

## Section a: State of the art and objectives

### **i** DRAM in a nutshell

The main purpose of the Systemic Distributed Recycling via Open Hardware (SDROM) is to establish a blueprint methodology for the design, implementation and (e)valuation of micro-value chains of distributed recycling at a urban territorial level. We seek to the achievement of a three-level target: 1) Understand 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) .....

## Section a. State-of-the-art and objectives

### **Plastics and the Anthropocene: a change is needed**

In the current paradigm, mass manufacturing plastic products are often globalized value creation chains. The mass production system, in the lens of deep transition<sup>1</sup> framework, is the fruit of a complex co-evolution of single unit productions and interconnected systems that have intensified several forms of environmental degradation without fully assuring the social foundation's minimum standards (e.g. healthcare, energy, water etc)<sup>2</sup>. Thus, the humanity is not only as biological but as geological force, on what is recently considered as the Anthropocene era<sup>3,4</sup>. 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 indicator<sup>5,6</sup>. 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<sup>2,7,8</sup> threat associated with chemical pollutants. Then, the use and disposal of plastics is a societal problem characterized by high complexity and multifaceted feedback loops that calls for a systemic view of the entire plastics value chain from producers -petrochemical companies<sup>9,10</sup>, converters<sup>11</sup>, brand owners or manufacturers<sup>12,13</sup>, retailers and consumers<sup>14-16</sup>, and recycling operators<sup>17,18</sup>, as well as the influences of policy-makers in wider economic and societal changes<sup>11</sup>. The delay that implies to put in place an alternative productive model is the main the paradox in this issue. Therefore, how to manage the huge amount of waste already present in the nature and the plastic waste generated in the short term?, How to rethink production, consumption systems (and even urban future cities) based on an engineering that is concordance with the bio-geological cycles?, or What are alternative trajectories for a socio-technical productive systems that take into account the natural capital and externalities<sup>19</sup> since the fuzzy front-end design phase?. These major scientific questions remains open towards a sustainable transition socio-technical model.

### **Towards circular cities: a promise to fulfill**

Various schools of thought are proposing alternative socio-technical manufacturing systems (and in some cases consumption), based on circular economy<sup>20</sup>, bioeconomy, frugal innovation and degrowth. The circular economy concept in the policy<sup>21</sup>, industrial<sup>22</sup> and scientific<sup>23-25</sup> arenas as an umbrella concept, but also as a contested one<sup>26-28</sup>. While the first two are not directly critical to capitalism and economic growth, degrowth proponents argue that economic growth cannot be sufficiently decoupled from environmental impacts, which renders further growth of the economy unsustainable. Nevertheless, 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”<sup>refBarles?</sup>.

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<sup>29,30</sup> and there are many challenges to implementation (Institutional, Political, Regulatorial, Socio Economical)<sup>31</sup>. Particularly, the key challenge lies in the bridging the boundaries of urban planning and urban production systems a one coherent, continuum and multi-scale design process<sup>32–34</sup>.

### Openness for ‘Design global / Manufacturing local’

A major trend in the development of production systems seeks to establish an urban production model<sup>32,34</sup> with decentralized and distributed characteristics<sup>35,36</sup> as an alternative of globalized manufacturing values chains. Aiming at a ‘*design global / manufacturing local*’ (DGML)<sup>37</sup> seems a proto-industrialization<sup>38</sup> transition that is taking place in urban settlements that could a major impact in the next short future. 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)<sup>39</sup> and peer-to-peer (P2P)<sup>40</sup> approaches have been seen potential drivers to propose an alternative globalisation manufacturing paradigm<sup>41</sup>.

The open source (OS) approach has become well-established to provide improved product innovation over proprietary product development<sup>42–45</sup>. The evidence is most mature for software development because free and open source software (FOSS) provides: i) diversification and open innovation<sup>46–48</sup>, ii) cumulative innovation<sup>49</sup>, iii) development efficiency<sup>50</sup>, iv) organizational innovation<sup>48</sup>, v) higher technical quality of code<sup>51</sup>, vi) encourages creativity<sup>52</sup> and vii) perhaps most importantly, it avoids redundant work<sup>53</sup>. The OS approach is now also gaining traction in free and open source hardware (FOSH)<sup>54–58</sup> and appears to be roughly 15 years behind FOSS in development and adoption<sup>59</sup>. 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<sup>60–63</sup>.

