

"Circularity is not a trend; it's a culture shift"; Ken Webster

The Circular Economy

Who benefits, where and how ?

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Introduction

“Circularity is not a trend; it’s a culture shift”; Ken Webster

(Webster and Ellen Macarthur Foundation, 2017)

According to the European Commission (2015), a CE “... is an economy where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimised”. CE is based on the principles of industrial ecology (Andersen, 2007), how material and energy flows from extraction from the natural resources and is transformed by the industrial processes using energy into products and services.

The Circular Economy (CE) has relatively lately become one of the more focussed themes to address the sustainability of user consumption across practically every aspect of everyday life. As such, there is a wealth of research and survey metrics aimed at both quantifying and qualifying the degree of implementation of CE strategies and outcomes. The benefits of CE contribute to the attainment of environmental goals while considering the economics behind such actions

Overview

CE activities focus exclusively on one of three levels (Yong, 2007, Yuan, Bi and Moriguchi, 2008): the macro level, concentrating on geo-bounded regions such as cities, provinces and countries ; the meso level, concentrating on eco-industrial networks, wherever waste (material or energy) from one company is utilised by another company; and the micro level, concentrating on refining or improving the environmental performance within an organisation, for example, by reducing resource consumption, waste dumping or by manufacturing less environmentally impactful products.

The four Rs (4Rs) (reduction, repairing, remanufacturing, and recycling) collectively describe strategies deliberately or unknowingly employed by organisations to become more efficient. Surveys suggest on a micro level, (Barreiro-Gen and Lozano, 2020), referring to organisations and their practice of CE strategies, suggest that amongst respondent organisations most do not appear to have a full appreciation of the four Rs, with a focus on reducing and recycling in contrast to repair and refurbishing. Also, there is a significant lack of awareness of the principles of CE, even amongst those who are using the 4Rs to improve their businesses. Amongst those that claim to explicitly use CE practices, in reality, implementation is poor (Barreiro-Gen and Lozano, 2020).

To close the CE loop and improve efficiencies, theory and practice require closer coupling, engaging collaboratively with the stakeholders, all those who use or are otherwise impacted by the organisational activities.

Preparing to launch

The precursors and enablers to the 4Rs comprise to some extent on the approach to design (or redesign/ adaptation) of a product or service.

Fig.1 illustrates the positioning of the 4Rs within a potential holistic ‘cradle to cradle’ CE methodology and forms a template for the consideration of each stage.

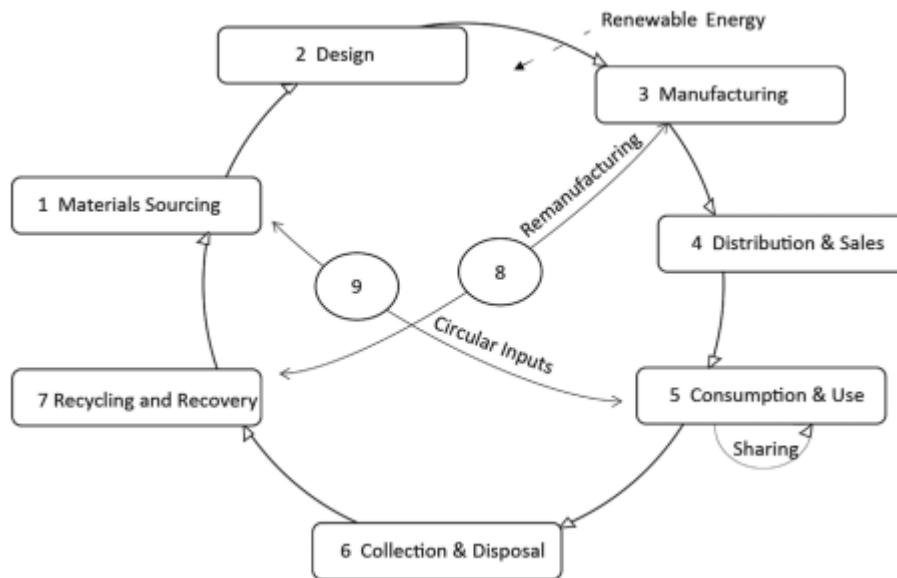


Fig. 1. Resource flows through a value chain in a circular economy, from (Kalmykova et al., 2018) the numbers denote codes for parts of the value chain in Table 1. CE Strategies Database

Material sourcing

In the later part of the 20th Century, 'dematerialisation', the reduction of the intensity of use of materials and energy (Bernardini and Galli, 1993), was already becoming a focus following the acknowledgement in the 1960's of the anticipated contraction of access to and availability of material resource, and the consequential future impact on society.

Interesting new categories of classification to describe material efficiencies in service arose to complement those already used. Economy-wide material flow accounting (EW-MFA) established a standardized framework for aggregating overall material inputs into an economy. Consumption-based material footprint (MF) analysis (Jiri Klemeš, 2015), describing the link between the beginning of a production chain (where raw materials are extracted from the natural environment) and its end (where a product or service is consumed), extended the system boundary to cover global resource extraction along supply chains to satisfy final consumption. Consideration of evolving MF on a global basis opens a window on the wider material supply chains, the responsibility and ownership, direct or by proxy, of the extraction, processing, and consumption of environmental resources within a delineated region, such as a country or province.

