

ERC Starting Grant 2023
Research proposal [Part B1]

My project title

ACRO

- Principal investigator (PI): My Name
- Host institution: My University
- Full title: My project title
- Proposal short name: ACRO
- Proposal duration: 60 months

.

Section a: Extended Synopsis of the scientific proposal [max. 5 pages]

i DRAM in a nutshell

The aim of Systemic Distributed Recycling for Additive Manufacturing (SDRAM) is to establish a blueprint methodology for the implementation of micro-value chains of distributed recycling at a urban territorial level. We seek to the achievement of a three-level target: 1) Undertand the establishment of a free-open source technical ecosystem that can be printed, 2) to establish a set indicators to possible help decision-makers and in the local implementation of these initiatives in Europe/(America?), 3)

1. The State of the art.

Arriving to the limits for global and mass manufacturing paradigm

Plastic waste contamination¹, climate change², biodiversity loss³ are majors markups of what is recently disscused as the Anthropocene era^{4,5}. The anthropocene frames the humans not only as biological but as geological force acknowledging the new status of humanity given the different indicators in the natural ecosystems that are impacting the stability of the earth system. The globalized mass manufacturing paradigm have played a major role not only as motor for the economic development, but also the transgression of the planetary boundaries⁶⁻⁸. The mass manufacturing socio-technical systems is understood as a deep transition⁹. Manufacturing systems requires materials as well as human and physical capital to produce goods. The co-evolution of single unit productions systems, interconnected systems, and industrial modernity have been gradually intensified various forms of environmental degradation^{ref?}. This co-evolution remains not to solve recurring issues of social inequality in connection to unequal access to healthcare, energy, water, food, mobility, security, finance, education, and communication^{ref?}. Even if the importance of manufacturing as the heart of an economy has not changed, the way of producing goods and the setup of the location start to change dramatically. The circular economy concept entry in the policy¹⁰, industrial¹¹ and scientific¹²⁻¹⁴ arenas as an umbrella concept, but also as a contested one¹⁵⁻¹⁷, aiming to change the societal conciousness that the ecological systems have nearly endless capacity to provide resources and adsorb wastes. Engineering science needs to integrate that the externalities¹⁸ of human activites' impacts on the earth systems since the fuzzy front-end phase of the innovation process.

■ Paragraph à developper sur les systemes de Manufactures

Major long vision: Circular and production

Today, a major societal issue rely on how to conceived socio-technical 'circular units' for manufacturing that integrates values of sobriety^{ref?}, resilience^{19,20}, adaptability²¹ and evolutive in urban settlements. The reuse, repairing, recycling approaches will need to converge in a post-growth economy context considering the societal issues of resource scarcity and waste accumulation in the urban settlements^{22,23}. Indeed, today the establishment of these socio-technical systems need to include all ecosystem externalities and the carrying capacity of the ecosystem to claim to sustainability^{24,25}. The trend is reinforced by the fact that by 2050, it is expected that about 70% of the world's population will live in urban settlements²³. Urban cities will be responsible for non-negligible environmental impact^{26,27}, producing about 50% of global waste, and 75% of greenhouse gas emissions which affects the sustainability of cities²⁸ and the quality of city life²⁹.

Open source and digital commons for 'Design global / Manufacturing local'

As an alternative of globalized manufacturing values chains, a major trend in the development of production systems seeks to establish an urban production model^{30,31} with decentralized and distributed characteristics^{32,33}. Aiming at a 'design global / manufacturing local'³⁴ seems a proto-industrialization³⁵ transition that is taking place in urban settlements that could a major impact in the next short future. The Open Source Appropriate Technology (OSAT)³⁶ and peer-to-peer (P2P)³⁷ approaches have been seen potential drivers to propose an alternative globalisation manufacturing paradigm³⁸. The open source (OS) approach has become well-established to provide improved product innovation over proprietary

product development^{39–42}. The evidence is most mature for software development because free and open source software (FOSS) provides: i) diversification and open innovation^{43–45}, ii) cumulative innovation⁴⁶, iii) development efficiency⁴⁷, iv) organizational innovation⁴⁵, v) higher technical quality of code⁴⁸, vi) encourages creativity⁴⁹ and vii) perhaps most importantly, it avoids redundant work⁵⁰. The OS approach is now also gaining traction in free and open source hardware (FOSH)^{51–55} and appears to be roughly 15 years behind FOSS in development and adoption⁵⁶. One of the primary drivers, is that all forms of free and open source technology software and hardware (FOSS and FOSH) can provide a substantial cost savings^{57–60}. The open source additive manufacturing technology, also know as 3D printing, have played a major role in the idea of democratization of manufacturing means⁶¹. Thousands of open-source products are shared by the global community from consumer goods to scientific⁶² and medical equipment^{62,63}. This model has been proven to be effective for emergency manufacturing during the COVID-19 pandemic^{62,64}. This is a driver communities to fabricate their own products for less than the price of purchasing them. In that sense, the concept of urban factory is evolving as a disruptive approach and is the materialization of this manufacturing paradigm. The urban factory is defined as “a factory located in an urban environment that is actively utilizing the unique characteristics of its surroundings”. It creates products with a focus on the local market and allows customer involvement during value creation^{30,65}.

Distributed recycling for additive manufacturing: a promising inclusion

Since 2014, I have been working on the validation of the open-source 3D printing, filament⁶⁶ and pellet-based⁶⁷, as a robust manufacturing system, but also as a potential enabler of the mechanical recycling^{68–70} of plastic waste feedstock. Likewise, I have been working on the design of the pertinent closed-loop supply chain^{71,72}, considering some of the sustainability indicators⁷³ needed in the based on the literature. In a recent paper⁷⁴, I could highthligh a great interest by the scientific community of thi topic which is called distributed recycling for additive manufacturing (DRAM). DRAM (See Figure 2) is a breakthrough promise in the constitution of a micro-circular industry units to validate the technical feasibility, and several technological pathways are maturing to allow individuals to recycle waste plastic directly by 3D-printing it into valuable products.

