Section a: State of the art and objectives

SDROSAT in a nutshell

The main purpose of the Systemic **D**istributed** Recycl**ing via Open S**ource **Appropriate Technologies** (DRECYCLOS)** is to establish a systemic blueprint methodology for the design, implementation and (e)valuation of micro-value chains of distributed recycling at an urban territorial level. We seek the achievement of a two-level target: 1) The understanding of the design of socio-technical configurations of distributed plastic recycling networks as a resilience strategy for an urban territory. 2) Holistic and pluralistic evaluation of the open source appropriate technologies as assets for urban development.

Plastics and the Antropocene: a change is needed

In the current paradigm, mass manufacturing value chains of plastic products are often globalized. The mass production system, in the lens of a deep transition framework, is the fruit of a complex co-evolution of single unit productions and interconnected systems[1]. Several forms of environmental degradation have intensified without fully assuring the social foundation's minimum standards (e.g. healthcare, energy, water etc)[2]. Thus, humanity is not only a biological, but a geological force, and this is what is recently considered the Anthropocene era[3,4]. This new status of humanity is given the different indicators in the natural ecosystems that are impacting the stability of the earth system. For instance, the plastic waste contamination is one of the relevant stratigraphic indicators[5,6]. More precisely, the soil and marine plastic pollution shows ecological, biogeochemical and physical thresholds and they are becoming a key component of the planetary boundaries threat associated with chemical pollutants[2,7,8].

Plastics waste management: the centralized paradigm

The use and disposal of plastics is a societal problem characterized by high complexity and multifaceted feedback loops that calls for a systemic view[9]. This issue needs to include the entire plastics value chain from producers -petrochemical companies-[10,11], converters[12], brand owners or manufacturers[13,14], retailers and consumers[15–17], and recycling operators[18,19], as well as the influences of policy-makers in wider economic and societal changes[12].

Since 2015, the strategy of the European for Plastics in a Circular Economy point out the ambition of all plastic packaging (only packaging unfortunately!) on the EU market is either reusable or can be recycled in a cost-effective manner by 2030[20]. However, the paradox is that packaging consumption[21] (influenced by the pandemic situation) has never been as high as it is today, with nearly 250 million tons of waste generated globally[22,23]. In Europe (which is supposed to be the most advanced region in terms of recycling programs), only 14% of the plastic produced has been recycled by 2016[24–26]. This is even optimistic as these statistics are based on the materials that are collected, not on the material that is already in circulation[27]. From the scientific perspective, whether the measurement of plastics inputs comes from the rivers or from shoreline communities, fundamentally it is not a question of 'mismanagement' but about reducing this material in our global supply chains. The root of the plastic waste problem is the extraction and production. It is urgent to reduce the usage, given the adaptive injustice in terms that those who find ways to adapt to changing social realities, whether forced or voluntary, are not those who are responsible for the negative changes to which they are adapting[28]. While this political issue is taking place, a transformative principle that I think it is urgent to better understand is the redefinition of Recycling as 'having the capacity to process discard materials material within the *15-minute city concept*"[29,30]. This would mean urban centers would need to have the capacity to recycle the materials they use within the region. However, the challenge is the delay that implies to put in place alternative production/recycling models. How to manage the huge amount of waste already present in nature and the plastic waste generated in the short term? How to rethink production, consumption systems (and even urban future cities) coherent with the biogeological cycles? What are the alternative trajectories for a socio-technical productive system that take into account the natural capital and externalities[31] since the fuzzy front-end design phase?. These are major scientific questions that remain open towards a sustainable transition of socio-technical model.

Towards circular cities: a promise to fulfill

The circular economy (CE) concept in the policy[32], industrial[33] and scientific[34–37] arenas as an umbrella concept, but also as a contested concept[38–40]. CE has been conceptualized as an ecological modernization project that builds on capitalist economic growth narratives. On the other hand, degrowth proponents argue that economic growth cannot be sufficiently decoupled from environmental impacts, which renders further growth of the economy unsustainable. In any case, many cities have taken up the resource management discourse to design circular economy action plans, which aim to reduce urban environmental impacts while generating new jobs, social well-being and room for innovation. Working to make cities more circular implies adopting a particular approach, using the concept of "territorial metabolism" designating "the set of energy and material flows brought into play by the functioning of a given territory".

This approach consists of understanding cities as the result of a specific socio-ecological regime, no longer solely through their functions or activities, but through their flows and stocks of materials and resources. Indeed, cities worldwide are committed to becoming more circular in their resource use. Looping actions —reuse, recycling and recovery of resources (materials, energy, water, land and infrastructure)— can help to address resource scarcity and wastage in cities. However, whether or not their actions help them to reduce their environmental impacts is unclear[41,42] and there are many challenges to implementation (Institutional, Political, Regulatorial, Socio Economical)[43]. Particularly, a key challenge lies in bridging the boundaries of urban planning and urban production systems in a one coherent, continuum and multi-scale design process[44–46].

'Design global / Manufacturing local'

A major trend in the development of production systems seeks to establish an urban production model[44,46] with decentralized and distributed characteristics[47,48] as an alternative of globalized manufacturing values chains. Aiming at a *'design global / manufacturing local'* (DGML)[49] seems a proto-industrialization[50] transition that is taking place in urban settlements. DGML is an emerging productive model that builds on the convergence of the digital commons of knowledge, software and design with local manufacturing technologies. More precisely, the Open Source Appropriate Technology (OSAT)[51] and peer-to-peer (P2P)[52] approaches are seen as potential drivers to propose an alternative globalization manufacturing paradigm[53].

The open source (OS) approach has become well-established to provide improved product innovation over proprietary product development[54–57]. The evidence is most mature for software development because free and open source software (FOSS) provides: i) diversification and open innovation[58–60], ii) cumulative innovation[61], iii) development efficiency[62], iv) organizational innovation[60], v) higher technical quality of code[63], vi) encourages creativity[64] and vii) perhaps most importantly, it avoids redundant work[65]. Likewise, the OS approach is now also gaining traction in free and open source hardware (FOSH)[66–70] and appears to be roughly 15 years behind FOSS in development and adoption[71]. 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[72–75].

The open source additive manufacturing technology, also known as 3D printing, is playing a major role in the idea of democratization of manufacturing means[76,77]. In particular, fused filament fabrication units are widely used, thanks to the simplicity of operation, the Do-It-Yourself (DIY) approach and the open-support communities. Thousands of open-source products are shared by the global community from consumer goods to scientific[78] and medical equipment[78,79]. This model has been proven to be effective for emergency manufacturing during the COVID-19 pandemic[78,80]. This is a way for 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[44,81].