A new life cycle impact assessment (LCIA) method Product Material Footprint PMF an extension to the MF is described (Mostert and Bringezu, 2019) Two indicators are used to quantify the PMF: from source to consumer Raw Material Input RMI and the Total Material Requirement TMR. The LCIA is a further indicator of how virgin and existing resources contribute to the realisation of new products and services, described by the involved contributing regional boundaries., where the resources were, and where the consumption occurred.

Not to be ignored, water stewardship and land use/ environmental damage is also considered under the wider MF umbrella.

Tangible product or service design

Products can be designed to be compatible with circular economy principles (Bocken et al., 2016). Specifically, research has been carried out to classify products according to the circular economy approaches best suited to them, which may include consideration through design, posing questions around maintaining a product's material value by lengthening its life or by recycling it (Mugge, 2018, Bakker et al., 2014), based on factors such as lifespan, function, energy consumption and consumer perceived value.

Design effort aimed at ensuring the CE credentials of the product are exploitable at many different levels and at multiple timepoints in the product (and its component materials) lifecycle, and is the focus of wide research and implementable practices, legitimately overlapping multiple discrete elements of Fig. 1.

Design

Long-term investments of design time, tooling costs, verification and validation costs are justified by enhanced Return on Investment (ROI). Design which moves away from the traditional lowest cost, disposable or limited life expectancy facilitates product refurbishment. Repairability is now a factor considered by the good citizens of design. Many routes to repair exist, by the original manufacturers or their licensed repairers; by independent repairers; by profit and non-profit organisations; by community groups; and by private people (Hughes, 2021, Godwin, 2021). Particularly within the community, organised or by individual enthusiasts, a developing movement is emerging, with benefits beyond just 'fixing stuff', but extending to mental wellbeing, a sense of joy, developing technical skills, cooperative skills and nurturing creative and co-creative thinking, is revealed through participant interviews (Bradley and Persson, 2022).

Recent effort in the EU and notably France's introduction of the "reparability index", motivate producers to design and manufacture repairable products (ALVAREZ, 2020; Hughes 2021), promoting more thought and effort be put into repairability to promote a future, potentially more circular economy.

Manufacturing

Volume /Customisation

There is little doubt technology has enabled the customisation of product manufacture and assembly. The adoption of adaptive assembly modules leveraging automation or collaborative robotics (CoBots) are now commonplace (WiredWorkers, 2020). Multiple variations of similar products exist in various stages of completeness side by side, their components selectively arriving at the assembly line location and in time for operator or automated integration, all orchestrated by preprogrammed logistical menus, aimed at reducing inventory stock levels and increasing assembly efficiencies. Ordering through intelligent online agents can lower the hurdles to custom product ordering, uploading graphics for customising clothing or selecting colours, engine sizes or assistive technologies in new automotive direct to manufacturer orders. (Further discussed within *Distribution and Sales*)

Energy consumed in manufacture/ in use

Advanced manufacturing technology, coupled with the reduction of consumed materials through lean design methodologies such as realising alternative load-adapted components, offer numerous possibilities to influence the energy requirement and thereby the consequential protection of the environment. Tekkaya (2018), referring the automotive industry, provides case study examples

highlighting not only the immediate manufacturing energy savings through adopting lightweight designs, but also the consequential in-use energy savings.

Fig 2 illustrates a shift in material consumed by >50%. It should be noted the energy cost of the plastic solution is much higher than the metal alternatives, so material selection should be justified by the 'in-service' energy savings, in this case, a lighter vehicle and consequential reduced fuel consumption.

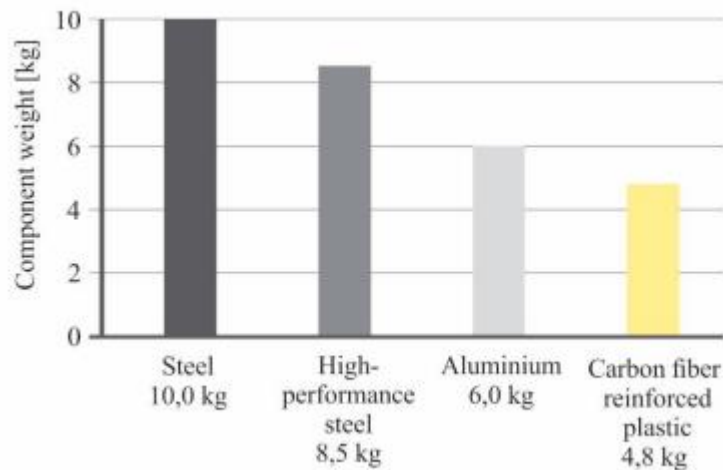


Figure 2 Possible weight reduction by materials for a car body demonstrator with steel as reference; from (Tekkaya, 2018)

Opportunities are being exploited to reduce the demand from manufacturing process for 'dirty' energy, that generated by consumption of fossil fuels. A social premium is placed on the use of 'green' and to a lesser extent 'grey' (stored dirty energy) by manufacturers. Incentives or credits under government backed initiative are now bring the costs of purchasing renewable energy into a closer alignment with traditional energy sourcing, sometimes even making renewables a cost-saver (De Lombaerde, 2021). Co-location of manufacturing facilities to energy production such as wind farms, hydro-electric also serve to reduce transmission overhead and affect unit cost to the user.