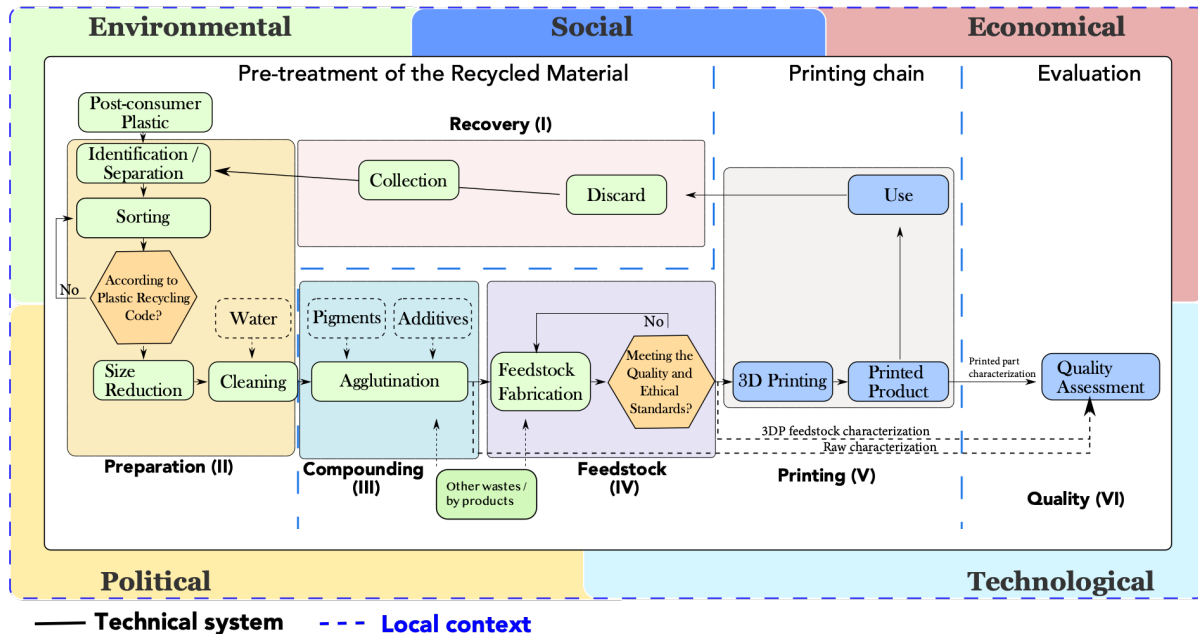


Figure 1: Distributed recycling via additive manufacturing. Source

To appreciate the ground-breaking scientific nature of this idea, let me state that the most adopted form of additive manufacturing is fused filament fabrication (FFF), which is a material extrusion process [40]. DRAM starts with waste plastic that is produced everywhere from packaging to broken products (*Recovery (I)*). It is washed, dried and then ground or cut into particles using a waste plastic granulator or office shredder (*Preparation (II)*). The raw material for FFF can be manufactured economically using

distributed means with a waste plastic extruder (often called a “recyclebot”)⁷⁵ for mono or composite materials (*Compounding (II) and Feedstock (IV)*). Filament made with a recyclebot costs less than 10 cents per kg, whereas commercial filament costs \$20/kg or more. This can produce valuable products at remarkably low costs. For example, using a recyclebot/3D-printer combination can produce over 300 units (e.g., camera lens hoods) for the price of one such item listed on Amazon.com. Fused granular fabrication is a recent experimental approach enabling the printing process directly from pellets^{76,77}, which reduces the degradation cycles of the plastic. For this process, I worked in the desktop format⁶⁷, but it seems that this technology could further expand the boundaries of additive manufacturing and eventually recycling^{78–80} for larger object⁸¹. Distributed recycling fits into the circular economy paradigm^{82–84}, as it eliminates most embodied energy and pollution from transportation between processing steps. Also, it decreases the embodied energy of filament by 90% compared to traditional centralized filament manufacturing using fossil fuels as inputs^{85–87}. Additionally, open-source investment should result in an extremely high return on investment (ROI)⁶². This makes distributed recycling environmentally superior to other methods of plastic recycling systems.

However, I realized that the global system maturity is ambiguous given that not all the value chain for the implementation of a community-driven of plastic recycling are matured⁷⁴. Major efforts in the scientific literature have been only concentrated in the materials and technical validation. However, the system validation remains to be difficult to implement. More important, the analysis of the holistic impact that this process can have in the context of a city remains not well understood. In the framework of a EUH2020 project called INEDIT¹, I have been leading the implementation of the *Green Fablab* demonstrator inside the third place called Octroi-Nancy Association² since November 2021³. INEDIT project aims to create an ecosystem to transform the *Do-It-Yourself* practices largely documented in FabLabs/Hacker/Maker spaces into a professional approach called Do-It-Together to capitalise on the knowledge, creativity and ideas of design and engineering. The Green Fablab is a distributed recycling demonstrator that that use living lab approach^{88,89} to experiment in real conditions with citizens, final users and large general public. This experiment is enframned as a design for sustainability at a socio-technical system level⁹⁰. We have collected and recycling around 100kg of plastic waste for the pedagogical and architectural uses given the fact that we are connected with a creative ecosystem of designers and makers participatin in the Octroi-Nancy projet. This hands-on experience confirms the literature that a recycled resources industry (RRI) is starting to conceived inside the cities⁹¹. RRI is seen as driver consists of a series of activities related to recycled resources – e.g., recycling, refining, remanufacturing, etc. – aspiring to mitigate the negative externality caused by the linear economy . The sustainable development of the RRI has thus been highlighted on many countries’ agendas to promote the circular society^{92–94}, as well as the goals of carbon peak and carbon neutralization. In the case of plastic waste, the main difficulty remains to make affordable the use of new secondary material applicability by the industry⁹⁵, but more profoundly, how these socio-technical experiments will interact with the urban planning and polycimaking to make concrete the ambition of circular economy inside the urban and regional settlements.

2. Ambition & objectives

The material rarefaction⁹⁶, the ecological integration in the fuzzy-front end design of manufacturing systems^{25,97,98} and the resilience of production systems⁹⁹ remains a systemic problem and it calls for pushing forward the boundaries of knowledge in the fuzzy front-end design phases of socio-technical manufacturing configurations. There is a urgent necessity to better understand how to design, orchestrate¹⁰⁰ and evaluate the socio-technical circular demonstrators at urban levels to unleash a sustainability transition towards appropriate and inclusive micro-manufacturing and recycling values chains inspired on the “*Design Global / Manufacturing local*” principles. By exploring the case of Green Fablab At Octroi Nancy, **the purpose of SDRAM project is create a systemic methodological blueprint approach to fully expand the frontiers of the design socio-technical manufacturing systems as a sustainable transitions in urban settlements.** To do so, the SDRAM project aims to deep understanding of

¹See <https://cordis.europa.eu/project/id/869952>

²See <https://www.octroi-nancy.fr/>

³This demonstrator found retard because of the pandemic situation.

the three major layers and the boundary objects between them:

1. Urban space in the lens of the urban manufacturing opportunity and material rarefaction.
2. Design for a technodiversity baseline based on open source appropriate technologies (OSAT) for distributed recycling, and
3. Pluralistic (e)valuation of socio-technical alternatives to mass production in the frame of a urban sustainability transition.

