to involve those with less slack and ability to take part in such online market places from the very beginning. Especially SMEs, which are important sources of innovation and employment, are prone to lag behind in

[3] Block Chain Solutions currently appear as a means to this end. As platforms for contracts without the need for trust they have been established in banking environments and are also making their way to the energy markets specifically for CO_2-certificates (Cross 2016).

digitizing their processes and coming to terms with the Digital Transformation (Roland Berger 2016). This might be of specific relevance for the recycling sector that is still dominated by small SMEs that already lack financial resource for necessary investments into state-of-the art technologies (Wilts et al. 2016), let alone into new digitalisation based business models. However, exclusion from digital platforms could lead to serious structural disadvantages for SMEs and also render platforms less effective. For successful participation, SMEs may therefore require specific support regarding know-how, technology and funding (Rizos et al. 2016).
Lastly, as mentioned before, indirect macro-effects should be observed. This includes net-effects on job creation. Current estimates on job creation through environmentally effective technologies ("Green tech") are as unclear as for the digital transformation as a whole. While digital platforms may spur trade, foster resource conservation and create new business models and sources of income, jobs could be lost if concentration effects occurred, or automation replaces human labour. However, taking into account the massive job creation potentials of becoming more circular and climbing up the waste hierarchy (see Morgan and Mitchell 2015), such effects might be of lesser importance for digital circular platforms but should nevertheless be supervised as well as the rebound potential of platforms, welfare and sustainability effects obtained or impeded through a platform. These risks reveal the need for platforms to be monitored and regulated where need arises.

4. Conclusion

This article has shown that digital platforms are a promising field for applying the means of digital transformation to put circular economy into effect and thus to reduce the demand for resource intensive primary raw materials. They can be especially apt to solve information related shortcomings of current markets for waste and recycling materials where transaction costs, search costs, information asymmetries, etc. prevent effective market constellations. Moreover such market places can be effective means to create value creation networks between the producing sector, the waste and recycling industry and the digital sector.
So far it has not been addressed, who should run and maintain such a platform. We are optimistic that it would be possible and profitable to build and maintain such a platform as an online-to-offline platform on a private basis. Like other commodity markets. Profits could be realized based on deals conducted, tons of material sold, or flat membership fee, etc. In our perspective, natural candidates for starting such platforms are much more likely to originate from the digital industries than from the side of production or waste management. One reason for this is that these businesses are more likely to understand and hence profit from the economies created by such platforms. However, as circular economy is prone to support the goals set for resource conservation and efficiency set by nations, federal states or even within the SDGs there is also an incentive for public institutions to run a digital platform for a circular economy. This may also have benefits: First of all public actors may be more rigorous in setting standards that support ecological aspects of trade, and secondly, it might be easier for them to bear potential launching costs. Private-Public-partnerships are of course another variant that could bring together the best of both worlds.
Once established, such platforms can therefore be a strong push factor towards a resource conserving circular economy. Ultimately, their impact will depend on the range and scope of their features and most importantly on the competitive advantage or profitable business cases created. However, it was shown that there are numerous questions to be solved in order to make digital platforms meaningful instruments in terms of a beneficial impact on participants and sustainability alike.
Looking at the challenges, it is quite likely that a digital platform will need initial steering and support. Steering regards the implementation of economic and environmental standards as well as legal frameworks that make platforms both safe to use and accessible for all relevant parties, specifically SMEs. Support relates to funding and acquiring critical mass thus overcoming the size-benefit trade-off. This can come from different sources: Both public funds and private equity come to mind here. While the former may have the virtue of lending more focus to the environmental side, the latter is more likely to create market legitimacy, involve dedicated networks and ensure the pursuit of a profitable business case for the platform and its participants. Improving the circular economy through digital platforms will ultimately depend on playing these cards right.

Conflicts of Interest:
The authors declare that no conflicts of interest exist.

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