Major long vision: Appropriate urban production

A major societal issue rely on how to conceived socio-technical 'circular units' for manufacturing that integrates values of sobriety[ref?], resilience[82,83], adaptability[84] and evolutive in urban settlements. The technologies that empower communities through access to means of production; promote localisation of production and logistics; tend to lean towards sufficiency and creativity; are easily and economically utilized from readily available resources by local communities; adopt the open-source philosophy; are designed for affordability and durability; explore tacit knowledge; are defined as **Appropriate** (in the sense of Schumacher[85]) or **Convivial** [[47];] (in the sense of Ivan Illich[86]). Appropriateness (or Conviviality) criteria may foster more systemic and thus sustainable design[47,87,88].

Indeed, 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[89,90]. Indeed, today the establishment of these socio-technical systems need to include all ecosystem externalities and the carrying capacity of the ecosystem to claim sustainability[91,92]. 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 settlements[90].

Distributed recycling via additive manufacturing: a promising inclusion

Since 2014, I have been working on the Distributed Recycling via Additive Manufacturing (DRAM)[93]. DRAM refers to the use of recycled polymer wastes materials by means of a mechanical recycling process in the 3D printing process chain[93]. This marks the technical evolution of additive manufacturing (AM) enabling a new path for a distributed recycling and production.

In a first time, I validate the open-source 3D printing, filament-[94] and pellet-based[95], as a robust manufacturing system, but also as a potential enabler of the mechanical recycling[96–98] of thermoplastic biopolymers wastes like polylactic acid (PLA). Likewise, I worked on the design of the pertinent closed-loop supply chain[99,100], considering the social, political, technological and technological indicators[101] based on the scientific literature. DRAM (See Figure 1) is a breakthrough promise in the constitution of 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.

To appreciate the ground-breaking scientific nature of this idea, let me state that historically, plastic recycling has been oriented to centralized facilities in order to take advantage of economies of scale through the production of low-value products. However, it is proved to be an expensive process due to the inherent separate collection, transportation, processing and remanufacturing[26,102].

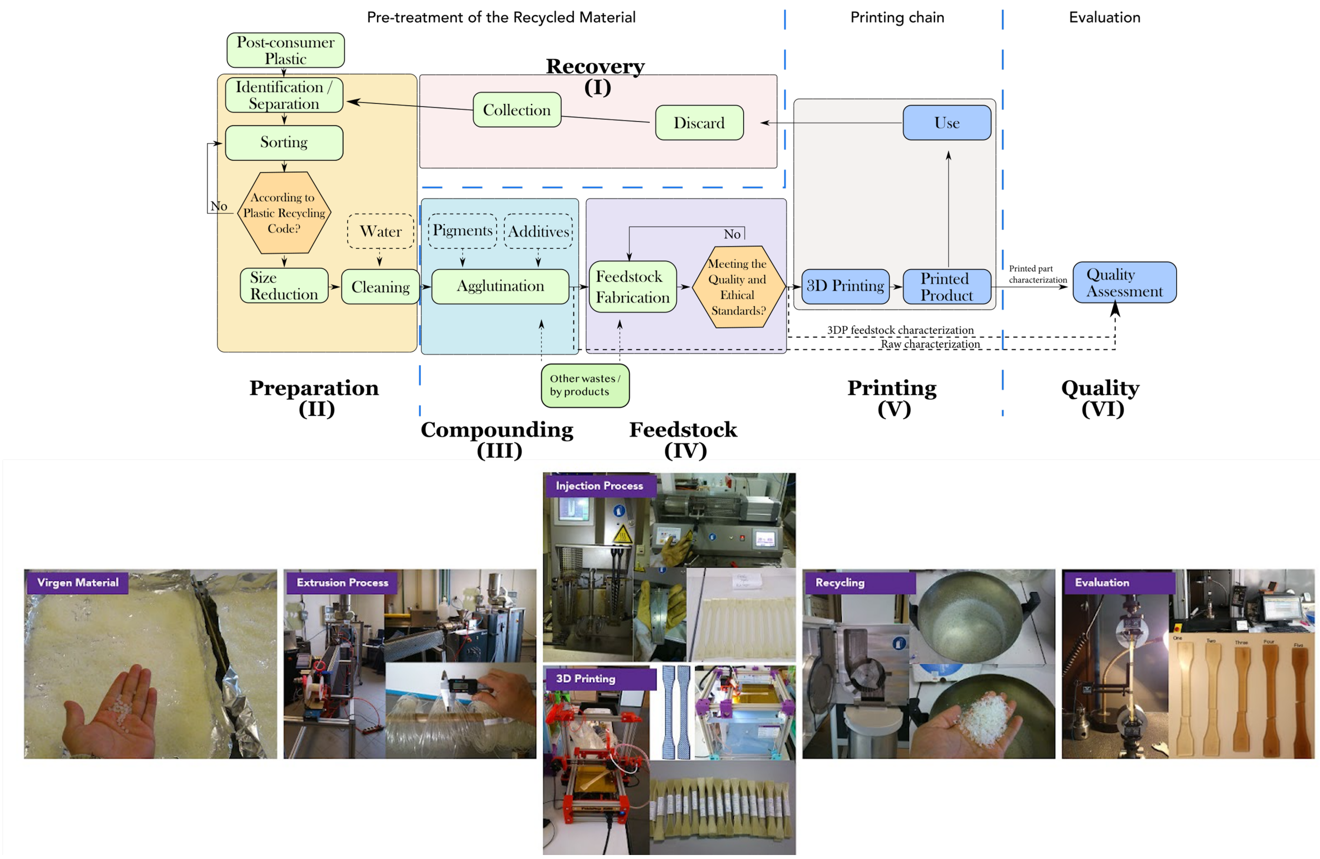


Figure 1: Distributed recycling via additive manufacturing. Source

Plastic production increased at a compound annual growth rate of 8.4%, passing from 2Mt in 1950 to 368Mt in 2019, but the statistics proves that only 9% have been recycled while 79% was accumulated in landfills or the natural environment[22]. **We need another paradigm to tackle this wicked problem.**

On the other hand, DRAM can starts with local plastic waste 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 filament feedstock can be manufactured economically using distributed means such as waste plastic extruder (often called a "recyclebot")[103] for mono-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 marketplaces (e.g. Amazon). Fused granular fabrication is a recent experimental approach enabling the printing process directly from pellets[104,105], which reduces the degradation cycles of the plastic. For this process, I worked in the desktop format[95], but it seems that this technology could further expand the boundaries of additive manufacturing and eventually recycling[106–108] for larger objects (60X60cm) using opeen hardware[109]. Distributed recycling fits into the circular economy paradigm[110–112], 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[113–115]. Additionally, open-source investment should result in an extremely high return on investment (ROI)[78]. This makes distributed recycling environmentally superior to other methods of plastic recycling systems.

The scientific problem: Connect the dots of City-Material-Recycling nexus.