Manufacturing and an urban priority for resilience and agility. The significance and main challenge of sustainable urban production lies in the bridging of disciplinary boundary of urban and manufacturing systems fields¹⁰¹. One major drawback is the lack of holistic and shared framework to connect the urban and manufacturing development. There is an opportunity to create a City-Factory-Product nexus^{102,103} understanding that aims to be adaptable, resilient^{104,@ 105} and considering the carrying capacity of the urban ecosystem.

The open-source appropriate technology (OSAT) as alternative. The OSAT relies on small-scale, economically affordable, decentralised, energy-efficient, environmentally sound and easily utilized by local communities to meet their needs¹⁰⁶. This approach have been valuable for scientific equipment to reduce the cost with equal of quality^{107,108}, and having implication in national level^{38,109}. Therefore, a OSAT technodiversity is a breakthrough to possible open up the valorization of material loops inside urban settlements fostering the creation of urban closed-loop supply chains. The establishment of development of a technological open source maturity level focalised on the distributed recycling is part of the technical blueprint.

Pluralistic (e)valuation for emerging industrial micro-values chains that integrate ecosystem characteristics. Reconciling urban development and industrial development is not an easy task (wicked problem). Thus, the type of information that decision-makers take into account is relevant at the moment to put in place industrial systems. From systemic design thinking and ecological economics fields^{110@,111}, it is needed to new forms of (e)valuation beyond the economics¹¹² to identify major feedbacks in the strategic, the tactical and the operational decisional levels. The integration of ecological aspects¹¹³ in the decision-making seems not evident given the complexity to define the boundaries and interactions of industrial and ecological systems. However, it is urgent to expand the boundaries for engineering design from the lowest molecular- / process-level, to the higher levels of value chains, ecosystems and the planet^{114,115}. We need to integrate ecological carrying capacity since the fuzzy front end phase of an industrial systems.

The ambition of this project is to open up the possibilities of a new field of socio-technical design of distributed and circular urban production systems to the scientific community.

A challenging task for a systemic blueprint

The major gap that currently prevents from exploring the potential of alternative distributed and circular manufacturing relies on a knowledge gap in terms of the maturity in the connection between the unit-facility-urban levels including the respective boundary objects¹¹⁶ that needs to be considered between the layers. From a design for sustainability^{90,117} perspective, this implies the aid-decision tools to help makers, practitioners and decision-makers in the implementation phase considering the technosphere (molecule, material, process unit) but also the also to the ecosystem impact. Therefore as a systemic blueprint, I aim to make linkage of the micro-meso-macro levels of the technical, system and valuation layers embeeded in a urban spatio-temporal context (See Figure network)

Rethinking the design of efficient and effective production system under the perspective of small and modular machines in combination with the means provided by rapidly increasing digitalization can support the development of sustainable and competitive urban production systems. Urban production systems can be developed in a way that is sustainable and competitive by rethinking the design of efficient and effective production systems from the perspective of tiny and modular machines in conjunction with the tools afforded by rapidly rising OSAT.

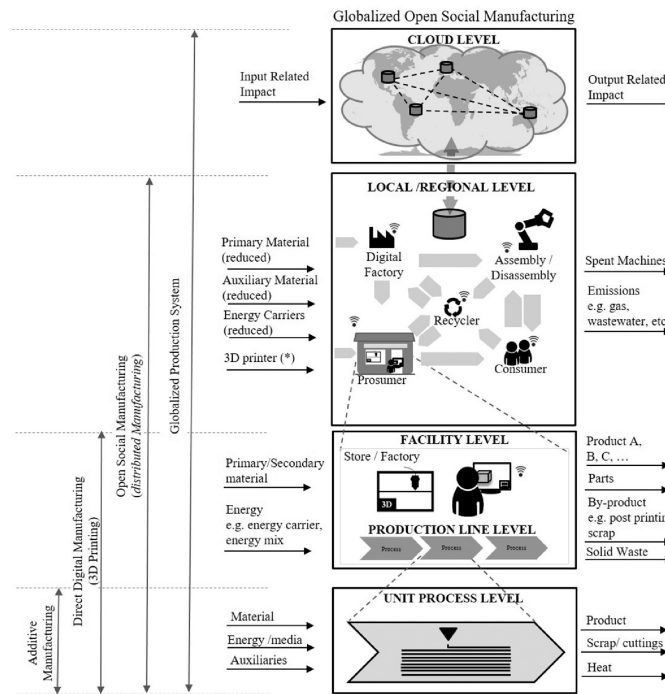


Figure 2: Gráfico a faire basee sur celui-la Source XX

3. The Methodology

SDRAM implement a methodology made of four working packages (WP), as illustrated in Fig. 3. The aim of WP1 is to set a literature baseline for an integrative and critical analysis of urban territory in the frame of micro-value chains for local recycling loops. This working package gives the insights for the WP2, and WP3, which are key of the project. The WP2 seeks to consolidate systematize a design process for OSAT for a complete distributed recycling process establishing an unit maturity level index for each, but more important, a system maturity level for the integration in a urban ecosystem. The main goal is to establish a complete OSAT ecosystems to valorize the waste niches opportunities identified in WP1.

The WP3 aims to identify a pluralistic (e)valuation framework for the urban closed-loop system network integrating three essential issues: sustainability, resiliency, and agility into a circular economy praxis. Finally, WP4 is dedicated to the experimentation of the several products case studies of the urban circular manufacturing taking into at case studies the implementation of the Green Fablab Project at the third place of OK3 at Nancy-France. The object is to replicate this analysis in other territories such Chile, in collaboration with Prof. Pavlo Santander, and in Canada with collaboration of Joshua Pearce. Work packages are synthetically detailed hereinafter.