The open source additive manufacturing technology, also know as 3D printing, is playing a major role in the idea of democratization of manufacturing means<sup>64,65</sup>. In particular, material extrusion based 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<sup>66</sup> and medical equipment<sup>66,67</sup>. This model has been proven to be effective for emergency manufacturing during the COVID-19 pandemic<sup>66,68</sup>. 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<sup>32,69</sup>.

### Major long vision: Convivial urban production

Today, a major societal issue rely on how to conceived socio-technical ‘circular units’ for manufacturing that integrates values of sobriety<sup>ref?</sup>, resilience<sup>70,71</sup>, adaptability<sup>72</sup> and evolutive in urban settlements. The technologies that tend to lean towards sufficiency and creativity; adopt the open-source philosophy; are designed for affordability and durability; explore tacit knowledge; empower communities through access to means of production; and promote localisation of production and

logistics; are defined as **convivial**<sup>35</sup>. Moreover, 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<sup>73,74</sup>. 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<sup>75,76</sup>. 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<sup>74</sup>. Urban cities will be responsible for non-negligible environmental impact<sup>77,78</sup>, producing about 50% of global waste, and 75% of greenhouse gas emissions which affects the sustainability of cities<sup>79</sup> and the quality of city life<sup>80</sup>.

### Distributed recycling via additive manufacturing: a promising inclusion

Since 2014, I have been working on the validation of the open-source 3D printing, filament-<sup>81</sup> and pellet-based<sup>82</sup>, as a robust manufacturing system, but also as a potential enabler of the mechanical recycling<sup>83-85</sup> of plastic waste feedstock. Likewise, I have been working on the design of the pertinent closed-loop supply chain<sup>86,87</sup>, considering the applicable sustainability indicators<sup>88</sup> based on the scientific literature. In a recent paper<sup>89</sup>, I could establish *distributed recycling for additive manufacturing (DRAM)* as a theoretical model a great to possible recycling locally. DRAM (See Figure 1) 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.

