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A Master's Course Can Emphasize Circular Economy in Municipal Solid Waste Management: Evidence from the University of Pisa

Claudia Pisuttu, Francesca Adducci, Sofia Arena, Daniela Bigongiali, Liliangela Callea, Paolo Carmignani, Alessio Cavicchi, Mariagrazia Chianura, Luisa Ciulli, Marianna Contaldo, Lorenzo Cotrozzi *, Claudia D'Alessandro, Annapia Ferrara, Ivan Fiaccadori, Besmira Gajda, Chiara Guarnieri, Marco Landi, Luca Lanini, Rocco Roberto Lomuto, Daniela Lucente, Cristina Lugli, Francesca Maffei, Francesca Marconi, Silvia Micale, Chiara Mignani, Cristina Nali, Elisa Pellegrini, Vito Scarongella, Sabrina Tomasi, Carolina Vatteroni and Giacomo Lorenzini

Master Course on Sustainable Development and Climate Change, c/o Department of Agriculture, Food and Environment, Via del Borghetto 80, 56124 Pisa, Italy; claudia.pisuttu@agr.unipi.it (C.P.); alessio.cavicchi@unipi.it (A.C.); annapia.ferrara@agr.unipi.it (A.F.); ivan.fiaccadori@phd.unipi.it (I.F.); marco.landi@unipi.it (M.L.); luca.lanini@unipi.it (L.L.); cristina.nali@unipi.it (C.N.); elisa.pellegrini@unipi.it (E.P.); mastersscc@agr.unipi.it (G.L.)

* Correspondence: lorenzo.cotrozzi@unipi.it; Tel.: +39-050-2210563

Abstract: Municipal solid waste (MSW) represents a significant global threat, which has to be managed by a model of production and consumption involving the sharing, leasing, reusing, repairing, refurbishing, and recycling of existing materials and products for as long as possible, otherwise known as a circular economy (CE). However, there is not a universal rule for waste recycling strategies, and it has been demonstrated that active public participation is crucial in the satisfactory management of waste. In this context, citizen participation and education are two interrelated approaches, which can help to engage and inform people regarding waste and its wider impact. The present study describes the development of an interdisciplinary hackathon (hackathons are events whereby individuals from different backgrounds are brought together to work on the solutions to different problems), targeted to students of a postgraduate Master's course on Sustainable Development and Climate Change in order to develop and understand the MSW problems and priorities currently being targeted, with the aim to propose new potential solutions for MSW reduction, reuse, and recycling. Following an empirical approach, four working groups were established and assigned the following specific tasks: (i) communication/citizen education on MSW; (ii) the reduction of MSW production; (iii) innovative solutions to recover and enhance secondary raw materials deriving from MSW processing; and (iv) the eco-design of the cities of the future concerning CE principles applied to MSW recycling. Overall, the following main findings were derived from the hackathon event: (i) an essential objective of the CE strategy is to drive Europe's internal market towards the production and consumption of more sustainable products, thus reducing environmental and social pressures, while still retaining value; (ii) the most effective ways of tackling environmental problems are to 'change the way we consume', as well as to 'change the way we produce and trade', with the responsibility shared between businesses, governments, and the EU, as well as the citizens themselves. In this scenario, research and innovation play a key role in driving the necessary systemic changes to reach climate neutrality and ensure an inclusive ecological and economic transition. Overall, the present study confirms how the hackathon represents an effective tool to engage citizens in participation and education.