Energy storage, energy security and temporal generation to address demand fluctuations are important drivers for innovative solutions partially enabled I4.0 technologies. Reseller of energy are responding to customer demands for responsible sourcing and delivery of their energy. One example is Octopus Energy (Octopus Energy, 2023), aside from enabling customers to engage in community ownership of wind and solar farms to contribute to their consumption, participate in initiatives to leverage Artificial Intelligence (AI) to mediate emerging technology driven challenges in time varying supply and demand, such as intelligent vehicle charging (Octopus Energy, 2023b). Distribution of energy to EV domestic chargers are optimally organised with the collaboration of consumer apps, Industrial Internet of Things (IIoT) enabled EV charger devices, and cloud based supervisory/distribution algorithms.

In collaboration, the user, green supply availability, and temporally fluctuating network capacity, work to balance the load on the network to avoid unrestricted surges in demand normally experienced when large numbers of EV chargers are concurrently programmed to turn on at set 'off -peak' tariff times. This strategy significantly mitigating the large peak surge to multiple intelligently distributed smaller, less stressful pulses more readily managed by the by distribution network. It is also noted, legacy distribution networks benefit through this I4.0 approach by the modification its peak utilisation

events and related stresses, minimising damaging peaks, thereby increasing the remaining useful life of the distribution infrastructure.

Distribution & Sales

Potential changes in product consumption already impact on distribution and sales models, and coupled to manufacture and material footprint, are enabled by Industry 4.0 technologies different degrees based on the product.

- Additive Manufacture (AM) of parts on demand
 - Rather than ordering from existing inventory lists, consumers have an option to order, and even customise orders where AM provides a functionally suitable solution.
- Reduction of 'food' miles
 - The displacement between manufacturer and consumer can be reduced, minimising delivery cost and environmental impacts of moving goods.
- Inventory management
 - Production is reactive to demand, changes in demand potentially eliminates stock redundancy further negating the raw material, labour, production space and energy investment otherwise invested in 'new old stock'.
- Localising production/ 'Pod' satellite factories as an advantageous adaptation to local demand, local availability of resources, which may be raw materials, labour, production space, energy or to overcome last mile delivery difficulties (Lowe, 2021).
- Elimination of the 'Man in the middle', direct ordering may be facilitated by virtualisation of customers' dynamic product configurations, enabled by 3D real time rendering and visualised online. Customer confidence in virtualisations is growing to the extent a visit to a showroom is no longer an absolute necessity. Even high value expenditure such as a automobile is routinely effected without physical inspection of an exemplar of the intended purchase. Such an example is Tesla's direct to customer model (Tesla, 2022).
- Practically any customisable consumer item can be ordered directly with manufacturers as the 'batch size of one' capability becomes affordable through technological advances in lower cost intelligent manufacturing equipment from clothing based on highly accurate 3D CAD models of individual customers derived from 3D scanning (Paganelli, 2019) to metal components (Brancher, 2016)

The generally accepted caveat is, customisation and availability come at a price, although premium margins are diminishing as manufacturers realise the wealth of benefits the 'batch of one' offers.

"What should be self-evident is that the direct cost of low volume 'make to demand' manufacturing to tight time schedules will always be greater than for high volume scheduled production – irrespective of the method. It is important not to conflate the inherently higher costs of low volume production with Additive as a production method." (Brancher, 2016).

Consumption

“Looking at the inefficient and polluting way that energy is produced and used worldwide, it becomes apparent that we are still following the linear economic development model of “take, make, use, lose” (Raworth, 2017), also applies to the post processed raw materials. Within a consumer sphere of control, a circular ethos presents several opportunities to break the linearity that funnels product and MF investment to landfill.

CE has evolved to a new level making the entire society responsible to achieve uphill targets. Kirchherr et al., (2017) following an extensive review of 114 CE definitions, frame CE as “an economic system that is based on business models which replace the ‘end of life’ concept with reducing, alternately reusing, recycling and recovering materials in production/ distribution and consumption processes , ... , with the aim to accomplish sustainable development, which implies creating environmental quality, economic prosperity, and social equity, to the benefit of current and future generations.”

Refurb, reuse & social sharing

Within consumption, product is no longer deemed a mere commodity, but an asset to which a responsibility is attached. Supplemental to previously discussed design for repair, which in part encompasses refurbishment, design for refurbishment will be dependent on who the refurbishment entity is, manufacturer, independent company, or a private individual. The design for repair can accommodate the private person given adequate technical guidance and skill, additional design effort is required to enable volume refurbishment for the larger entities.

(Reike et al., (2018) describe educating consumer behaviours to reduce recurring demand, such as using purchased products less frequently, taking more care, or extending life by repair, including participation in social sharing through pooling (simultaneous use) and sharing of products (sequential use). In contrast, reduce and repair i.e., refurbishment, which occur without change of ownership, infers different actors.