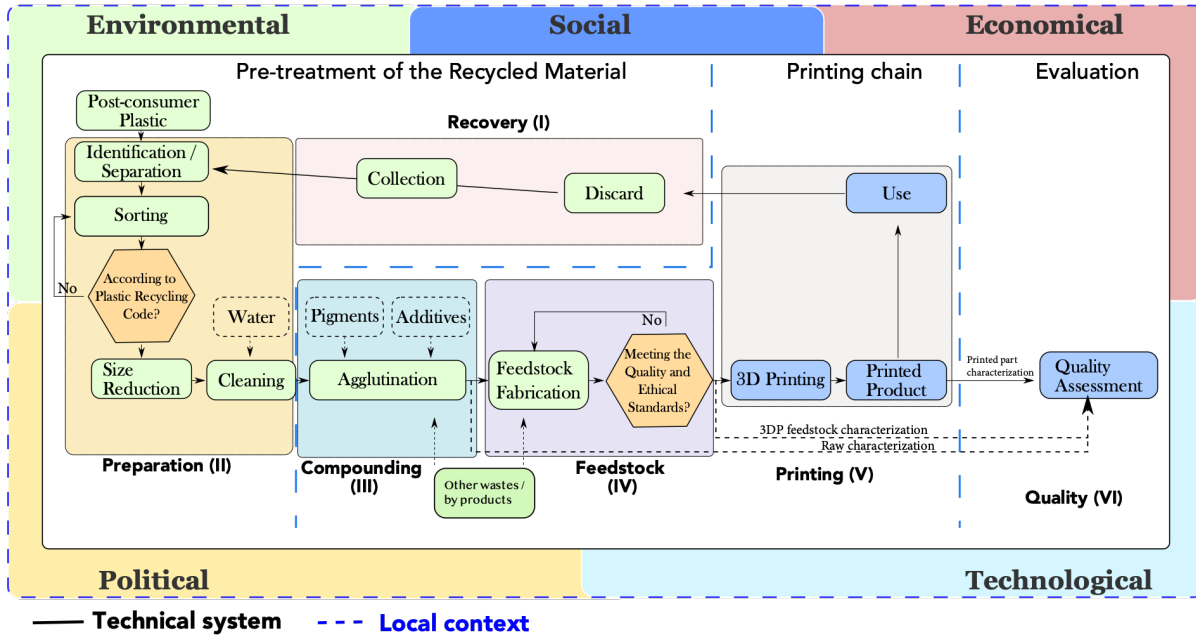


Figure 1: Distributed recycling via additive manufacturing. Source

To appreciate the ground-breaking scientific nature of this idea, let me state that historically, the 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<sup>90,91</sup>. Plastic production increased at 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<sup>92</sup>. **We need other 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 FFF can be manufactured economically using distributed means with a waste plastic extruder (often called a “recyclebot”)<sup>93</sup> 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 marketplaces (e.g. Amazon). Fused granular fabrication is a recent experimental approach enabling the printing process directly from pellets<sup>94,95</sup>, which reduces the degradation cycles of the plastic. For this process, I worked in the desktop format<sup>82</sup>, but it seems that this technology could further expand the boundaries of additive manufacturing and eventually recycling<sup>96–98</sup> for larger object<sup>99</sup>. Distributed recycling fits into the circular economy paradigm<sup>100–102</sup>, 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<sup>103–105</sup>. Additionally, open-source investment should result in an extremely high return on investment (ROI)<sup>66</sup>. This makes distributed recycling environmentally superior to other methods of plastic recycling systems.

### **The scientific problem: Connect the dots of City-Product-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 not 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 from the general public. A system validation is needed to possible understand the pertinent scale that his approach can take in urban settlements and to show the limits that can entail (Jevons Paradox<sup>106</sup>, Waste-Resource Paradox<sup>107</sup>).

### **First insights towards a systemic analysis.**

In the framework of a EUH2020 project called INEDIT<sup>1</sup>, I have been leading the implementation of the **Green Fablab** demonstrator inside the third place called Octroi-Nancy Association<sup>2</sup> since November 2021<sup>3</sup>. INEDIT project aims to create an ecosystem to transform the DIY 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 use living lab approach<sup>108,109</sup> to experiment in real conditions with citizens, final users and large general public. This experiment is enframend as a design for sustainability at a socio-technical system level<sup>110</sup>. 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 new recycled resources industry is starting to conceived inside the cities<sup>111</sup>. 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. The signal RRI has thus been highlighted on many countries’ agendas to promote the circular society<sup>112–114</sup>. In the case of plastic waste, the main difficulty remains to make affordable the use of new secondary material

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

<sup>2</sup>See <https://www.octroi-nancy.fr/>

<sup>3</sup>This demonstrator found retard because of the pandemic situation.

applicability by the industry<sup>115</sup>, 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.

## 2. Ambition & objectives

The material' rarefaction<sup>116</sup>, the need for ecological integration of manufacturing systems<sup>76,117,118</sup> and the urban resilience<sup>119</sup> 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 production systems based on the “*Design Global / Manufacturing local*” principles**. 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 of the resilience capacities and taking into account the energy sobriety of european territories. 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 resilience strategy.
- 2) Holistic and pluralistic (e)valuation of the open source appropriate technologies and design as assets for urban territorial development.

I aims further develop the distributed recycling analysing the as illustrated in figure 2 (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.

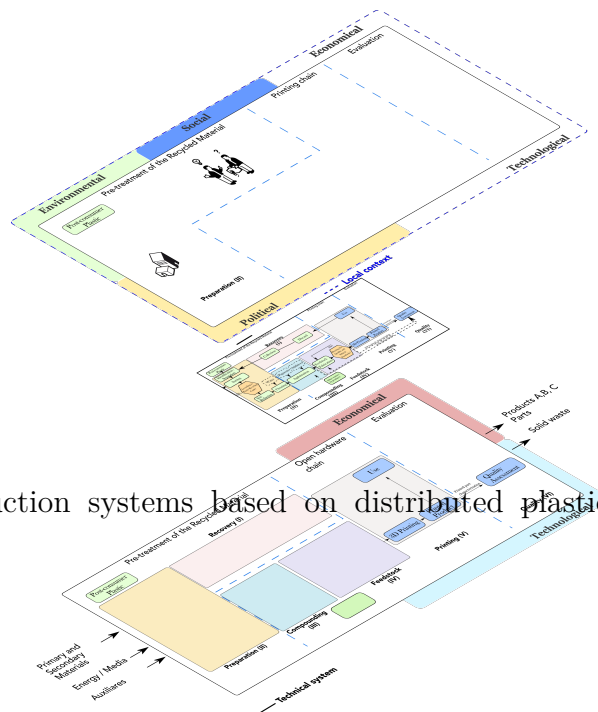


Figure 2: Methodology

---

**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?
  - How would 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 needed to develop and implement a 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 urban / manufacturing systems?
  - How to support the process from collective consensus to the deployment of these emerging systems under a purpose oriented approach?
- 

### 3. 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 the 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 decision-makers the implementation of local recycling circuits of available plastic waste by means of small, distributed recycling socio-technical units for plastic recycling.