Major efforts in the DRAM scientific literature have been only concentrated in the materials and technical validation in laboratory conditions. However, the holistic impact that distributed recycling can have in the context of an urban city suffers from the critical uncertainty of its relevance in implementation and (e)valuation affecting the support and monitoring of this urban strategy. From the urban planning perspective, there are no methodological tools to (e)valuate (to see the impact but also to see the worth) of possible distributed plastic networks supported by the open source. Indeed, a community-driven of plastic recycling remains in the makers, fablabs spheres where the competences and values may differ from the general public. A system validation is needed to possibly understand the pertinent scale that his approach can take in urban settlements and to show the limits that can entail (Jevons Paradox[116], Waste-Resource Paradox[117]).

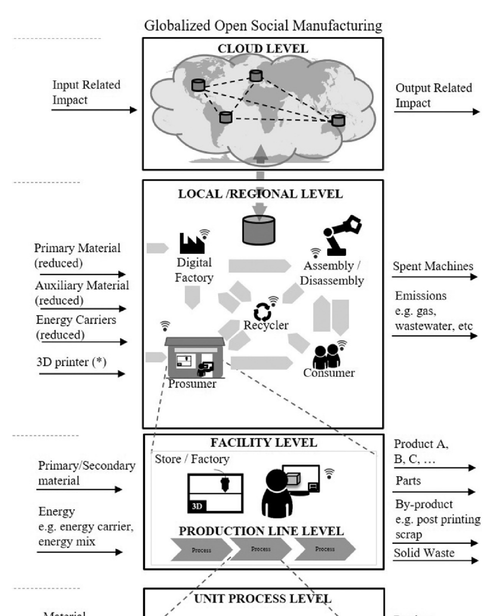
First insights towards a systemic analysis.

In the framework of a EUH2020 project called INEDIT , I have been leading the implementation of the Green Fablab demonstrator inside the third place called Octroi-Nancy Association since November 2021 . INEDIT project aims to create an ecosystem to transform the DYI practices largely documented in FabLabs/Hacker/Maker spaces into a professional approach called Do-It-Together to capitalize on the knowledge, creativity and ideas of design and engineering. The Green Fablab is a distributed recycling demonstrator that use living lab approach[118,119] to experiment in real conditions with citizens, final users and large general public. This experiment is enframed as a design for sustainability at a spatio-social level[120]. We have collected and recycled 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 in the Octroi-Nancy project. This hands-on experience confirms the literature that a new recycled resources industry is starting to conceived inside the cities[121]. This industry 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. More deep insights seek to promote a circular society[122–124]. In the case of plastic waste, the main difficulty remains to make affordable the use of new secondary material applicability by the industry[125], but more profoundly, how these new socio-technical technical systems will interact with the urban planning process and policymaking to make concrete the ambition of circularity inside the urban settlements.

Ambition & objectives

The material' rarefaction[126], the need for ecological integration of manufacturing systems[92,127,128] and the urban resilience[129] calls for pushing forward the boundaries of knowledge of the design of urban production systems to unleash a sustainability transition.

Therefore, the main objective of this project is **to establish a systemic methodological blueprint to fully understand how to design, implement and (e)valuate urban distributed recycling systems based on the Open Source Appropriate technologies.** The deployment of circularity marks a return to a more productive design



of the city, that must consider the natural and urban ecosystem services, the strengthened resilience capacities of cities Thus, this project seeks two level targets:

1. The scientific understanding of the design of socio-technical configurations of urban production systems based on distributed plastic recycling as a resilience strategy.
2. Holistic and pluralistic (e)valuation of the open source appropriate technologies and design as assets for urban territorial development.

The ambition is to better understand distributed recycling, not only by means of additive manufacturing but a whole technodiversity of open source hardware, considering three major layers and the boundaries objects to connect them 1) technical layer (2) urban layer (3) Evaluation layer.

Based on that, table XX presents an outline of the research question of the three major layers to consider in this project.

Challenge 1: Urban systems' role in the deployment of the circularity.

In order to identify the design process of an urban circular production system, some relevant questions are the following:

- How to dimension production systems to be consistent with the resources and materials (recycled plastics) (first and second hand) considered as local ?
- How to establish the link to integrate territorial planning priorities with respect to production systems priorities within an urban circular economy context?
- What are the acceptability conditions for the deployment of urban demonstrators of circularity?
- How to identify the opportunities and barriers from a social, technological, political and legal point of view for the implementation of an urban production/recycling network?
- What strategies can be implemented so that socio-technical systems of circular production can be in line with urban needs and their contribution to the SDGs?
- How to establish an open source value chain in order to foster resilience and technological and energetic sobriety of the urban territory?
- In what extend the implementation of urban production systems affect the functional blocks of an urban territory?

Challenge 2: Systematize the open source technodiversity as territorial asset.

To implement an open source appropriate technology ecosystem suitable for circular urban production system, some relevant research questions are the following:

- How to design a technodiversity baseline based on open source appropriate technologies (OSAT) for distributed recycling?
- How can the design process of an appropriate open source technology be analyzed to avoid what is known as the Jevons paradox?
- How to facilitate the adoption of open source practices and tools, for a public that goes beyond the fablab/makerspaces that have been pioneers?
- What would be the relevant business model for open hardware adoption to allow the introduction of open source tools and practices?
- How to evaluate the degree of maturity of a small company so that within its strategy it can implement the adoption of open hardware as a disruptive practice?
- What open source technologies are needed to develop and implement an urban closed-loop supply chain ?
- How open source technologies would allow the development of urban productive systems in coherence to favor the resilience of the territory?
- What are the core competences needed in an open source ecosystem for urban circularity?

Challenge 3: Pluralistic (e)valuation of distributed recycling units and networks.

In order to (e)valuate in a pluralistic way the development and implementation of urban distributed units, some relevant questions are the following:

- How to connect ecological and economic indicators within the same evaluation framework?
- Which territorial and production system indicators would make it possible to establish a minimum scale of operation, but also a maximum scale that respects urban ecosystem services?
- How to establish scenarios of evolution and impact so that territorial decision-makers can encourage the adoption and piloting of these initiatives?
- What would be the relevant functional unit to delimit the range of action of the production/recycling system within the urban metabolism?
- What are the necessary considerations to represent the preferences of the stakeholders in the decision-making process of integration of urban / manufacturing systems?
- How to support the form process from collective consensus to the deployment of these emerging systems under a purpose oriented approach?