WP 1: Theoretical baseline on urban value chains

WP1 aims at developing a integral methodology to diagnose, quantify and evaluate the potential urban value chains for distributed recycling loops on a territory considering the ecological priorities of the territory. The achievement to SDRAM target relies the urban spatial analysis and stakeholders characteristics as an entry point of the design of the socio-technical system mapping two major outputs: 1.1) The first output aims to highlights: (a) the identification of the priorities in terms of ecosystems services of the territory at the urban planning level, and how the plastic waste affects them. (b) the evaluation (technical, economic and environmental) of the current waste management system to identify the ' of the limits of the loop chains , existing plastic 'gaps' that distributed recycling approach can fill,

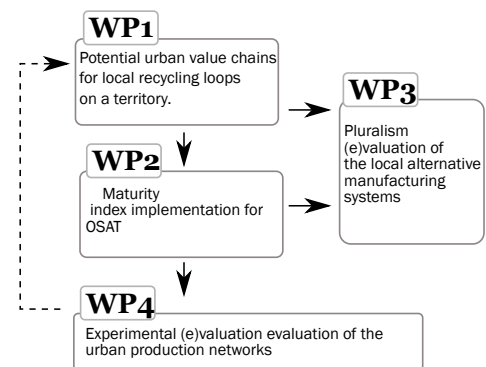


Figure 3: Methodology

and (c), a stakeholder characterization analysis needs (e.g. sorting centres, recycling centres, schools). Then in 1.2), the second output aims to close the existing data gaps¹¹⁸ in terms of secondary material availability at the urban level considering its complexity level of revalorization. The goal is to couple $\{territory \times material\}$ together as a material flow quantitative analysis to assess the potential to material for a closed-loop supply chain. This is particularly relevant in the context of plastic products where governments worldwide are placing ambitious circularity targets due to the accumulation. The priority is to reveal a list of ‘suitable’ secondary plastic materials wastes at the urban level that today are not fully understood and valorized. This analysis will be carried out at least every year, and if possible more frequently to see if there is a change or seasonality in the composition of this untreated waste.

WP 2: Maturity level and technodiversity level of the open source appropriate technology

The WP2 will be focused on the unit- and facility-level to better understand how OSAT can be implemented in urban micro-recycling systems. The main purpose of this task is to leverage a resilient manufacturing^{99,119} under the logic of Design Global/Manufacture Local robustness. To do so, three major tasks are seen:

2.1) definition of a scientific literature and critical analysis on the adoption¹²⁰ and barriers of the open-source appropriate technologies with particular focus on distributed recycling considering the modularity types¹²¹, gaps in the hardware development and .

2.2) Mapping of new/adapted practices and tools that would be needed to support local manufacturers and local decision makers to navigate and overcome the challenges of distributed recycling manufacturing.

2.3) Identification a system maturity level that enable the constitution of urban closed-loop supply chain

. ...

WP 3: Pluralistic (e)valuation of distributed recycling systems

In parallel of WP2, the WP3 aims to consolidate aid-decision tool to reveal and better understand under which conditions these distributed recycling/manufacturing urban chains are pertinent for the local territory. This tool describe and characterize the new value chain to include new form of pluralism valuation¹¹² and techno-ecological interactions^{98,122,123}. More important to avoid Jevons paradox¹²⁴, it is determine the scale of action considering the technical maturity, economic viability and environmental respect of the ecosystem services. In (4.1), one strategical point in sustainability relies on explicitly account for their demand and supply of of ecosystem goods and services framework given by the micro-value chains¹²⁵. then (4.2), the main aim is to reveal the components and the structure of the urban circular networks to the combining Material Flow Analysis¹²⁶, System Dynamics^{127–131} and Circularity Indicators¹³².

WP 4: Experimentation and deployment in function of the local territory

The WP4 aims to consolidate a starting point for a longitudinal study¹³³ to evaluate of the implementation these distributed recycling strategies at a urban territorial level. WP4 is devoted to the iteration and evaluation of the urban production networks to deep understand the evolution. 4.1) Several case studies of distributed fabrication / recycling will be documented and developed in complement with a comparative and contextualized Life Cycle Assessment (LCA) of the new secondary AM material compared to actual materials. 4.2) A strategic roadmap will be a major delivered to understand the possible evolution of

To pass from ecodesign to an operation design for sustainability approach, this WP4 will be based ten different models at operational, tactical, and strategical levels¹¹⁷.

3. Conceptual risk and feasibility assessment

SDRAM is a high operation and conceptual-risk project mainly because the integration of multiples disciplines in a one basis framework need to establish boundary object to have a coherent framework.

Table 1: ss

ID	Risk items	Effect of the risk	Causes of the risk	Grade	Actions to minimize the risk
1	Difficulty to data access to local territorial diagnosis	Constraint to define WP1		Middle	There have been pre-exists between the partners and these territories and recycling actors.
2					
3					

Table 2: Feasible challenges in the methodology

ID	Main challenges	Feasibility
1	Theoretical baseline on urban value chains	
2	Maturity level and technodiversity level of the open source appropriate technology	
3	Pluralism (e)valuation of the distributed recycling systems	
4		

4. An Impact project

- **Main scientific impacts.** (1) the breakthrough understating of the implementation and evaluation of the design of sustainability of socio-technical systems
- **Main societal impacts.** If the expected modeling are confirmed, the outcome of this pproject will allow urban and technical desicion-makers the implementation of local recycling circuits of available plastic waste by means of small, ro distribed recycling socio-technical units.

5. Resources and budget

The research team

The budget required for the development of SDRAM is XXX €. The most significant cost is the personnel cost (XXXX € - XX %). Minor cost cover the purchase of open hardware equipement (XXXX € - XX %), travels for dissemination of results (XXXX € - XX %), Open access fees for at least 8 publications (XXXX € - XX %). %

	Semester (S)									
Activity	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
WP1:										
WP2:										
WP3:										
WP4:										