If the pertinence expected of small size of these recycling unit are

## Section b. Methodology

### 3. Introduction the scientific methodology

This project implements a methodology made of four working packages (WP), as illustrated in Fig. 3. We recognize appropriate 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 to 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 of the project. The WP2 seeks to consolidate systematize a design process for OSAT for a complete distributed manufacturing/recycling

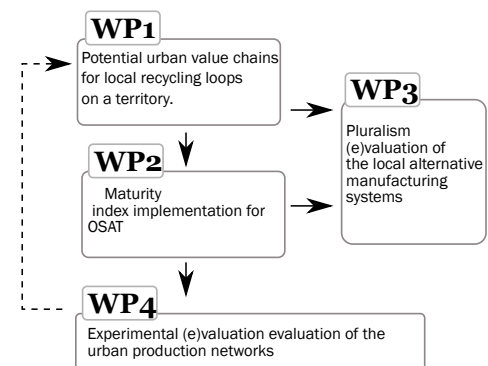


Figure 3: Methodology

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 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 case studies of the urban circular manufacturing taking as exemple 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 european territories and americas territories. Work packages are synthetically detailed hereinafter.

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

**Main objective:** This WP deals with the theoretical grid analysis to unfold the potentials micro-value chains and exchange flows induced by distributed recycling at urban territories. This framework is based on the urban spatial analysis and stakeholders characteristics as an entry point for The distributed and decentralize recycling considering the different characteristics of urban municipalities. In this work package, the major output will be an aid-decision tool to possible be the input for WP2 and WP3.

#### **Main Research method and approach:**

Based on systematic literature review and semi-structured interviews, I aim to constitute what we call an open

**Task 1.1: Closing the data gap:** 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<sup>120</sup>. This task aims to establish a methodological framework that close the existing data gaps in terms of secondary plastic material availability at the urban level considering its complexity level of revalorization. The goal is to define a  $\{territory \times material\}$  index from a quantitative approach and urban metabolism to study resource use in a urban city. This assessment aims to quantify hotspots (availability and level of contamination) based on territorial and footprint indicators and assess scenarios for the design of a recycling closed-loop supply chain. For the case of plastic material, this is particularly relevant given ambitious circularity targets that certain governments have putting in place<sup>france?</sup> due to the their impact. The priority is 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 (France, Spain and Greece) 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: Qualitative analysis of the established valorization recycling systems the urban territorial:** The main aim in this task is a methodological tool to align priorities in the development of urban production and urban development priorities, and in that way, to take informed decisions on the development of urban (circular) factories in a local territory.

**Task 1.3: Multi-criteria analysis of the urban territorial priorities in the frame of ecosystems services.** The main aim in this task is a methodological analysis to confront the urban development priorities with urban industrial priorities taking as lens of analysis the of ecosystem services (ES) framework. Human life and activities rely on ecosystem services (ES) provided by nature. The ecosystem services are the ecological characteristics, functions or processes that contribute (actively or passively) to the human well-being<sup>121,122</sup>. Ecosystem goods (e.g; Food) and services (e.g. waste assimilation) illustrate the benefits that human derive from the ecosystem



functions<sup>121</sup>. 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. Likewise, the concept of ecosystem dis-service denotes the processes and functions that affect humans in ‘negative’ way, making damage and costs<sup>ref?</sup>. With the concentration of people and activities in cities, these services are intensively utilized in urban space 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. 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<sup>123</sup>. This entails the necessity to create knowledge for transdisciplinary approaches using ES as boundary object for sustainability for diverse stakeholders<sup>124</sup>.

## Delivrables

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

**Main objective:** In parallel of WP1, the WP2 will be focused on the unit- and facility-level to propose the design process for open source appropriate technology can be implemented in urban distributed recycling networks. Inspired by the study of the resilience of natural ecosystems<sup>ref?</sup>, the purpose of this task is to analyze the technodiversity of the complete technical chain for distributed recycling. This analysis aims to leverage the baseline for a resilient manufacturing<sup>119,125</sup> under the logic of ‘Design Global/Manufacture’ Local.