Vanegas et al., (2018) proposes a robust method “eDiM” (ease of Disassembly Metric), to calculate the disassembly time based on the Maynard operation sequence technique (MOST). With evolving ecolabels and national CE directives under consideration, eDiM or an equivalent relative measure potentially assist manufacturers in recognising the value of considering ease of disassembly and helping to implement measurable design iterations with a view to future refurb/ repair and material/ sub-component recovery for reuse or sorting to recycle.

There are many different instances of refurbishment by non-owning actors undertaking repairs which are beyond the competency of private owners, with no or limited access to spares or specialist tools. Internal combustion Engine (ICE) and associated auto components refurbishments on a swap basis have been commonplace for decades. Within a developing collective CE responsibility, willingness to refurb, repair, share and recycle no longer have a perceived minimum worth to qualify for consideration.

Convenient consumer drop-off opportunities of ‘used’ products enables industry actors to acquire the component elements as input for their remanufacturing processes. The methodology has been exemplary in the case of printer toner cartridges, designed to be robust but with a consumable element exhausted very much in advance of the enclosing structure. Auto parts commonly remanufactured/refurbished are deemed functionally acceptable and even more desirable on a cost basis.

Recovery and Second life

As a further example of recovery, the Lithium-Ion Battery focuses on a problematic resource with high value material contents. Efficacy of collection of EOL batteries is key to successful recycling policy. The collection rate determines the number of EOL batteries that enter the recycling stream and determines the efficiency of the strategy (Neumann et al., 2022). Similar ease and breath of collection centre criteria apply to many materials and devices. Beyond the elemental recovery for new battery manufacture, an economically viable intermediate reuse may be available. The Remaining Useful Life (RUL) of the battery beyond its original application is significant. Reuse in applications tolerant of a lower energy density can be considered, for example solar energy storage provisioned by retired EV battery modules.

A Servitisation Business Model

Supplemental to design for repair, refurbishment and extended useful life, collectively fundamental to reducing waste, models to exploit these new or enhanced deliberately designed-in features of a product or service becomes commercially exploitable. Coined *something* As A Service, popular in the early years, Software As A Service (SAAS), has evolved to include Product, Platform, Function etc. as the 'service', the servitisation model is ideally suited to delivering and charging users for functionality on a use episode or a rate of consumption basis.

The benefits for the consumer include reduced cost of access and often, due to the absence of the initial investment, the choice to move between services without penalty, increasing consumer choice and satisfaction.

The service provider has similar incentives, access to a broad customer base, lower costs of acquiring and retaining customers, and almost exclusively in the present times, delivering the service aspect through remote third party managed cloud-based platforms such as AWS (Amazon, 2022) and Google Cloud (Google, 2019). The wealth of tools and templates provisioned within each platform ecosystem allow the business to develop, test, deploy and scale their service offerings cost effectively.

Fundamental to servitisation is remote data-intensive connectivity (Liu et al., 2021), arguably one of the most significant developments of the Industry 4.0 age. The Internet of Things (IoT), proliferation of personal mobile devices enabled with sensors, imaging, geolocation, and powerful computational capabilities serve to enable businesses and consumers to collaborate in achieving mutual benefit, potentially shifting computational costs closer to the consumer, and reducing service latency through realisation of Edge or Fog layers. In summary, cloud platforms enable connected networks of people, products, and systems (Ranta et al., 2021).

Conclusion

Within the medical device sector, specifically a micro-scale start-up, alignment with CE principles not only provides a 'good citizen' credential, but also promises increased profit and competitive opportunities. Adopting a Prescriptive Maintenance (PM) at the embryonic phase of the design process enables lower costs (Choubey et al., 2020) through reduced servicing overheads and enhanced service life. Investing at the design stage to achieve maximum useful life complements revenue generation through a Product or Function As A Service business model (FAAS), the business can gain revenue from the same product over a longer period before replace or upgrade. The low technical and cost barriers to the adoption of FAAS, even extending to low-cost revenue collection by the hosting platform, allows resource limited start-ups to focus on product development rather than product delivery.

I4.0 technologies which have significantly empowered the CE culture and particularly servitisation (Zhou et al., 2021), allow even the very smallest business entry to the global marketplace, with access to deployment resources equalling those of much larger competitors.

It is difficult to find argument to counter a CE aligned business model, however absence of formal definitions of how CE can promote sustainable development present future uncertainties, it is too convenient to focus on the immediate tangible benefits CE strategies undoubtedly present, without the hindsight of the potential for damage (Millar et al., 2019).

Moreover, insufficient research on the impacts of the CE on social equity, how improvements are measured and direct related policy (Merli et al., 2018) demand addressing.

"It is not realistic to expect circular economy, degrowth or for that matter any sustainability philosophy to be all encompassing. Each conception and action will have limitations, blind angles, and unintended consequences" (Schröder et al., 2019).

Bibliography

ALVAREZ, D.G. (2020). *Circular Economy Action Plan. For a Cleaner and More Competitive Europe*. [online] JRC Science Hub Communities - European Commission. Available at: <https://ec.europa.eu/jrc/communities/en/community/city-science-initiative/document/circular-economy-action-plan-cleaner-and-more-competitive> [Accessed 30 Jan. 2023].