An Impact project

- **Main scientific impacts.**
  1. This project aims to make a breakthrough ontological contributions on the understanding of the implementation and evaluation of **distributed recycling** as a socio-technical unit for urban sustainability transition.
  2. In sustainable transitions research, this dilemma has evoked significant efforts to move beyond the single-case embracing of irreducible complexity, involving modelling approaches and indicator development. This remains one of the main methodological frontiers for transitions research.
- **Main societal impacts.** If the expected results are confirmed, the outcome of this project will allow urban and technical desicion-makers the implementation of local distributed recycling circuits. In the case of this project, the focus is plastic waste. However, we expect that the

systemic blueprint can be applicable to other value chains that available plastic waste by means of small, distributed recycling socio-technical units for plastic recycling.

Section b. Methodology

Introduction the scientific methodology

This project implements a methodology made of four working packages (WP), as illustrated in Fig XX. Intermediate objectives (tasks) and we individuate the specific interventions of the members of the research team. Moreover, we discuss the particular methodologies that we plan to adopt and we make a balance among the risks and gains associated with each action. The aim of WP1 is to set a baseline for an integrative and generic analysis of urban territory in the frame of micro-value chains for manufacturing/recycling production. This working package gives the insights for the WP2, and WP3, which are key to 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, but more important, a system maturity level for the integration into an urban ecosystem. The main output is to establish a complete OSAT design framework 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, resilience, and agility into a circular praxis. Finally, WP4 is dedicated to the experimentation of the several case studies of urban circular manufacturing taking as example the implementation of the Green Fablab Project at the third place of OK3 at Nancy-France. The objective is to replicate this analysis at least in three European territories. Work packages are synthetically detailed hereinafter.

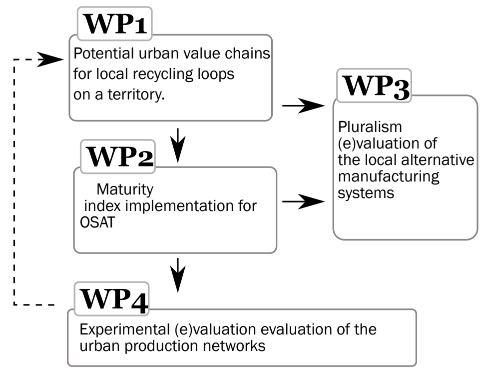


Figure 3: Methodology

WP 1: Theoretical baseline analysis for closed-loop urban value chains

Main objective: This WP deals with the theoretical grid analysis to unfold the potential micro-value chains and exchange flows induced by distributed recycling at urban territories. The granularity level of this methodological analysis is to understand 'archetypes' of neighborhood structures inside the territory. In this granularity, the main impact is to quantify and qualify their urban metabolism in terms of the stock of potential plastic waste, but also, possible secondary usages or territorial needs. This analysis is a first of what could be an '*open source industrial symbiosis*'[130]. This framework is based on the urban spatial analysis and stakeholders characteristics as an entry point of the design. This is a major step because given the particularities of the urban settlement, the nature of the *distributed recycling* may differ from the different 'archetypes' considering the different characteristics of urban municipalities.

A second major output is the analysis of the territory in the lens of ecosystem services framework. To design a distributed recycling network implies that the industrial system takes into account the impact on the territory, anticipating that the possible demultiplication of this socio-technical unit may counter-productive in the long term. Thus this work package the major output will be a methodological tool to characterize the territory, the stakeholders and ecosystem services priorities. These are key inputs for WP2 and WP3.

Task 1.1: Closing the data gap

The goal of this task is to define a {territory x material} index from an urban metabolism to study resource use in an urban city. This assessment aims to quantify hotspots (availability vs complexity) based on territorial and footprint indicators and assess scenarios for the design of a recycling closed-loop supply chain.

- **Step 1:** Proposition of a generic territorial diagnostic approach to fully identify relevant recycling actors in the centralized urban waste management systems.
- **Step 2:** Based on a systematic/integrative literature review, establish a data baseline on the major barriers stakeholders in the centralized urban waste management systems. and confront the literature with qualitative methods (e.g. semi-structured interviews) to validate the identified barriers in the recycling system.
- **Step 3:** to establish a methodological framework that closes the existing data gaps in terms of secondary plastic material availability at the urban level considering its complexity level of revalorization. The monitoring and assessing material consumption and material productivity is critical, both from a macroeconomic perspective — to assess whether sufficient action has been taken, as well as from a local perspective— to support local decision makers in setting new priorities toward long-term objectives[131]. For the case of plastic material, this is particularly relevant given ambitious circularity targets that certain governments.
- **Step 4:** To reveal a list of 'suitable' secondary materials wastes at the urban level that today are not fully understood and valorized. This analysis will be carried out at least in three urban municipalities in Europe 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.

Task 1.2: Identification of the urban territorial priorities in the frame of ecosystems services

Human life and activities rely on ecosystem services (ES) provided by nature[132,133]. The ecosystem services are the ecological characteristics, functions or processes that contribute (actively or passively) to the human well-being[132,134]. Ecosystem goods (e.g; Food) and services (e.g. waste assimilation) illustrate the benefits that humans derive from the ecosystem functions[134]. Likewise, the concept of ecosystem dis-service denotes the processes and functions that affect humans in 'negative' way, making damage and costs[135].

The main aim in this task is to identify the urban priorities based on the ecosystem services (ES) framework. A methodological analysis will be started in this task in order to confront the urban development priorities with urban industrial priorities and to establish an ecosystem-base decision making process[136].

This is an important axis given that one of the crucial issues is that from a decision-maker perspective, there is no an multi-criteria (eco)systemic evaluation tool at early development stages of urban production (and recycling) with the urban territorial development to put in evidence the impact on nature. With the concentration of people and activities in cities, these services are intensively utilized in urban space (e.g. Provisioning, Regulance & Maintenance, Cultural, Land use and cover)to an extent that in most cases cannot be provided by the local ecosystem. Thus, cities (and urban factories) have to rely on supply regions and connection to their hinterland.

- **Step 1:** Literature review and critical analysis of the Urban Ecosystem frameworks (eg. cascade)
- **Step 2:** Establish a data collection tool to apply a participatory approach on the identifi-

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cation and prioritization by local territorial actors.

- **Step 3:** Establish a valuation approach to quantify the potential supply of ES that urban territory can give for a potential distributed recycling system. This project aims to quantify and valuate the potential supply of ES that urban territory can give for the potential distributed recycling system.
- **Step 4:** To estimate the damage that plastic waste not valorized have on the the urban territory in terms of ES.

One major point that ES make clear is to raise awareness on the recognition of interdependence of human, humanity's primary dependances on the 'functions of' natural capital which reflects the fact that, however they may perceive themselves, humans are part of, and not apart from, nature[137].

The ecosystem services do not flow to human well-being without crucial interactions with the different forms of capital (Natural, Social, Human, Built), which entails the need of understanding, modelling, measuring, and managing ES in a transdisciplinary approach. One major hypothesis in this project is the use of ES concept as a boundary object for sustainability for diverse stakeholders[138]. This entails the necessity to create knowledge for transdisciplinary approaches.