**Main Research method and approach:** As Based on systematic literature review and semi-structured interviews, I aim to constitute what we call an open

To do so, three major tasks are seen:

**Task 2.1 Modularity, Openess and Conviviality index of a complet OSAT technical chain.** The purpose of this task is threefold. (1) firstly, 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 on open source hardware from scientific literature (e.g. HardwareX journal) and from grey/maker literature repositories (e.g. Github, Forums, Precious Plastic). (2) Secondly, a quantitative analysis based on the network science will be made to evaluate the modularity type<sup>126</sup> of the avaialble OSATs found in step 1. (3) and thirdly, a qualitative analysis on the openness<sup>127</sup> and the conviviality matrix<sup>128</sup> will also be performed to the OSATs of step 1. The major output of this task is to consolidate a first multi-criteria database of the technodiversity development of distributed recycling.

**Task 2.2 Mapping of new/adapted practices and tools for adoption:** The main of this task is to identify the adoption hinders and the technological lock-ins of open hardware for distributed recycling. Recently, using interpretative structural modeling (ISM) methodology, 22 technical barriers were identifying in the adoption from the maker perspective<sup>129</sup>. Nevertheless, we will make a deeper analaysis in how mayor factors like stability and modularity and active ecosystem can possible give answer to these technical challenges based on recent experiments of open hardware ecosystems<sup>130,131</sup>. A definition of key performance indicators from a scientific will highlight the priority to support *practitioners* overcome the challenges of distributed recycling for the adoption of industrial actors (e.g. SMEs).

**(2.3) Identify a Unit- and System maturity to the constitution of urban closed-loop supply chain.** Based on the Task.2.1 and Task 2.2, the aim of this task is to establish a Multi-

Criteria Decision Making (MCDM) approach can be established for selecting the best process for distributed process that can be optential pertinent for urban territory. This MCDM model will deals with user preferences of the territorial but also witht the theoretical maturity level.

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

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 valuation<sup>132</sup> and techno-ecological interactions<sup>118,133,134</sup>. More important to avoid Jevons paradox<sup>106</sup>, 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 chains<sup>135</sup>. then (4.2), the main aim is to reveal the components and the structure of the urban circular networks to the combining Material Flow Analysis<sup>136</sup>, System Dynamics<sup>137–141</sup> and Circularity Indicators<sup>142</sup>.

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

The WP4 aims to consolidate a starting point for a longitudinal study<sup>143</sup> 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.

As starting point, we will analyze the sites 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 possible replicate the analysis for other terrotories.

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 levels<sup>144</sup>.

## 3. Conceptual risk and fesability 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 4: 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					

ID	Risk items	Effect of the risk	Causes of the risk	Grade	Actions to minimize the risk
3					

Table 5: 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		

## 5. 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. In particular, Joshua Pearce that is profesor at the Western University of Canada on the OS. Sina and Anna

Vasilis Kostakis

Therefore, the funding will serve to enrol: three Ph.D. students (36 p.m. for each Ph.D.) with strong basis in urban metabolism and territorial analysis (PhD1), open source hardware and systems analysis (PhD2); and ecological economics and system dynamics modelling (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 quantum chemistry calculations (Postdoc2) and strong skills in qualitative methodological approach tests on power cycles (Postdoc3). The planning of their activities is summarized in Fig. 8 and detailed hereinafter.

**PhD1** will devote a part of the first two years of his doctoral studies on the consolidation of urban the development of the thermodynamic models and of the computational tool (WP1). At the end of S1, this tool will include, at least, the preliminary simplified models needed to start with task 2.a, which aims to define thermodynamic criteria needed to select thermodynamically suitable reactions in the next phase (2.b). During S2 and S3, PhD1 will work on this task (2.a) of WP2 and, during S3 and S4 he will finalize the thermodynamic computational tool, including real fluid equations of state. In S3, PostDoc1 will start developing the procedure of task (2.b), aimed to search and to design reactions fulfilling the thermodynamic criteria provided by Ph.D.1 at the end of S3. This activity will take 3 semesters (S3-S5). In S5, Dr. Olivier Herbinet, associate professor at UL and affirmed expert developer of kinetic models of gas-phase reactions both by quantum chemistry calculation and experimental techniques, will provide his expertise in setting up, with PostDoc2, the activity of prediction of kinetic models by quantum chemistry calculations (task (2.c)). PostDoc2 will devote 2 years (S5-S8) to the prediction of the kinetics of the thermodynamically suitable reactions. However, quantum chemistry - automatized- calculations will take time. This is why, in parallel to this activity, PostDoc2 will work on task (2.d), aiming to