Figure 4: Gantt diagram and task allocation

References

1. De-la-Torre GE, Diones-Salinas DC, Pizarro-Ortega CI, et al. [New plastic formations in the Anthropocene](#). *Science of The Total Environment* 2021; 754: 142216.
2. Stoddard I, Anderson K, Capstick S, et al. [Three Decades of Climate Mitigation: Why Haven't We Bent the Global Emissions Curve?](#) <https://doi.org/10.1146/annurev-environ-012220-011104> 2021; 46: 653–689.
3. Hermoso V, Carvalho SB, Giakoumi S, et al. [The EU Biodiversity Strategy for 2030: Opportunities and challenges on the path towards biodiversity recovery](#). *Environmental Science & Policy* 2022; 127: 263–271.
4. Steffen W, Rockström J, Richardson K, et al. [Trajectories of the Earth System in the Anthropocene](#). *Proceedings of the National Academy of Sciences* 2018; 115: 8252–8259.
5. Steffen W, Grinevald J, Crutzen P, et al. [The Anthropocene: Conceptual and historical perspectives](#). *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 2011; 369: 842–867.
6. O'Neill DW, Fanning AL, Lamb WF, et al. [A good life for all within planetary boundaries](#). *Nature Sustainability* 2018; 1: 88–95.
7. Raworth K. [A Doughnut for the Anthropocene: Humanity's compass in the 21st century](#). *The Lancet Planetary Health* 2017; 1: e48–e49.
8. Rockström J, Steffen W, Noone K, et al. [A safe operating space for humanity](#). *Nature* 2009; 461: 472–475.
9. Kanger L, Bone F, Rotolo D, et al. [Deep transitions: A mixed methods study of the historical evolution of mass production](#). *Technological Forecasting and Social Change* 2022; 177: 121491.
10. European Commision. [Summary for Policymakers](#). In: Intergovernmental Panel on Climate Change (ed) *Climate Change 2013 - The Physical Science Basis*. Cambridge: Cambridge University Press, pp. 1–30.
11. Ellen MacArthur Foundation. [Growth within: A circular economy vision for a competitive europe](#). *Ellen MacArthur Foundation* 2015; 100.
12. Nobre GC, Tavares E. [The quest for a circular economy final definition: A scientific perspective](#). *Journal of Cleaner Production* 2021; 314: 127973.
13. Kirchherr J, Reike D, Hekkert M. [Conceptualizing the circular economy: An analysis of 114 definitions](#). *Resources, Conservation and Recycling* 2017; 127: 221–232.
14. Schögl J-P, Stumpf L, Baumgartner RJ. [The narrative of sustainability and circular economy - A longitudinal review of two decades of research](#). *Resources, Conservation and Recycling* 2020; 163: 105073.
15. Calisto Friant M, Vermeulen WJV, Salomone R. [A typology of circular economy discourses: Navigating the diverse visions of a contested paradigm](#). *Resources, Conservation and Recycling* 2020; 161: 104917.
16. Rödl MB, Åhlvik T, Bergeå H, et al. [Performing the Circular economy: How an ambiguous discourse is managed and maintained through meetings](#). *Journal of Cleaner Production* 2022; 360: 132144.
17. Corvellec H, Stowell AF, Johansson N. Critiques of the circular economy. *Journal of Industrial Ecology*. Epub ahead of print 2021. DOI: [10.1111/JIEC.13187](https://doi.org/10.1111/JIEC.13187).
18. Zhen H, Gao W, Yuan K, et al. [Internalizing externalities through net ecosystem service analysis—A case study of greenhouse vegetable farms in Beijing](#). *Ecosystem Services* 2021; 50: 101323.
19. Touriki FE, Benkhathi I, Kamble SS, et al. [An integrated smart, green, resilient, and lean manufacturing framework: A literature review and future research directions](#). *Journal of Cleaner Production* 2021; 319: 128691.
20. Van Fan Y, Lee CT, Lim JS, et al. [Cross-disciplinary Approaches Towards Smart, Resilient and Sustainable Circular Economy](#). *Journal of Cleaner Production* 2019; 232: 1482–1491.

21. Weichhart G, Mangler J, Raschendorfer A, et al. [An adaptive system-of-systems approach for resilient manufacturing](#). *e & i Elektrotechnik und Informationstechnik* 2021; 138: 341–348.
22. Kallis G, Kostakis V, Lange S, et al. [Research On Degrowth](#). *Annual Review of Environment and Resources* 2018; 43: 291–316.
23. Savini F. [The circular economy of waste: Recovery, incineration and urban reuse](#). *Journal of Environmental Planning and Management* 2021; 64: 2114–2132.
24. Bakshi BR, Gutowski TG, Sekulic DP. [Claiming Sustainability: Requirements and Challenges](#). *ACS Sustainable Chemistry & Engineering* 2018; 6: 3632–3639.
25. Bakshi BR. [Toward sustainable chemical engineering: The role of process systems engineering](#). *Annual Review of Chemical and Biomolecular Engineering* 2019; 10: 265–288.
26. Zheng C, Yuan J, Zhu L, et al. [From digital to sustainable: A scientometric review of smart city literature between 1990 and 2019](#). *Journal of Cleaner Production* 2020; 258: 120689.
27. Sodiq A, Baloch AAB, Khan SA, et al. [Towards modern sustainable cities: Review of sustainability principles and trends](#). *Journal of Cleaner Production* 2019; 227: 972–1001.
28. Schraven D, Joss S, de Jong M. [Past, present, future: Engagement with sustainable urban development through 35 city labels in the scientific literature 1990–2019](#). *Journal of Cleaner Production* 2021; 292: 125924.
29. Riffat S, Powell R, Aydin D. [Future cities and environmental sustainability](#). *Future Cities and Environment* 2016; 2: 1.
30. Herrmann C, Juraschek M, Burggräf P, et al. [Urban production: State of the art and future trends for urban factories](#). *CIRP Annals* 2020; 69: 764–787.
31. Juraschek M. *Analysis and Development of Sustainable Urban Production Systems*. Cham: Springer International Publishing, 2022. Epub ahead of print 2022. DOI: [10.1007/978-3-030-76602-3](#).
32. Priovolou C, Troullaki K, Tsiouris N, et al. [Tracing sustainable production from a degrowth and localisation perspective: A case of 3D printers](#). *Journal of Cleaner Production* 2022; 376: 134291.
33. Cerdas F, Juraschek M, Thiede S, et al. [Life Cycle Assessment of 3D Printed Products in a Distributed Manufacturing System](#). *Journal of Industrial Ecology* 2017; 21: S80–S93.
34. Kostakis V, Latoufis K, Liarokapis M, et al. [The convergence of digital commons with local manufacturing from a degrowth perspective: Two illustrative cases](#). *Journal of Cleaner Production* 2018; 197: 1684–1693.
35. Sabel C, Zeitlin J. Historical Alternatives to Mass Production: Politics, Markets and Technology in Nineteenth-Century Industrialization. *Past & Present* 1985; 133–176.
36. Pearce JM, Morris Blair C, Laciak KJ, et al. [3-D Printing of Open Source Appropriate Technologies for Self-Directed Sustainable Development](#). *Journal of Sustainable Development* 2010; 3: 17–29.
37. Kostakis V, Papachristou M. [Commons-based peer production and digital fabrication: The case of a RepRap-based, Lego-built 3D printing-milling machine](#). *Telematics and Informatics* 2014; 31: 434–443.
38. Heikkinen ITS, Savin H, Partanen J, et al. [Towards national policy for open source hardware research: The case of Finland](#). 2020; 155: 119986.
39. DiBona C, Ockman S. *Open sources: Voices from the open source revolution*. ” O’Reilly Media, Inc.”, 1999.
40. Raymond E. The cathedral and the bazaar. *Knowledge, Technology & Policy* 1999; 12: 23–49.
41. Lakhani KR, Von Hippel E. How open source software works: ‘free’ user-to-user assistance. In: *Produktentwicklung mit virtuellen communities*. Springer, 2004, pp. 303–339.
42. Deek FP, McHugh JA. *Open source: Technology and policy*. Cambridge University Press, 2007.