Amazon (2022). *Amazon Web Services (AWS) - Cloud Computing Services*. [online] Amazon Web Services, Inc. Available at: <https://aws.amazon.com/>.

Andersen, M.S. (2007). An introductory note on the environmental economics of the circular economy. *Sustainability Science*, 2(1), pp.133–140.

Antonio, M., Jugend, D., Beatriz, A., Jose and Latan, H. (2022). Circular economy-based new products and company performance: The role of stakeholders and Industry 4.0 technologies. *Business strategy and the environment*, 31(1), pp.483–499.

Barreiro-Gen, M. and Lozano, R. (2020). How circular is the circular economy? Analysing the implementation of circular economy in organisations. *Business strategy and the environment*, 29(8), pp.3484–3494.

Bernardini, O. and Galli, R. (1993). Dematerialization: Long-term trends in the intensity of use of materials and energy. *Futures*, 25(4), pp.431–448.

Bocken, N. and Ritala, P. (2021). Six ways to build circular business models. *Journal of Business Strategy*, ahead-of-print(ahead-of-print).

Bocken, N.M.P., de Pauw, I., Bakker, C. and van der Grinten, B. (2016). Product design and business model strategies for a circular economy. *Journal of Industrial and Production Engineering*, [online] 33(5), pp.308–320.

Bradley, K. and Persson, O. (2022). Community repair in the circular economy fixing more than stuff. *Local environment*, 27(1011), pp.1321–1337.

Brancher, C. (2016). Additive and the ideal of ‘batch of one’ manufacture. *Metal Powder Report*, 71(5), pp.339–343.

Capello, R. and Lenzi, C. (2021a). Industry 4.0 and servitisation: Regional patterns of 4.0 technological transformations in Europe. *Technological forecasting & social change*, 173, p.121164.

Capello, R. and Lenzi, C. (2021b). Industry 4.0 and servitisation: Regional patterns of 4.0

technological transformations in Europe. *Technological forecasting & social change*, 173, p.121164.

Chen, C. (2020). Improving Circular Economy Business Models: Opportunities for Business and Innovation : A new framework for businesses to create a truly circular economy. *Johnson Matthey technology review*, 64(1), pp.48–58.

Chizaryfard, A., Trucco, P. and Nuur, C. (2021). The transformation to a circular economy: framing an evolutionary view. *J Evol Econ*, 31(2), pp.475–504.

Choubey, S., Benton, R.G. and Johnsten, T. (2020). A Holistic End-to-End Prescriptive Maintenance Framework. *Data-Enabled Discovery and Applications*, 4(1). [10.1007/s41688-020-00045-z](https://doi.org/10.1007/s41688-020-00045-z).

COBOD. (n.d.). *Gantry versus robotic arm* / *COBOD International*. [online] Available at: <https://cobod.com/products/bod2/gantry-vs-robotic-arm/>.

Conny Bakker, Marcel Den Hollander, Ed Van Hinte and Yvo Zijlstra (2015). *Products that last : product design for circular business models*. Delft: Tu Delft Library.

Corona, B., Shen, L., Reike, D., Rosales Carreón, Jesús and Worrell, E. (2019a). Towards sustainable development through the circular economy—A review and critical assessment on current circularity metrics. *Resources, conservation and recycling*, 151, p.104498.

Corona, B., Shen, L., Reike, D., Rosales Carreón, Jesús and Worrell, E. (2019b). Towards sustainable development through the circular economy—A review and critical assessment on current circularity metrics. *Resources, conservation and recycling*, 151, p.104498.

De Lombaerde, G. (2021). *StackPath*. [online] [www.industryweek.com](https://www.industryweek.com/operations/article/21212102/green-energy-becomes-critical-for-manufacturing). Available at: <https://www.industryweek.com/operations/article/21212102/green-energy-becomes-critical-for-manufacturing> [Accessed 31 Jan. 2023].

Dey, P.K., Malesios, C., De, D., Budhwar, P., Chowdhury, S. and Cheffi, W. (2020). Circular economy to enhance sustainability of small and medium-sized enterprises. *Business strategy and the environment*, 29(6), pp.2145–2169.

Godwin, C. (2021). Right to repair movement gains power in US and Europe. *BBC News*. [online] 7 Jul. Available at: <https://www.bbc.co.uk/news/technology-57744091>.

Google (2019). *Cloud Computing Services* / *Google Cloud*. [online] Google Cloud. Available at: <https://cloud.google.com/>.

Hughes, O. (2021). *Right to repair moves forward for your broken devices. But campaigners want to go much further*. [online] TechRepublic. Available at: <https://www.techrepublic.com/article/right-to-repair-moves-forward-for-your-broken->

[devices-but-campaigners-want-to-go-much-further/](#) [Accessed 30 Jan. 2023].

Jiri Klemeš (2015). *Assessing and measuring environmental impact and sustainability*. Oxford Etc.: Elsevier, Cop.

Kalmykova, Y., Sadagopan, M. and Rosado, L. (2018). Circular economy – From review of theories and practices to development of implementation tools. *Resources, Conservation and Recycling*, 135(135), pp.190–201.