thoroughly analyse the thermodynamic, kinetic, environmental and safety characteristics of the reactions that are gradually selected in task (2.c). PostDoc1 will also contribute to this task, working over the analysis of the environmental and safety characteristics of those reactions. PhD1 will spend the third (and last) year of his thesis (S5, S6) working over the same task, specifically in charge of the thorough analysis of the thermodynamic properties of screened reactions by means of the predictive thermodynamic tool that he contributed to develop in WP1. In S5, PhD2 will start his activities in REACHER, working with PhD1 in the thermodynamic analysis of fluids. In this period, he will acquire the expertise in using the thermodynamic tool developed in WP1. That tool represents a key input to the development of WP3, on which PhD2 will conduct his thesis. Indeed, along 5 semesters, he will work on the process and product design step, and on the assessment of the impact of kinetics on system's performances. At the beginning of his activity (in S5 and S6), PhD2 will also contribute to the design of the experimental cycle (task (4.a) of WP4)). In parallel, Dr. Philippe Arnoux, environmental engineer and assistant researcher at LRGP and expert in spectroscopy measurements, will assist PostDoc3 in the calibration of the spectrometer that will be acquired. P. Arnoux is an employee of CNRS ("Centre national de la recherche scientifique"); CNRS will be thus a Linked Third Party in REACHER. In S7, PostDoc3 will both work on the realization of the power cycle (WP4 (4.a)) and on the calibration of the spectrometer. He will finally conduct the experimental campaign, between S8 and S10.

### 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 equipment (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.

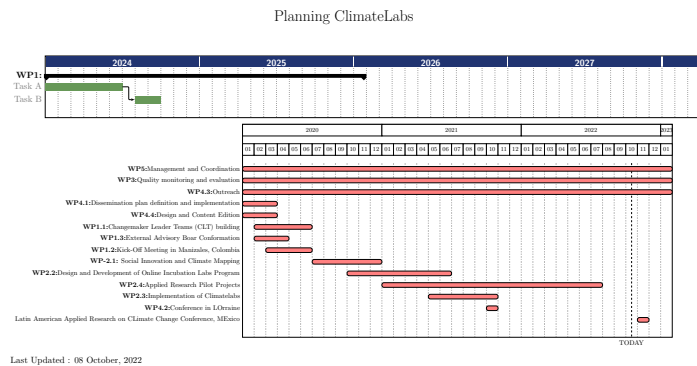


Figure 4: Gantt diagram and task allocation

## 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. Iles A, Martin AN. [Expanding bioplastics production: Sustainable business innovation in the chemical industry](#). *Journal of Cleaner Production* 2013; 45: 38–49.
10. 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.
11. 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.
12. 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.
13. Ma X, Park C, Moultrie J. [Factors for eliminating plastic in packaging: The European FMCG experts' view](#). *Journal of Cleaner Production* 2020; 256: 120492.
14. 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.
15. 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.
16. 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.
17. 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.
18. 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.

19. 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.
20. 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.
21. 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.
22. Ellen MacArthur Foundation. [Growth within: A circular economy vision for a competitive europe](#). *Ellen MacArthur Foundation* 2015; 100.
23. Nobre GC, Tavares E. [The quest for a circular economy final definition: A scientific perspective](#). *Journal of Cleaner Production* 2021; 314: 127973.
24. Kirchherr J, Reike D, Hekkert M. [Conceptualizing the circular economy: An analysis of 114 definitions](#). *Resources, Conservation and Recycling* 2017; 127: 221–232.
25. 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.
26. 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.
27. 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.
28. 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](#).
29. 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](#).
30. 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.
31. Williams J. [Circular Cities: Challenges to Implementing Looping Actions](#). *Sustainability* 2019; 11: 423.
32. 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.
33. 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.
34. 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](#).
35. 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.