43. Colombo MG, Piva E, Rossi-Lamastra C. Open innovation and within-industry diversification in small and medium enterprises: The case of open source software firms. *Research Policy* 2014; 43: 891–902.
44. Dodourova M, Bevis K. Networking innovation in the european car industry: Does the open innovation model fit? *Transportation Research Part A: Policy and Practice* 2014; 69: 252–271.
45. Alexy O, Henkel J, Wallin MW. From closed to open: Job role changes, individual predispositions, and the adoption of commercial open source software development. *Research Policy* 2013; 42: 1325–1340.
46. Boudreau KJ, Lakhani KR. Innovation experiments: Researching technical advance, knowledge production, and the design of supporting institutions. *Innovation Policy and the Economy* 2016; 16: 135–167.
47. Hienert C, Von Hippel E, Jensen MB. User community vs. Producer innovation development efficiency: A first empirical study. *Research policy* 2014; 43: 190–201.
48. Söderberg J. *Hacking capitalism: The free and open source software movement*. Routledge, 2015.
49. Martinez MG. Solver engagement in knowledge sharing in crowdsourcing communities: Exploring the link to creativity. *Research Policy* 2015; 44: 1419–1430.
50. Årdal C, Røttingen JA. Financing and collaboration on research and development for nodding syndrome. *Health Research Policy and Systems* 2016; 14: 1–7.
51. Thompson C. Build it. Share it. Profit. Can open source hardware work. *Work*; 10.
52. Fisher DK, Gould PJ. Open-source hardware is a low-cost alternative for scientific instrumentation and research. *Modern instrumentation* 2012; 1: 8.
53. Pearce JM. Building research equipment with free, open-source hardware. *Science* 2012; 337: 1303–1304.
54. Pearce JM. *Open-source lab: How to build your own hardware and reduce research costs*. Newnes, 2013.
55. Li Z, Seering W, Wallace D. Understanding value propositions and revenue models in open source hardware companies. In: *ICIE 2018 6th international conference on innovation and entrepreneurship: ICIE 2018*. Academic Conferences; publishing limited, 2018, p. 214.
56. Pearce J. Sponsored libre research agreements to create free and open source software and hardware. *Inventions* 2018; 3: 44.
57. Petch A, Lightowler C, Pattoni L, et al. Embedding research into practice through innovation and creativity: A case study from social services. *Evidence & Policy: A Journal of Research, Debate and Practice* 2014; 10: 555–564.
58. Pearce JM. Return on investment for open source scientific hardware development. *Science and Public Policy* 2015; 43: 192–195.
59. Pearce JM. Quantifying the value of open source hardware development. *Modern Economy* 2015; 6: 1–11.
60. Wittbrodt BT, Glover A, Laureto J, et al. Life-cycle economic analysis of distributed manufacturing with open-source 3-d printers. *Mechatronics* 2013; 23: 713–726.
61. Beltagui A, Sesis A, Stylos N. [A bricolage perspective on democratising innovation: The case of 3D printing in makerspaces](#). *Technological Forecasting and Social Change* 2021; 163: 120453.
62. Pearce JM. A review of open source ventilators for COVID-19 and future pandemics. *F1000Research*; 9. Epub ahead of print 2020. DOI: [10.12688/f1000research.22942.2](https://doi.org/10.12688/f1000research.22942.2).
63. He Y, Xue G, Fu J. [Fabrication of low cost soft tissue prostheses with the desktop 3D printer](#). *Scientific Reports* 2014; 4: 6973.