Kane, G.M., Bakker, C.A. and Balkenende, A.R. (2018). Towards design strategies for circular medical products. *Resources, Conservation and Recycling*, [online] 135(135), pp.38–47.

Kate Raworth (2017). *Doughnut economics : seven ways to think like a 21st-century economist*. London: Random House Business Books.

Kirchherr, J., Reike, D. and Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, [online] 127, pp.221–232.

Korhonen, J., Honkasalo, A. and Seppälä, J. (2018). Circular Economy: The Concept and its Limitations. *Ecological economics*, 143, pp.37–46.

Kristoffersen, E., Blomsma, F., Mikalef, P. and Li, J. (2020). The smart circular economy: A digitalenabled circular strategies framework for manufacturing companies. *Journal of business research*, 120, pp.241–261.

Liu, C., Zheng, P. and Xu, X. (2021). Digitalisation and servitisation of machine tools in the era of Industry 4.0: a review. *International journal of production research*, aheadofprint(aheadofprint), pp.1–33.

Loon and Wassenhove, V. (2020). Transition to the circular economy: the story of four case companies. *International journal of production research*, 58(11), pp.3415–3422.

Lowe, E. (2021). *Manufacturing a Circular Economy*. [online] www.makeuk.org. Available at: <https://www.makeuk.org/insights/blogs/manufacturing-a-circular-economy#:~:text=Manufacturing%20also%20has%20the%20potential%20to%20develop%20closed> [Accessed 4 Feb. 2023].

Luiz, D., Alencastro, V., Luiz, O., Goyannes, R., GarzaReyes, J.A., RochaLona, L. and Tortorella, G. (2019a). Exploring Industry 4.0 technologies to enable circular economy practices in a manufacturing context: A business model proposal. *Journal of manufacturing technology management*, 30(3), pp.607–627.

Luiz, D., Alencastro, V., Luiz, O., Goyannes, R., GarzaReyes, J.A., RochaLona, L. and Tortorella, G. (2019b). Exploring Industry 4.0 technologies to enable circular economy practices in a manufacturing context: A business model proposal. *Journal of manufacturing*

technology management, 30(3), pp.607–627.

Millar, N., McLaughlin, E. and Börger, T. (2019). The Circular Economy: Swings and Roundabouts? *Ecological economics*, 158, pp.11–19.

Mostert and Bringezu (2019). Measuring Product Material Footprint as New Life Cycle Impact Assessment Method: Indicators and Abiotic Characterization Factors. *Resources*, 8(2), p.61.

Mugge, R. (2018). Product Design and Consumer Behaviour in a Circular Economy. *Sustainability*, 10(10), p.3704.

Neumann, J., Petranikova, M., Meeus, M., Gamarra, J.D., Younesi, R., Winter, M. and Nowak, S. (2022). Recycling of Lithium-Ion Batteries—Current State of the Art, Circular Economy, and Next Generation Recycling. *Advanced energy materials*, 12(17), pp.2102917-n/a.

Octopus Energy. (2023a). *How Octopus makes energy greener, for you and the world*. [online] Available at: <https://octopus.energy/green/>.

Octopus Energy. (2023b). *Intelligent Octopus: your questions answered*. [online] Available at: <https://octopus.energy/intelligent-faqs/#:~:text=Intelligent%20Octopus%20evolved%20from%20our%20Octopus%20Go%20smart> [Accessed 31 Jan. 2023].

Paganelli, N. (2019). Custom Clothing Technology: Diffusion of Luxury Practices in Fashion. *Fashion Studies*, 2(1), pp.1–27.

Parida, V., Burström, T., Visnjic, I. and Wincent, J. (2019). Orchestrating industrial ecosystem in circular economy: A twostage transformation model for large manufacturing companies. *Journal of business research*, 101, pp.715–725.

Patwa, N., Sivarajah, U., Seetharaman, A., Sarkar, S., Maiti, K. and Hingorani, K. (2021). Towards a circular economy: An emerging economies context. *Journal of business research*, 122, pp.725–735.

Qu, S., Guo, Y., Ma, Z., Chen, W., Liu, J., Liu, G., Wang, Y. and Xu, M. (2019). Implications of China's foreign waste ban on the global circular economy. *Resources, conservation and recycling*, 144, pp.252–255.

Rajput, S. and Singh, S.P. (2021). Industry 4.0 – challenges to implement circular economy. *Benchmarking : an international journal*, 28(5), pp.1717–1739.

Ranta, V., AarikkaStenroos, L. and Väisänen, J. (2021). Digital technologies catalyzing business model innovation for circular economy—Multiple case study. *Resources, conservation and recycling*, 164, p.105155.

Reike, D., Vermeulen, W.J.V. and Witjes, S. (2018). The circular economy: New or Refurbished as CE 3.0? — Exploring Controversies in the Conceptualization of the Circular Economy through a Focus on History and Resource Value Retention Options. *Resources, Conservation and Recycling*, 135(135), pp.246–264.