Delivrables

- D1 [M9]: A generic territorial diagnostic to possible potential plastic waste at the urban level.
- D2 [M18]: Identification of the transversal and particular barriers in the centralized systems at the urban level.
- D3 [M27]: Implementation and evaluation of the *{territory x material}* index as possible to estimate the potential stock of plastic waste to valorize.

WP 2: Maturity and technodiverstity level of the OSATs for distributed recycling.

Main objective: In parallel with WP1, the WP2 will be focused on the unit- and system-level to propose the design process for open source appropriate technologies (OSATs) to implement in urban **distributed recycling units and networks**.

The maintenance of (1) diversity and redundancy, (2) the connectivity and (3) and the management of slow variables and feedback are some principles inspired by the natural sciences for enhancing the resilience of ecosystem services[139]. Inspired by these, the purpose of this task is to analyze the techno-diversity of the complete technical chain for distributed recycling. This analysis aims to leverage the baseline for a resilient manufacturing[129,140].

Likewise, this WP entails the analysis of the actors that use open hardware to identify adoption drivers by actors industrial and SMEs actors that are not well informed on the potential of Open Source Hardware. This also includes decision-making actors at territorial spheres.

Task 2.1 Cross-case studies on technical recycling feasibility with the mix Comercial - OSATs technolgies

Make test on recyclability for different 'controled' plastic niches mono-(HDPE bottles) Eventually more complex?

Task 2.2 Establishment of an maturity in of unit- and system-levels for OSATs

The ambition of this task is to possibly identify an evaluation grid and potential index that can illustrate the robustness and adaptability of the open hardware for distributed recycling.

One assumption is that Modularity, Openness and Conviviality index of a complete OSAT technical chain.

- **Step 1:** to establish a complete database of the existent OSATs associated to each majors phases of distributed recycling (I - IV in figure Figure 1) identifying also the gaps in to be filled in hardware development. These initial mapping will be based on open source hardware from scientific literature (e.g. HardwareX journal) and from grey/maker literature repositories (e.g. Github, Forums, Precious Plastic).
- **Step 2:** a quantitative analysis based on the network science will be made to evaluate the modularity type[141] of the available OSATs found in step 1.
- **Step 3:** a qualitative analysis on the openness[142] and the conviviality matrix[143] will also be performed to the OSATs of step 1.
- **Step 4:** Consolidate to consolidate a multi-criteria database of the techn-odiversity development of distributed recycling identifying the gaps in terms of open hardware development.

Task 2.3 Mapping of new/adapted practices and tools for OSAT adoption

The main of this task is to identify the adoption hinders and the technological lock-ins of open hardware for distributed recycling. Also, in the level of practices, identify the main drivers and barriers to the adoption of open source practices.

Recently, using interpretive structural modeling (ISM) methodology, 22 technical barriers were identified in the adoption from the maker perspective[144]. The transfer of open source development practices has not taken off in Open Source Hardware to the level we know from FOSS, as exemplified by the iconic Linux project[145].

- **Step 1:** we will make a deeper analysis in how major factors like stability and modularity and active ecosystem can give answers to these technical challenges based on recent experiments of open hardware ecosystems[146,**Legenvre2020?**].
- **Step 2:** A definition of key performance indicators from a scientific literature will highlight the priority to support practitioners overcome the challenges of distributed recycling for the adoption of industrial actors (e.g. SMEs).

The ambition of this task is to reveal what makes a product appropriate for open design and for what products is open design appropriate. The challenge is even harder for the use of plastic waste assets. So to that extent, the idea is to highlight design features that facilitate success in open design endeavors and put in perspective the design principles to be identified as best practices.

Deliverables

- **D1 [M12]:** Literature review on the
- **D2 [M18]:** Web-based participatory tool database with the OSATs indicating the degree to maturity
- **D3 [M27]:** Establishment of

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WP 3: Pluralistic evaluation of distributed recycling systems

Main objective: The WP3 is the heart of the project. It aims to connect the urban and technical layers to better understand under which conditions the distributed recycling are pertinent for an urban territory. The ambition is the complete understanding of the development of a short-circuit plastic recycling chain potentialized by the open source hardware development. This technological system is anchored in the territory forming a series of open source industrial symbiosis enabling the technical feasibility and acceptance locally.

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The connection of urban and technical layers will enable to reveal the value of this socio-technical systems given the challenges posed by the offshoring of global value chains in an urban territorial context to improve the resilience of the territory and making informed decisions on sustainability.

Task 3.1 Structuring a systems dynamic causal loop model:
The aim of this task is to establish a techno-ecological synergy[127] combining the Ecosystem services and the Life cycle assessment[149–152] for the case of distributed recycling. This methodological framework aims to be the boundary object of connection between the urban and technical system. This is a major breakthrough in the conception of urban manufacturing systems.

- **Step 1:** the ES identified in task 1.3 from the perspective of the urban territory will be confronted to the ES that the industrial configuration will need and eventually provide.
- **Step 2:** To define an initial connection of the urban and technical layers using the techno-ecological framework and the LCA.
- **Step 3:** Definition of unified model that to be used in the evaluation phase considering main indicators, criteria and principles.
- **Step 4:** Establish a Multi-Criteria Decision Making (MCDM) approach for selecting the best technical configuration of the closed-loop supply chain in function of the previous steps 1-3 and the territorial analysis.

Task 3.2 Structuring a systems dynamic causal loop model:
The main aim in this task is to reveal the components and the structure of the urban circular networks to the combining Material Flow Analysis[153], System Dynamics[154–158] and Circularity Indicators[159]. One strategical point in sustainability relies on the integration of the outputs of Task 3.3 explicitly in the modeling

- **Step 1:** Definition of the major components of the systems, with initial parameters
- **Step 2:** Establishment of the qualitative causal loops
- **Step 3:** Participatory and living lab workshops to validate the structure, pertinence and scope of the qualitative and quantitative causal loops with major stakeholders (territorial and technical)
- **Step 2:** Quantification and mathematical modeling of the established causal loops.

Task 3.3 Definition of the plausible hypothesis and evolution scenarios:
In this task, based on the tasks 3.1 and 3.2, the main objective is to establish plausible scenarios of evaluation considering the scale of action considering the technical maturity, economic viability and environmental respect of the ecosystem services. This aid-decision model is a major output in the project.