- 384 64. Tan HW, Choong YYC. [Additive manufacturing in COVID-19: Recognising the challenges and driving for assurance](https://doi.org/10.1080/1745275920211975882). <https://doi.org/10.1080/1745275920211975882> 2021; 1–6.
- 385
- 386 65. Ijassi W, Evrard D, Zwolinski P. [Characterizing urban factories by their value chain: A first step towards more sustainability in production](#). *Procedia CIRP* 2022; 105: 290–295.
- 387
- 388 66. Cruz Sanchez FA, Boudaoud H, Muller L, et al. [Towards a standard experimental protocol for open source additive manufacturing](#). *Virtual and Physical Prototyping* 2014; 9: 151–167.
- 389
- 390 67. Alexandre A, Cruz Sanchez FA, Boudaoud H, et al. [Mechanical Properties of Direct Waste Printing of Polylactic Acid with Universal Pellets Extruder: Comparison to Fused Filament Fabrication on Open-Source Desktop Three-Dimensional Printers](#). *3D Printing and Additive Manufacturing* 2020; 3dp.2019.0195.
- 391
- 392 68. Cruz F, Lanza S, Boudaoud H, et al. Polymer Recycling and Additive Manufacturing in an Open Source context : Optimization of processes and methods. In: *Solid Freeform Fabrication*. Austin, Texas, 2015, pp. 1591–1600.
- 393
- 394 69. Cruz Sanchez FA, Boudaoud H, Hoppe S, et al. [Polymer recycling in an open-source additive manufacturing context: Mechanical issues](#). *Additive Manufacturing* 2017; 17: 87–105.
- 395
- 396 70. López VM, Carou D, Cruz S FA. [Feasibility study on the use of recycled materials for prototyping purposes: A comparative study based on the tensile strength](#). *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture* 2022; 09544054221113378.
- 397
- 398 71. Pavlo S, Fabio C, Hakim B, et al. [3D-Printing Based Distributed Plastic Recycling: A Conceptual Model for Closed-Loop Supply Chain Design](#). In: *2018 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC)*. IEEE, 2018, pp. 1–8.
- 399
- 400 72. Santander P, Cruz Sanchez FA, Boudaoud H, et al. [Closed loop supply chain network for local and distributed plastic recycling for 3D printing: a MILP-based optimization approach](#). *Resources, Conservation and Recycling* 2020; 154: 104531.
- 401
- 402 73. Santander P, Cruz Sanchez FA, Boudaoud H, et al. [Social, political, and technological dimensions of the sustainability evaluation of a recycling network. A literature review](#). *Cleaner Engineering and Technology* 2022; 6: 100397.
- 403
- 404 74. Cruz Sanchez FA, Boudaoud H, Camargo M, et al. [Plastic recycling in additive manufacturing: A systematic literature review and opportunities for the circular economy](#). *Journal of Cleaner Production* 2020; 264: 121602.
- 405
- 406 75. Baechler C, DeVuono M, Pearce JM. Distributed recycling of waste polymer into RepRap feedstock. *Rapid Prototyping Journal* 2013; 19: 118–125.
- 407
- 408 76. Justino Netto JM, Idogava HT, Frezzatto Santos LE, et al. [Screw-assisted 3D printing with granulated materials: A systematic review](#). *The International Journal of Advanced Manufacturing Technology* 2021; 1–17.
- 409
- 410 77. Netto JMJ, Sarout AI, Santos ALG, et al. [DESIGN AND VALIDATION OF AN INNOVATIVE 3D PRINTER CONTAINING A CO-ROTATING TWIN SCREW EXTRUSION UNIT](#). *Additive Manufacturing* 2022; 103192.
- 411
- 412 78. Billah KMM, Heineman J, Mhatre P, et al. [Large-scale additive manufacturing of self-heating molds](#). *Additive Manufacturing* 2021; 47: 102282.
- 413
- 414 79. Reich MJ, Woern AL, Tanikella NG, et al. [Mechanical Properties and Applications of Recycled Polycarbonate Particle Material Extrusion-Based Additive Manufacturing](#). *Materials* 2019; 12: 1642.
- 415
- 416 80. Byard DJ, Woern AL, Oakley RB, et al. [Green fab lab applications of large-area waste polymer-based additive manufacturing](#). *Additive Manufacturing* 2019; 27: 515–525.
- 417
- 418 81. Petsiuk A, Lavu B, Dick R, et al. [Waste Plastic Direct Extrusion Hangprinter](#). *Inventions* 2022; 7: 70.
- 419

82. Zhong S, Pearce JM. [Tightening the loop on the circular economy: Coupled distributed recycling and manufacturing with recyclebot and RepRap 3-D printing](#). *Resources, Conservation and Recycling* 2018; 128: 48–58.
83. Garmulewicz A, Holweg M, Veldhuis H, et al. [Disruptive Technology as an Enabler of the Circular Economy: What Potential Does 3D Printing Hold?](#) *California Management Review* 2018; 60: 112–132.
84. Despeisse M, Baumers M, Brown P, et al. [Unlocking value for a circular economy through 3D printing: A research agenda](#). *Technological Forecasting and Social Change* 2017; 115: 75–84.
85. Kreiger M, Pearce JM. [Environmental Impacts of Distributed Manufacturing from 3-D Printing of Polymer Components and Products](#). *MRS Proceedings* 2013; 1492: 85–90.
86. Zhong S, Rakhe P, Pearce J. [Energy Payback Time of a Solar Photovoltaic Powered Waste Plastic Recyclebot System](#). *Recycling* 2017; 2: 10.
87. Horta JF, Simões FJP, Mateus A. [Large scale additive manufacturing of eco-composites](#). *International Journal of Material Forming* 2018; 11: 375–380.
88. Tyl B, Allais R. [A design study into multi-level living labs for reuse and repair activities in France](#). *Journal of Cleaner Production* 2021; 321: 129032.
89. Compagnucci L, Spigarelli F, Coelho J, et al. [Living Labs and User Engagement for Innovation and Sustainability](#). *Journal of Cleaner Production* 2020; 125721.
90. Ceschin F, Gaziulusoy I. [Evolution of design for sustainability: From product design to design for system innovations and transitions](#). *Design Studies* 2016; 47: 118–163.
91. Wang M, Liu P, Gu Z, et al. [A Scientometric Review of Resource Recycling Industry](#). *International Journal of Environmental Research and Public Health* 2019; 16: 4654.
92. Leipold S, Weldner K, Hohl M. [Do we need a ‘circular society’? Competing narratives of the circular economy in the French food sector](#). *Ecological Economics* 2021; 187: 107086.
93. Hobson K, Holmes H, Welch D, et al. [Consumption Work in the circular economy: A research agenda](#). *Journal of Cleaner Production* 2021; 321: 128969.
94. Jaeger-Erben M, Jensen C, Hofmann F, et al. [There is no sustainable circular economy without a circular society](#). *Resources, Conservation and Recycling* 2021; 168: 105476.
95. Klotz M, Haupt M, Hellweg S. [Limited utilization options for secondary plastics may restrict their circularity](#). *Waste Management* 2022; 141: 251–270.
96. Hultman J, Corvellec H, Jerneck A, et al. [A resourcification manifesto: Understanding the social process of resources becoming resources](#). *Research Policy* 2021; 50: 104297.
97. Bakshi BR, Ziv G, Lepech MD. [Techno-Ecological Synergy: A Framework for Sustainable Engineering](#). *Environmental Science & Technology* 2015; 49: 1752–1760.
98. Saladini F, Gopalakrishnan V, Bastianoni S, et al. [Synergies between industry and nature – An emergy evaluation of a biodiesel production system integrated with ecological systems](#). *Ecosystem Services* 2018; 30: 257–266.
99. Xu X, Wang L, Fratini L, et al. [Smart and resilient manufacturing in the wake of COVID-19](#). *Journal of Manufacturing Systems* 2021; 60: 707–708.
100. Ritala P, De Kort C, Gailly B. [Orchestrating Knowledge Networks: Alter-Oriented Brokering](#). *Journal of Management* 2022; 01492063221086247.
101. Tsui T, Peck D, Geldermans B, et al. [The role of urban manufacturing for a circular economy in cities](#). *Sustainability (Switzerland)* 2021; 13: 1–22.
102. Herrmann C, Juraschek M, Kara S, et al. [Urban Factories: Identifying Products for Production in Cities](#). In: Hu AH, Matsumoto M, Kuo TC, et al. (eds) *Technologies and Eco-innovation towards Sustainability I: Eco Design of Products and Services*. Singapore: Springer, 2019, pp. 185–198.