36. 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.
37. 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.
38. Sabel C, Zeitlin J. Historical Alternatives to Mass Production: Politics, Markets and Technology in Nineteenth-Century Industrialization. *Past & Present* 1985; 133–176.
39. 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.
40. 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.
41. Heikkinen ITS, Savin H, Partanen J, et al. [Towards national policy for open source hardware research: The case of Finland](#). 2020; 155: 119986.
42. DiBona C, Ockman S. *Open sources: Voices from the open source revolution*. ” O’Reilly Media, Inc.”, 1999.
43. Raymond E. The cathedral and the bazaar. *Knowledge, Technology & Policy* 1999; 12: 23–49.
44. 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.
45. Deek FP, McHugh JA. *Open source: Technology and policy*. Cambridge University Press, 2007.
46. 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.
47. 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.
48. 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.
49. 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.
50. Hienert C, Von Hippel E, Jensen MB. User community vs. Producer innovation development efficiency: A first empirical study. *Research policy* 2014; 43: 190–201.
51. Söderberg J. *Hacking capitalism: The free and open source software movement*. Routledge, 2015.
52. Martinez MG. Solver engagement in knowledge sharing in crowdsourcing communities: Exploring the link to creativity. *Research Policy* 2015; 44: 1419–1430.
53. Årdal C, Røttingen JA. Financing and collaboration on research and development for nodding syndrome. *Health Research Policy and Systems* 2016; 14: 1–7.
54. Thompson C. Build it. Share it. Profit. Can open source hardware work. *Work*; 10.

55. Fisher DK, Gould PJ. Open-source hardware is a low-cost alternative for scientific instrumentation and research. *Modern instrumentation* 2012; 1: 8.
56. Pearce JM. Building research equipment with free, open-source hardware. *Science* 2012; 337: 1303–1304.
57. Pearce JM. *Open-source lab: How to build your own hardware and reduce research costs*. Newnes, 2013.
58. 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.
59. Pearce J. Sponsored libre research agreements to create free and open source software and hardware. *Inventions* 2018; 3: 44.
60. 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.
61. Pearce JM. Return on investment for open source scientific hardware development. *Science and Public Policy* 2015; 43: 192–195.
62. Pearce JM. Quantifying the value of open source hardware development. *Modern Economy* 2015; 6: 1–11.
63. 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.
64. 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.
65. Powell A. [Democratizing production through open source knowledge: From open software to open hardware](#). *Media, Culture & Society* 2012; 34: 691–708.
66. 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).
67. He Y, Xue G, Fu J. [Fabrication of low cost soft tissue prostheses with the desktop 3D printer](#). *Scientific Reports* 2014; 4: 6973.
68. Tan HW, Choong YYC. [Additive manufacturing in COVID-19: Recognising the challenges and driving for assurance](#). <https://doi.org/10.1080/1745275920211975882> 2021; 1–6.
69. 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.
70. 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.
71. 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.
72. 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.
73. Kallis G, Kostakis V, Lange S, et al. [Research On Degrowth](#). *Annual Review of Environment and Resources* 2018; 43: 291–316.
74. Savini F. [The circular economy of waste: Recovery, incineration and urban reuse](#). *Journal of Environmental Planning and Management* 2021; 64: 2114–2132.

75. Bakshi BR, Gutowski TG, Sekulic DP. [Claiming Sustainability: Requirements and Challenges](#). *ACS Sustainable Chemistry & Engineering* 2018; 6: 3632–3639.
76. Bakshi BR. [Toward sustainable chemical engineering: The role of process systems engineering](#). *Annual Review of Chemical and Biomolecular Engineering* 2019; 10: 265–288.
77. 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.
78. 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.
79. 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.
80. Riffat S, Powell R, Aydin D. [Future cities and environmental sustainability](#). *Future Cities and Environment* 2016; 2: 1.
81. 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.
82. 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.
83. 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.
84. 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.
85. 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.
86. 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.
87. 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.
88. 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.
89. 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.
90. Hopewell J, Dvorak R, Kosior E. [Plastics recycling: Challenges and opportunities](#). *Philosophical Transactions of the Royal Society B: Biological Sciences* 2009; 364: 2115–2126.