Deliverables

- **D1 [M12]:**
- **D2 [M18]:**
- **D3 [M27]:**

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

Main objective: The WP4 aims to consolidate the starting point for a longitudinal study[160] to evaluate the implementation of distributed strategies at a urban territorial level. WP4 is devoted to the iteration and evaluation of the urban production networks to deeply understand the possible evolution according to the particularities of the urban context. As a starting
257 point, we will analyze the site and the territories concerned by the Green Fablab project,

namely the urban community of "Grand Nancy" (CUGN). We benefit from the support of the municipality and the recognition of the project in the local area. We will be able to perform a field diagnosis of this territory to map and characterize the existing stakeholders needs, a SWOT analysis (Strengths, Weaknesses, Opportunities, and Threats) including technical, economic and environmental evaluations of the existing value chains, to understand where the value chain could be positioned in the future. This test is the first step to possibly replicate the analysis at least in other two European territories.

Task 4.1: Participatory Workshops for a pluralistic evaluation In this task, a qualitative valuation using the pluralistic evaluation framework[Gunton2022?] through a living lab workshops will be made: This process has three stages:

- **Step 1:** from Task 1.2, we enable us to identify relevant types of functional stakeholder along with system processes of concern to them;
- **Step 2:** from Task 2.2 and Task 2.3, we will map the technical process eliciting potential judgments from each stakeholder group, to compare the centralized and distributed recycling scenarios;
- **Step 3:** the resulting information is then synthesized to draw conclusions about overall relative impact of the distributed recycling system.

Task 4.2: Experimentation and validation of the System dynamics model The purpose 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.

Task 4.3: Community engagement, documentation and dissemination to scientific and open communities This task aims to build awareness on the core open community and industrial communities of distributed recycling practices and products. The development of communications open source communication methods is key

Conceptual risk and fesability assessment

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

Table 4: Feasible challengues in the methodology

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

Resources and budget

The project will be hosted by the Équipe de Recherche de Processus Innovatifs (ERPI) of Université de Lorraine (UL), in Nancy (France). ERC funding will be necessary to consolidate my research team ERPI and, but also the European and international partners that I have been working on. Therefore, the funding will serve to enroll: three Ph.D. students (36 p.m. for each) with strong basis in urban metabolism and territorial analysis (**PhD1**) , open source hardware and systems analysis (**PhD2**) ; and environmental assessment and system dynamics modeling (**PhD3**).

Additionally, three post-doctorate researchers (24 p.m. for each PostDoc) having a solid background on environmental science and technology with particular emphasis on urban and industrial ecology (**Postdoc1**), and operational research (**Postdoc2**) and strong skills in qualitative approaches and ethnographic research (**Postdoc3**). The planning of their activities is summarized in

PhD1 will devote a part of the first two years ..

PhD2 will devote a part of the first two years ..

PhD3 will devote a part of the first two years ..

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 %). %

As for me, I will dedicate 42 p.m. of my work to manage this five-year exciting project. I will manage each phase of the project, in the full awareness of the responsibility that I will have in its successful realization, which highly depends on my capability to -humanely and scientifically- conduct, coordinate and supervise the activities carried on by the scientific team.

References

1. 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.
2. Raworth K. A Doughnut for the Anthropocene: Humanity's compass in the 21st century. *The Lancet Planetary Health* 2017; 1: e48–e49.
3. 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.
4. 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.
5. Porta R. Anthropocene, the plastic age and future perspectives. *FEBS Open Bio* 2021; 11: 948–953.
6. De-la-Torre GE, Dioses-Salinas DC, Pizarro-Ortega CI, et al. New plastic formations in the Anthropocene. *Science of The Total Environment* 2021; 754: 142216.
7. O'Neill DW, Fanning AL, Lamb WF, et al. A good life for all within planetary boundaries. *Nature Sustainability* 2018; 1: 88–95.
8. Rockström J, Steffen W, Noone K, et al. A safe operating space for humanity. *Nature* 2009; 461: 472–475.
9. Siltaloppi J, Jähi M. Toward a sustainable plastics value chain: Core conundrums and emerging solution mechanisms for a systemic transition. *Journal of Cleaner Production* 2021; 315: 128113.
10. Iles A, Martin AN. Expanding bioplastics production: Sustainable business innovation in the chemical industry. *Journal of Cleaner Production* 2013; 45: 38–49.
11. de Vargas Mores G, Finocchio CPS, Barichello R, et al. Sustainability and innovation in the Brazilian supply chain of green plastic. *Journal of Cleaner Production* 2018; 177: 12–18.
12. Paletta A, Leal Filho W, Balogun AL, et al. Barriers and challenges to plastics valorisation in the context of a circular economy: Case studies from Italy. *Journal of Cleaner Production* 2019; 241: 118149.
13. Gong Y, Putnam E, You W, et al. Investigation into circular economy of plastics: The case of the UK fast moving consumer goods industry. *Journal of Cleaner Production* 2020; 244: 118941.
14. Ma X, Park C, Moultrie J. Factors for eliminating plastic in packaging: The European FMCG experts' view. *Journal of Cleaner Production* 2020; 256: 120492.
15. Confente I, Scarpi D, Russo I. Marketing a new generation of bio-plastics products for a circular economy: The role of green self-identity, self-congruity, and perceived value. *Journal of Business Research* 2020; 112: 431–439.
16. Friedrich D. How regulatory measures towards biobased packaging influence the strategic behaviour of the retail industry: A microempirical study. *Journal of Cleaner Production* 2020; 260: 121128.
17. Filho WL, Salvia AL, Bonoli A, et al. An assessment of attitudes towards plastics and bioplastics in Europe. *Science of The Total Environment* 2021; 755: 142732.
18. Huysveld S, Hubo S, Ragaert K, et al. Advancing circular economy benefit indicators and application on open-loop recycling of mixed and contaminated plastic waste fractions. *Journal of Cleaner Production* 2019; 211: 1–13.