103. Williams J. [Circular Cities: Challenges to Implementing Looping Actions](#). *Sustainability* 2019; 11: 423.
104. Shabbir MS, Mahmood A, Setiawan R, et al. [Closed-loop supply chain network design with sustainability and resiliency criteria](#). *Environmental Science and Pollution Research* 2021; 1–16.
105. Mubarik MS, Naghavi N, Mubarik M, et al. [Resilience and cleaner production in industry 4.0: Role of supply chain mapping and visibility](#). *Journal of Cleaner Production* 2021; 292: 126058.
106. Pearce JM. [The case for open source appropriate technology](#). *Environment, Development and Sustainability* 2012; 14: 425–431.
107. Pearce JM. [Open-Source Lab](#). In: *Open-Source Lab*. Elsevier, 2014, pp. 95–162.
108. Pearce JM. [Return on investment for open source scientific hardware development](#). *Sci Public Policy* 2016; 43: 192–195.
109. Pearce JM. [Strategic Investment in Open Hardware for National Security](#). *Technologies* 2022; 10: 53.
110. Kish K, Mallery D, Yahya Haage G, et al. [Fostering critical pluralism with systems theory, methods, and heuristics](#). *Ecological Economics* 2021; 189: 107171.
111. Economics E, Ee W. Ecological economics : The next 30 years. 190. Epub ahead of print 2021. DOI: [10.1016/j.ecolecon.2021.107211](#).
112. Gunton RM, Hejnowicz AP, Basden A, et al. [Valuing beyond economics: A pluralistic evaluation framework for participatory policymaking](#). *Ecological Economics* 2022; 196: 107420.
113. Kennedy C. [The Intersection of Biophysical Economics and Political Economy](#). *Ecological Economics* 2022; 192: 107272.
114. Martinez-Hernandez E. [Trends in sustainable process design—from molecular to global scales](#). *Current Opinion in Chemical Engineering* 2017; 17: 35–41.
115. Kurtz SA. [Beyond the lifetime of organizations: A framework for multi-generational goal survival in the ecology of goals](#). *Futures* 2021; 127: 102699.
116. Abson DJ, von Wehrden H, Baumgärtner S, et al. [Ecosystem services as a boundary object for sustainability](#). *Ecological Economics* 2014; 103: 29–37.
117. Rocha CS, Antunes P, Partidário P. [Design for sustainability models: A multiperspective review](#). *Journal of Cleaner Production* 2019; 234: 1428–1445.
118. Bianchi M, Tapia C, del Valle I. [Monitoring domestic material consumption at lower territorial levels: A novel data downscaling method](#). *Journal of Industrial Ecology* 2020; 24: 1074–1087.
119. Zhang WJ, van Luttervelt CA. [Toward a resilient manufacturing system](#). *CIRP Annals* 2011; 60: 469–472.
120. Reinauer T, Hansen UE. [Determinants of adoption in open-source hardware: A review of small wind turbines](#). *Technovation* 2021; 102289.
121. Gavras K, Kostakis V. [Mapping the types of modularity in open-source hardware](#). *Design Science* 2021/ed; 7: e13.
122. Liu X, Bakshi BR, Rugani B, et al. Quantification and valuation of ecosystem services in life cycle assessment: Application of the cascade framework to rice farming systems. *Science of the Total Environment*; 747. Epub ahead of print 2020. DOI: [10.1016/j.scitotenv.2020.141278](#).
123. Liu X, Bakshi BR. [Ecosystem Services in Life Cycle Assessment while Encouraging Techno-Ecological Synergies](#). *Journal of Industrial Ecology* 2019; 23: 347–360.
124. Giampietro M, Mayumi K. Unraveling the complexity of the Jevons Paradox: The link between innovation, efficiency, and sustainability. *Frontiers in Energy Research*; 6. Epub ahead of print April 2018. DOI: [10.3389/FENRG.2018.00026](#).

- 506 125. Diwekar U, Amekudzi-Kennedy A, Bakshi B, et al. [A perspective on the role of uncertainty in sustainability science and engineering](#). *Resources, Conservation and Recycling* 2021; 164: 105140.
- 507
- 508 126. Saidani M, Yannou B, Leroy Y, et al. [Multi-tool methodology to evaluate action levers to close the loop on critical materials – Application to precious metals used in catalytic converters](#). *Sustainable Production and Consumption* 2021; 26: 999–1010.
- 509
- 510 127. Kuo T-C, Hsu N-Y, Wattimena R, et al. [Toward a circular economy: A system dynamic model of recycling framework for aseptic paper packaging waste in Indonesia](#). *Journal of Cleaner Production* 2021; 301: 126901.
- 511
- 512 128. Marche B, Camargo M, Bautista Rodriguez SC, et al. [Qualitative sustainability assessment of road verge management in France: An approach from causal diagrams to seize the importance of impact pathways](#). *Environmental Impact Assessment Review* 2022; 97: 106911.
- 513
- 514 129. Tomoaia-Cotisel A, Allen SD, Kim H, et al. [Rigorously interpreted quotation analysis for evaluating causal loop diagrams in late-stage conceptualization](#). *System Dynamics Review* 2022; 38: 41–80.
- 515
- 516 130. Castro C. [Systems-thinking for environmental policy coherence: Stakeholder knowledge, fuzzy logic, and causal reasoning](#). *Environmental Science & Policy* 2022; 136: 413–427.
- 517
- 518 131. Pérez-Pérez JF, Parra JF, Serrano-García J. [A system dynamics model: Transition to sustainable processes](#). *Technology in Society* 2021; 65: 101579.
- 519
- 520 132. Saidani M, Yannou B, Leroy Y, et al. [A taxonomy of circular economy indicators](#). *Journal of Cleaner Production* 2019; 207: 542–559.
- 521
- 522 133. Langley A, Smallman C, Tsoukas H, et al. [Process Studies of Change in Organization and Management: Unveiling Temporality, Activity, and Flow](#). *Academy of Management Journal* 2013; 56: 1–13.
- 523