Richard, C.C., Davidson, M., Hutchings, G.J. and Mulholland, A. (2020). Science to enable the circular economy. *Philosophical transactions of the Royal Society of London. Series A: Mathematical, physical, and engineering sciences*, 378(2176), pp.20200060–20200060.

Schröder, P., Bengtsson, M., Cohen, M., Dewick, P., Hofstetter, J. and Sarkis, J. (2019). Degrowth within – Aligning circular economy and strong sustainability narratives. *Resources, conservation and recycling*, 146, pp.190–191.

Suzanne, E., Absi, N. and Borodin, V. (2020). Towards circular economy in production planning: Challenges and opportunities. *European journal of operational research*, 287(1), pp.168–190.

Tekkaya, A.E. (2018). Energy saving by manufacturing technology. *Procedia Manufacturing*, 21, pp.392–396.

Tesla (2022). *Electric Cars, Solar Panels & Clean Energy Storage | Tesla*. [online] Tesla. Available at: <https://www.tesla.com/>.

Ünal, E. and Shao, J. (2019). A taxonomy of circular economy implementation strategies for manufacturing firms: Analysis of 391 cradleto cradle products. *Journal of cleaner production*, 212, pp.754–765.

Vanegas, P., Peeters, J.R., Cattrysse, D., Tecchio, P., Ardente, F., Mathieux, F., Dewulf, W. and Duflou, J.R. (2018). Ease of disassembly of products to support circular economy strategies. *Resources, Conservation and Recycling*, [online] 135(135), pp.323–334. [10.1016/j.resconrec.2017.06.022](https://doi.org/10.1016/j.resconrec.2017.06.022).

Webster, K. (2021). A Circular Economy Is About the Economy. *Circular Economy and Sustainability*.

Webster, K. and Ellen Macarthur Foundation (2017). *The circular economy : a wealth of flows*. Isle Of Wight: Ellen Macarthur Foundation Publishing.

WiredWorkers. (2020). *How do I deliver customization at the price of a mass product? | Blog*. [online] Available at: <https://wiredworkers.io/blog/cobots-customization/> [Accessed 4 Feb. 2023].

Yong, R. (2007). The circular economy in China. *Journal of Material Cycles and Waste Management*, 9(2), pp.121–129.

Yu, Z., Rehman, A. and Umar, M. (2022). Circular economy practices and industry 4.0 technologies: A strategic move of automobile industry. *Business strategy and the environment*, 31(3), pp.796–809.

Yuan, Z., Bi, J. and Moriguchi, Y. (2008). The Circular Economy: A New Development Strategy in China. *Journal of Industrial Ecology*, 10(1-2), pp.4–8.

Zhang, C., Chen, W.-Q. and Ruth, M. (2018). Measuring material efficiency: A review of the historical evolution of indicators, methodologies and findings. *Resources, Conservation and Recycling*, 132(132), pp.79–92.

Zhang, M., Guo, H. and Zhao, X. (2017). Effects of social capital on operational performance: impacts of servitisation. *International journal of production research*, 55(15), pp.4304–4318.

Zhou, T., Ming, X., Chen, Z. and Miao, R. (2021). Selecting industrial IoT Platform for digital servitisation: a framework integrating platform leverage practices and cloud HBWMTOPSIS approach. *International journal of production research*, aheadofprint(aheadofprint), pp.1–23.