19. Pazienza P, De Lucia C. The EU policy for a plastic economy: Reflections on a sectoral implementation strategy. *Business Strategy and the Environment* 2020; 29: 779–788.
20. European Commission. *A european strategy for plastics in a circular economy*. Brussels: European Commission, November 2018. Epub ahead of print November 2018. DOI: 10.1021/acs.est.7b02368.
21. Kalina M, Tilley E. 'This is our next problem': Cleaning up from the COVID-19 response. *Waste Management* 2020; 108: 202–205.
22. Geyer R, Jambeck JR, Law KL. Production, use, and fate of all plastics ever made. *Science Advances* 2017; 3: e1700782.
23. Wang C, Zhao L, Lim MK, et al. Structure of the global plastic waste trade network and the impact of China's import Ban. *Resources, Conservation and Recycling* 2020; 153: 104591.
24. Plasctic Europe -. Plastics – the Facts 2020 An analysis of European Production demand and waste data. *Plastic Europe* 2020; 1–64.
25. Ragaert K, Delva L, Van Geem K. Mechanical and chemical recycling of solid plastic waste. *Waste Management* 2017; 69: 24–58.
26. Singh N, Hui D, Singh R, et al. Recycling of plastic solid waste: A state of art review and future applications. *Composites Part B: Engineering* 2017; 115: 409–422.
27. Kranzinger L, Pomberger R, Schwabl D, et al. Output-oriented analysis of the wet mechanical processing of polyolefin-rich waste for feedstock recycling. *Waste Management & Research* 2018; 36: 445–453.
28. Conlon K. Adaptive injustice: Responsibility to act in the plastics economy. *Resources, Conservation and Recycling* 2020; 153: 104563.
29. Pozoukidou G, Chatziyiannaki Z. 15-Minute City: Decomposing the New Urban Planning Eutopia. *Sustainability* 2021; 13: 928.
30. Moreno C, Allam Z, Chabaud D, et al. Introducing the '15-Minute City': Sustainability, Resilience and Place Identity in Future Post-Pandemic Cities. *Smart Cities* 2021; 4: 93–111.
31. 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.
32. 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.
33. Ellen MacArthur Foundation. Growth within: A circular economy vision for a competitive europe. *Ellen MacArthur Foundation* 2015; 100.
34. Murray A, Skene K, Haynes K. The Circular Economy: An Interdisciplinary Exploration of the Concept and Application in a Global Context. *Journal of Business Ethics* 2017; 140: 369–380.
35. Nobre GC, Tavares E. The quest for a circular economy final definition: A scientific perspective. *Journal of Cleaner Production* 2021; 314: 127973.
36. Kirchherr J, Reike D, Hekkert M. Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling* 2017; 127: 221–232.
37. Schöggl 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.

38. 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.
39. 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.
40. 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.
41. Petit-Boix A, Apul D, Wiedmann T, et al. Transdisciplinary resource monitoring is essential to prioritize circular economy strategies in cities. *Environmental Research Letters*; 17. Epub ahead of print February 2022. DOI: 10.1088/1748-9326/ac44c6.
42. Petit-Boix A, Leipold S. Circular economy in cities: Reviewing how environmental research aligns with local practices. *Journal of Cleaner Production* 2018; 195: 1270–1281.
43. Williams J. Circular Cities: Challenges to Implementing Looping Actions. *Sustainability* 2019; 11: 423.
44. 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.
45. 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.
46. 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.
47. Priavolou 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.
48. 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.
49. 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.
50. Sabel C, Zeitlin J. Historical Alternatives to Mass Production: Politics, Markets and Technology in Nineteenth-Century Industrialization. *Past & Present* 1985; 133–176.
51. 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.
52. 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.
53. Heikkinen ITS, Savin H, Partanen J, et al. Towards national policy for open source hardware research: The case of Finland. 2020; 155: 119986.
54. DiBona C, Ockman S. *Open sources: Voices from the open source revolution*. " O'Reilly Media, Inc.", 1999.

55. Raymond E. The cathedral and the bazaar. *Knowledge, Technology & Policy* 1999; 12: 23–49.
56. 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.
57. Deek FP, McHugh JA. *Open source: Technology and policy*. Cambridge University Press, 2007.
58. 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.
59. 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.
60. 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.
61. 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.
62. Hienerth C, Von Hippel E, Jensen MB. User community vs. Producer innovation development efficiency: A first empirical study. *Research policy* 2014; 43: 190–201.
63. Söderberg J. *Hacking capitalism: The free and open source software movement*. Routledge, 2015.
64. Martinez MG. Solver engagement in knowledge sharing in crowdsourcing communities: Exploring the link to creativity. *Research Policy* 2015; 44: 1419–1430.
65. Årdal C, Røttingen JA. Financing and collaboration on research and development for nodding syndrome. *Health Research Policy and Systems* 2016; 14: 1–7.
66. Thompson C. Build it. Share it. Profit. Can open source hardware work. *Work*; 10.
67. Fisher DK, Gould PJ. Open-source hardware is a low-cost alternative for scientific instrumentation and research. *Modern instrumentation* 2012; 1: 8.
68. Pearce JM. Building research equipment with free, open-source hardware. *Science* 2012; 337: 1303–1304.
69. Pearce JM. *Open-source lab: How to build your own hardware and reduce research costs*. Newnes, 2013.
70. 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.
71. Pearce J. Sponsored libre research agreements to create free and open source software and hardware. *Inventions* 2018; 3: 44.
72. 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.
73. Pearce JM. Return on investment for open source scientific hardware development. *Science and Public Policy* 2015; 43: 192–195.

74. Pearce JM. Quantifying the value of open source hardware development. *Modern Economy* 2015; 6: 1–11.

75. 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.

76. 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.

77. Powell A. Democratizing production through open source knowledge: From open software to open hardware. *Media, Culture & Society* 2012; 34: 691–708.

78. 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.

79. He Y, Xue G, Fu J. Fabrication of low cost soft tissue prostheses with the desktop 3D printer. *Scientific Reports* 2014; 4: 6973.

80. Tan HW, Choong YYC. Additive manufacturing in COVID-19: Recognising the challenges and driving for assurance. *https://doiorg/101080/1745275920211975882* 2021; 1–6.

81. 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.

82. Touriki FE, Benkhati 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.

83. 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.

84. 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.

85. Schumacher EF. *Small is beautiful: Economics as If People Mattered*. London: Blond & Briggs, 1973.

86. Illich I. TOOLS FOR CONVIVIALITY. 1973; 138.

87. Kerschner C, Wächter P, Nierling L, et al. Degrowth and Technology: Towards feasible, viable, appropriate and convivial imaginaries. *Journal of Cleaner Production* 2018; 197: 1619–1636.

88. Ralph N. A conceptual merging of circular economy, degrowth and conviviality design approaches applied to renewable energy technology. *Journal of Cleaner Production* 2021; 319: 128549.

89. Kallis G, Kostakis V, Lange S, et al. Research On Degrowth. *Annual Review of Environment and Resources* 2018; 43: 291–316.

90. Savini F. The circular economy of waste: Recovery, incineration and urban reuse. *Journal of Environmental Planning and Management* 2021; 64: 2114–2132.

91. Bakshi BR, Gutowski TG, Sekulic DP. Claiming Sustainability: Requirements and Challenges. *ACS Sustainable Chemistry & Engineering* 2018; 6: 3632–3639.

92. Bakshi BR. Toward sustainable chemical engineering: The role of process systems engineering. *Annual Review of Chemical and Biomolecular Engineering* 2019; 10: 265–288.

93. 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.

94. 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.

95. 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.

96. 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.

97. 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.

98. 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.

99. 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.

100. 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.

101. 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.

102. Hopewell J, Dvorak R, Kosior E. Plastics recycling: Challenges and opportunities. *Philosophical Transactions of the Royal Society B: Biological Sciences* 2009; 364: 2115–2126.