91. 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.
92. Geyer R, Jambeck JR, Law KL. [Production, use, and fate of all plastics ever made](#). *Science Advances* 2017; 3: e1700782.
93. Baechler C, DeVuono M, Pearce JM. Distributed recycling of waste polymer into RepRap feedstock. *Rapid Prototyping Journal* 2013; 19: 118–125.
94. 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.
95. 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.
96. Billah KMM, Heineman J, Mhatre P, et al. [Large-scale additive manufacturing of self-heating molds](#). *Additive Manufacturing* 2021; 47: 102282.
97. 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.
98. 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.
99. Petsiuk A, Lavu B, Dick R, et al. [Waste Plastic Direct Extrusion Hangprinter](#). *Inventions* 2022; 7: 70.
100. 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.
101. 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.
102. 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.
103. Kreiger M, Pearce JM. [Environmental Impacts of Distributed Manufacturing from 3-D Printing of Polymer Components and Products](#). *MRS Proceedings* 2013; 1492: 85–90.
104. Zhong S, Rakhe P, Pearce J. [Energy Payback Time of a Solar Photovoltaic Powered Waste Plastic Recyclebot System](#). *Recycling* 2017; 2: 10.
105. Horta JF, Simões FJP, Mateus A. [Large scale additive manufacturing of eco-composites](#). *International Journal of Material Forming* 2018; 11: 375–380.
106. 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](#).
107. 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.
108. 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.

109. Compagnucci L, Spigarelli F, Coelho J, et al. [Living Labs and User Engagement for Innovation and Sustainability](#). *Journal of Cleaner Production* 2020; 125:721.
110. 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.
111. 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.
112. 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.
113. Hobson K, Holmes H, Welch D, et al. [Consumption Work in the circular economy: A research agenda](#). *Journal of Cleaner Production* 2021; 321: 128969.
114. 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.
115. Klotz M, Haupt M, Hellweg S. [Limited utilization options for secondary plastics may restrict their circularity](#). *Waste Management* 2022; 141: 251–270.
116. Hultman J, Corvellec H, Jerneck A, et al. [A resourcification manifesto: Understanding the social process of resources becoming resources](#). *Research Policy* 2021; 50: 104297.
117. Bakshi BR, Ziv G, Lepech MD. [Techno-Ecological Synergy: A Framework for Sustainable Engineering](#). *Environmental Science & Technology* 2015; 49: 1752–1760.
118. 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.
119. 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.
120. 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.
121. 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.
122. 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.
123. 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.
124. 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.
125. Zhang WJ, van Luttervelt CA. [Toward a resilient manufacturing system](#). *CIRP Annals* 2011; 60: 469–472.
126. Gavras K, Kostakis V. [Mapping the types of modularity in open-source hardware](#). *Design Science* 2021/ed; 7: e13.
127. Bonvoisin J, Mies R. [Measuring openness in open source hardware with the open-o-meter](#). *Procedia CIRP* 2018; 78: 388–393.
128. Vetter A. [The Matrix of Convivial Technology – Assessing technologies for degrowth](#). *Journal of Cleaner Production* 2018; 197: 1778–1786.



129. 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.
130. Reinauer T, Hansen UE. [Determinants of adoption in open-source hardware: A review of small wind turbines](#). *Technovation* 2021; 102289.
131. Legenvre H, Kauttu P, Bos M, et al. [Is open hardware worthwhile? Learning from thales' experience with RISC-V](#). 2020; 63: 44–53.
132. Gunton RM, Hejnowicz AP, Basden A, et al. [Valuing beyond economics: A pluralistic evaluation framework for participatory policymaking](#). *Ecological Economics* 2022; 196: 107420.
133. 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](#).
134. Liu X, Bakshi BR. [Ecosystem Services in Life Cycle Assessment while Encouraging Techno-Ecological Synergies](#). *Journal of Industrial Ecology* 2019; 23: 347–360.
135. 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.
136. 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.
137. 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.
138. 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.
139. Tomoiaia-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.
140. Castro C. [Systems-thinking for environmental policy coherence: Stakeholder knowledge, fuzzy logic, and causal reasoning](#). *Environmental Science & Policy* 2022; 136: 413–427.
141. Pérez-Pérez JF, Parra JF, Serrano-García J. [A system dynamics model: Transition to sustainable processes](#). *Technology in Society* 2021; 65: 101579.
142. Saidani M, Yannou B, Leroy Y, et al. [A taxonomy of circular economy indicators](#). *Journal of Cleaner Production* 2019; 207: 542–559.
143. 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.
144. Rocha CS, Antunes P, Partidário P. [Design for sustainability models: A multiperspective review](#). *Journal of Cleaner Production* 2019; 234: 1428–1445.