1- MATERIALS SOURCING		
8	Diversity and cross-sector linkages	Establishment of industry standards to promote cross-sector collaboration through transparency, financial and risk-management tools, regulation and infrastructure development and education.
14	Energy production/Energy autonomy	Energy production from by-products and/or residual/process/waste heat recovery to support facility operation.
19	Green procurement	A process whereby public authorities/companies choose to procure goods and services with the same primary function but lower environmental impact as measured, for example, by LCA-based comparison of goods and services.
23	Life Cycle Assessment (LCA)	LCA is a structured, comprehensive and internationally standardized method. It quantifies all relevant emissions and resources consumed and the related environmental and health impacts and resource depletion issues that are associated with any goods or services (EC, 2010).
25	Material substitution	Replacing materials for the more abundant/renewable, hence making the production process more resilient to price fluctuations and resource scarcity.
41	Taxation	Taxes on technologies, products and inputs that are associated with negative externalities.
42	Tax credits and subsidies	Reducing the tax on resources, for example on bio-based materials and products.
2- DESIGN		
5	Customization/made to order	Products are tailor-made to meet the needs and preferences of the customer. Can reduce waste and prevent over-production. Customers who are satisfied with the products will return to the manufacturer to extend the service life of the products and keep their preferred features. Customer loyalty to the manufacturer is built in.
6	Design for disassembly/recycling	Design that considers the need to disassemble products for repair, refurbishment or recycling.
7	Design for modularity	Products composed of functional modules so that the products can be upgraded with newer features and/or functionalities. The modules can be individually repaired or replaced, thereby increasing longevity of the product core.
10	Eco design	Product design with a focus on its environmental impacts during the whole lifecycle.
30	Reduction	Design and manufacturing involving reduction in use of materials and elimination of harmful substances use.
3- MANUFACTURING		
13	Energy efficiency	Providing the required services with reduced energy input, which can be achieved by reduced consumption and energy efficient processes.
26	Material productivity	At the company level: the amount of economic value generated by a unit of material input or material consumption. On the economy-wide level: GDP per material input/consumption.
32	Reproducible & adaptable manufacturing	A transparent and scalable production technology that can be emulated at other places using indigenously available resources and skills.
4- DISTRIBUTION AND SALES		
27	Optimized packaging design	Efficient packaging design strategies abiding regulations and utilizing end-of-life of packaging material.
35	Redistribute and Resell	Resale extends the product life by second hand use. Therefore, fewer products, which serve for the same purpose, have to be produced. The complete products or their components can be re-sold.
5- CONSUMPTION AND USE		
4	Community involvement	The voluntary involvement of community and different stakeholders in organizing sharing platforms and providing guidance on product repair and replacement.
11	Eco-labelling	A voluntary environmental protection certification of proven environmental preference of a product/service within its respective category. Credible and impartial labelling of product/service is usually overseen by public or private third parties. The ownership of the product rests with the producer who provides design, usage, maintenance, repair and recycling throughout the lifetime of the product. The customer pays a rent for the time of its usage.
28	Product as a service or Product Service System	Aimed to guarantee that consumers have full information on the constituents, origin of raw materials etc. to enable them to make informed decisions. Indicates no environmental or otherwise preference for certain products, in contrast to #11 Eco-labelling.
29	Product labelling	Direct secondary re-use extends the product life by second hand use. Therefore, fewer products, which serve for the same purpose, have to be produced. The complete products or their components can be re-used.
34	Re-use	Shared use/access/ownership of for example space and products and sharing platforms enabling shared use. Multi-purpose space.
37	Sharing	A socially responsible consumer purchases products and services that are perceived to have less negative influence on the environment and/or that support businesses that also have positive social impact.
38	Socially responsible consumption	Taking responsibility in protecting the resource through conservation, recycling, regeneration, and restoration. A common good is considered, for example a natural resource, in contrast to #16 Extended Producer Responsibility
39	Stewardship	Dematerialization. For example electronic books/CDs, online shopping, use of telecommunication to decrease use of office space and travel.
45	Virtualize	
6- COLLECTION AND DISPOSAL		
16	Extended Producer Responsibility (E.P.R)	"Extended Producer Responsibility is as an environmental policy approach in which a producer's responsibility for a product is extended to the post-consumer stage of a product's life cycle" (OECD, 2015).
21	Incentivized recycling	A method for rewarding consistent and repeated recycling of recyclable materials, for example a deposit refund
24	Logistics/Infrastructure building	Facilities to promote cost-effective, time-saving and environmentally safe post-consumer collection and disposal. Solutions that render optimum collection.
36	Separation	The biological constituents should be separated from the technical or man-made/inorganic constituents. The technical nutrients ought to be used for remanufacture and the biological nutrients are to be restored or degraded naturally.
40	Take-back and trade-in systems	Efficient take-back systems ensure that the products are recovered from the consumer after end of life and proceed to be remanufactured. Take-back systems could ensure a continuous flow of material for remanufacture.
7- RECYCLING AND RECOVERY		
2	By-products use	Byproducts from other manufacturing processes and their corresponding value chains are used as raw materials for manufacturing new products.
3	Cascading	Materials and components used across different value streams after end of life. The embedded extraction, labor and capital are conserved across the cascade.
9	Downcycling	It is the process of converting used products into different new products of lower quality or reduced functionality.
12	Element/substance recovery	The process of recovering metals, non-metals and other re-usable substances from a material waste stream.
15	Energy recovery	The conversion of waste materials into useable heat, electricity, or fuel through a variety of waste-to-energy processes, including combustion, gasification, pyrolysis, anaerobic digestion, and landfill gas recovery.

(continued on next page)

Table 2 (continued)

1- MATERIALS SOURCING		
17	Extraction of bio-chemicals	Conversion of biomass into low-volume but high-value chemical products, thereby generating heat, power, fuel or chemicals from biomass.
18	Functional recycling	Process of recovering materials for the original purpose or for other purposes, excluding energy recovery.
20	High quality recycling	The recovery of materials in pure-form without contamination, to serve as secondary raw materials for subsequent production of the same or similar quality products.
22	Industrial symbiosis	Exchange and/or sharing of resources, services and by-products between companies.
33	Restoration	Also known as composting. Process where biological nutrients are returned to the soil after break-down by micro-organisms and other species.
43	Upcycling	Converting materials into new materials of higher quality and increased functionality.
8- REMANUFACTURE		
31	Refurbishment/Remanufacture	Rebuilding a product by replacing defective components by reusable ones.
44	Upgrading, Maintenance and Repair	The most efficient way to retain or restore equipment to desired level of performance is maintenance. Moreover, service after-sales is considered key for competitive advantage and business opportunity. Maintenance is also carried out in the form of repair. To eradicate product obsolescence or extend the useful life of the product, services like upgrading are necessary.
9-CIRCULAR INPUTS		
1	Bio-based materials	Resource inputs or materials that last for longer than a single life-cycle and can easily be regenerated.

Table 1 denote codes for parts of the value chain according to CE Strategies Database (Kalmykova et al., 2018)