103. Baechler C, DeVuono M, Pearce JM. Distributed recycling of waste polymer into RepRap feedstock. *Rapid Prototyping Journal* 2013; 19: 118–125.

104. 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.

105. 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.

106. Billah KMM, Heineman J, Mhatre P, et al. Large-scale additive manufacturing of self-heating molds. *Additive Manufacturing* 2021; 47: 102282.

107. 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.

108. 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.

109. Petsiuk A, Lavu B, Dick R, et al. Waste Plastic Direct Extrusion Hangprinter. *Inventions* 2022; 7: 70.
110. 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.
111. 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.
112. 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.
113. Kreiger M, Pearce JM. Environmental Impacts of Distributed Manufacturing from 3-D Printing of Polymer Components and Products. *MRS Proceedings* 2013; 1492: 85–90.
114. Zhong S, Rakhe P, Pearce J. Energy Payback Time of a Solar Photovoltaic Powered Waste Plastic Recyclebot System. *Recycling* 2017; 2: 10.
115. Horta JF, Simões FJP, Mateus A. Large scale additive manufacturing of eco-composites. *International Journal of Material Forming* 2018; 11: 375–380.
116. 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.
117. Greer R, von Wirth T, Loorbach D. The Waste-Resource Paradox: Practical dilemmas and societal implications in the transition to a circular economy. *Journal of Cleaner Production* 2021; 303: 126831.
118. 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.
119. Compagnucci L, Spigarelli F, Coelho J, et al. Living Labs and User Engagement for Innovation and Sustainability. *Journal of Cleaner Production* 2020; 125721.
120. 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.
121. 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.
122. 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.
123. Hobson K, Holmes H, Welch D, et al. Consumption Work in the circular economy: A research agenda. *Journal of Cleaner Production* 2021; 321: 128969.
124. 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.
125. Klotz M, Haupt M, Hellweg S. Limited utilization options for secondary plastics may restrict their circularity. *Waste Management* 2022; 141: 251–270.
126. Hultman J, Corvellec H, Jerneck A, et al. A resourcification manifesto: Understanding the social process of resources becoming resources. *Research Policy* 2021; 50: 104297.
127. Bakshi BR, Ziv G, Lepech MD. Techno-Ecological Synergy: A Framework for Sustainable Engineering. *Environmental Science & Technology* 2015; 49: 1752–1760.

128. 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.

129. 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.

130. Magnusson T, Andersson H, Ottosson M. Industrial ecology and the boundaries of the manufacturing firm. *Journal of Industrial Ecology* 2019; 23: 1211–1225.

131. 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.

132. Costanza R, de Groot R, Braat L, et al. Twenty years of ecosystem services: How far have we come and how far do we still need to go? *Ecosystem Services* 2017; 28: 1–16.

133. Gómez-Baggethun E, de Groot R, Lomas PL, et al. The history of ecosystem services in economic theory and practice: From early notions to markets and payment schemes. *Ecological Economics* 2010; 69: 1209–1218.

134. Costanza R, D'Arge R, de Groot R, et al. The value of the world's ecosystem services and natural capital. *Nature* 1997; 387: 253–260.

135. Von Döhren P, Haase D. Ecosystem disservices research: A review of the state of the art with a focus on cities. *Ecological Indicators* 2015; 52: 490–497.

136. Xu Z, Peng J. Ecosystem services-based decision-making: A bridge from science to practice. *Environmental Science & Policy* 2022; 135: 6–15.

137. Ekins P, Simon S, Deutsch L, et al. A framework for the practical application of the concepts of critical natural capital and strong sustainability. *Ecological Economics* 2003; 44: 165–185.

138. Honeck E, Gallagher L, von Arx B, et al. Integrating ecosystem services into policymaking – A case study on the use of boundary organizations. *Ecosystem Services* 2021; 49: 101286.

139. Biggs R, Schlüter M, Biggs D, et al. Toward Principles for Enhancing the Resilience of Ecosystem Services. *Annual Review of Environment and Resources* 2012; 37: 421–448.

140. Zhang WJ, van Luttervelt CA. Toward a resilient manufacturing system. *CIRP Annals* 2011; 60: 469–472.

141. Gavras K, Kostakis V. Mapping the types of modularity in open-source hardware. *Design Science* 2021/ed; 7: e13.

142. Bonvoisin J, Mies R. Measuring openness in open source hardware with the open-o-meter. *Procedia CIRP* 2018; 78: 388–393.

143. Vetter A. The Matrix of Convivial Technology – Assessing technologies for degrowth. *Journal of Cleaner Production* 2018; 197: 1778–1786.

144. Peeters B, Kiratli N, Semeijn J. A barrier analysis for distributed recycling of 3D printing waste: Taking the maker movement perspective. *Journal of Cleaner Production* 2019; 241: 118313.

145. Bonvoisin J, Mies R, Boujut J-F. Seven observations and research questions about Open Design and Open Source Hardware. *Design Science* 2021/ed; 7: e22.

146. Reinauer T, Hansen UE. Determinants of adoption in open-source hardware: A review of small wind turbines. *Technovation* 2021; 102289.

147. Liu X, Bakshi BR. Ecosystem Services in Life Cycle Assessment while Encouraging Techno-Ecological Synergies. *Journal of Industrial Ecology* 2019; 23: 347–360.

148. Gopalakrishnan V, Bakshi BR. Ecosystems as unit operations for local techno-ecological synergy: Integrated process design with treatment wetlands. *AIChE Journal* 2018; 64: 2390–2407.
149. Rugani B, Maia de Souza D, Weidema BP, et al. Towards integrating the ecosystem services cascade framework within the Life Cycle Assessment (LCA) cause-effect methodology. *Science of the Total Environment* 2019; 690: 1284–1298.
150. Liu X, Ziv G, Bakshi BR. Ecosystem services in life cycle assessment - Part 1: A computational framework. *Journal of Cleaner Production* 2018; 197: 314–322.
151. Liu X, Ziv G, Bakshi BR. Ecosystem services in life cycle assessment-Part 2: Adaptations to regional and serviceshed information. Epub ahead of print 2018. DOI: 10.1016/j.jclepro.2018.05.283.
152. 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.
153. 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.
154. 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.
155. 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.
156. 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.
157. Castro C. Systems-thinking for environmental policy coherence: Stakeholder knowledge, fuzzy logic, and causal reasoning. *Environmental Science & Policy* 2022; 136: 413–427.
158. Pérez-Pérez JF, Parra JF, Serrano-García J. A system dynamics model: Transition to sustainable processes. *Technology in Society* 2021; 65: 101579.
159. Saidani M, Yannou B, Leroy Y, et al. A taxonomy of circular economy indicators. *Journal of Cleaner Production* 2019; 207: 542–559.
160. 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.