Keywords: environmental education; hackathon; master's course on Sustainable Development and Climate Change; plastic packaging; the University of Pisa

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1. Introduction

Municipal solid waste (MSW)—more commonly known as trash or garbage—consists of the everyday items we use and then dispose of, such as bottles, food scraps, newspapers, packaging, clothing, grass clippings, batteries, and so on. This waste poses a significant threat to both the global economy and ecosystems [1]. Annually, an estimated 7 to 10 billion tonnes of waste are generated worldwide, with MSW accounting for a substantial 3.2 billion tonnes [2]. Of this generated MSW, approximately 47% is directed to landfills, 31% undergoes recycling, and the remaining 22% is incinerated [3,4]. This signifies that nearly 70% of MSW is not recycled or repurposed, representing a significant loss of valuable supplies, placing a substantial strain on primary resources [5]. Furthermore, it has been established that the excessive extraction of available resources and the prevalent disposal of MSW in landfills and incineration plants exert detrimental effects on both the environment and socio-economic structures [6]. For example, methane gas emissions from landfills contribute to 4% of global greenhouse gas emissions, while the uncontrolled disposal of waste in oceans poses a grave threat to marine life [7]. The generation of MSW is primarily contingent on the following two pivotal factors: population growth and urbanization, both of which are on a rapid ascent. Predictions by Dutta et al. [8] suggest that the global population will reach 9 billion by 2050, raising serious concerns about the colossal volume of future MSW and the intensification of resource extraction, which pose further severe threats to our planet's habitat [9]. In response to these pressing challenges, world leaders are currently prioritizing the expansion of renewable energy production and the adoption of the circular economy (CE) concept [10].

According to the European Union (EU), the CE concept is envisioned to «enhance global competitiveness, foster sustainable economic growth, and generate new employment opportunities» [11]. Circular economy employs the resource recovery and reuse (RRR) system to establish a sustainable resource loop, thereby boosting economic efficiency [12]. Concurrently, it also diminishes environmental pollution and reduces production costs, while increasing waste recycling [13]. As the transition to a CE has tremendous potential to transform economic systems and substantially contribute to sustainable development, waste recycling has several positive effects [14], including the following: (i) it reduces demand for virgin raw materials; (ii) there are fewer environmental impacts from material extraction, processing, and transportation; (iii) products made from recyclates ("secondary raw materials") rather than virgin materials generally consume less energy in manufacturing; and (iv) less waste material going to landfill means a reduction in environmental and economic costs, as well as in the health and environmental risks associated with landfilling. However, there is not a universal rule for waste recycling strategies, and a simple search reveals a plethora of approaches and recycling schemes, even within the same city or region, making proper waste management and related CE actions particularly complex and challenging.

It has been demonstrated that, above all else, active public participation is strongly helpful (together with laws or enforcements) to produce the desired results of the satisfactory management of waste [15]. Accordingly, citizen participation and education are two interrelated approaches which are needed to engage and inform people regarding waste and its impacts on health and well-being. Citizen participation means involving people in the decision making, planning, implementation, and evaluation of waste management activities. Citizen education means raising awareness, providing information, and developing skills and attitudes related to waste management. Both approaches can foster a sense of ownership, responsibility, and empowerment among community members in the field of MSW management, as these can (i) increase the knowledge and awareness of the causes and consequences of waste problems, and the potential solutions and benefits of waste reduction, reusing, and recycling; (ii) enhance the motivation and commitment of people to adopt sustainable waste practices and behaviours, such as segregating waste, composting organic waste, and avoiding littering; (iii) improve the collaboration and coordination among different stakeholders, such as local authorities, waste collectors, NGOs, and businesses, to address waste challenges and opportunities; and (iv) foster social cohesion, trust, and equity among community members, as well as reduce conflicts and disputes regarding waste issues. In this context, educational institutions represent the main components of sustainability promotion in our society [16–19]. An educational institution matching this scope is represented by the one-year postgraduate master's course on Sustainable Development and Climate Change (MSDCC), launched in 2022 by the University of Pisa, and aimed to address the increasing global need for scientific, policy, and communication professionals to take action in response to the threats posed by climate change, and to help ongoing transition to a more sustainable society.

According to the above, the present study describes the development and evaluation of an interdisciplinary hackathon (hackathons are events whereby individuals from different backgrounds are brought together and work on solutions to different problems [20], see below), which aims to develop MSDCC students' understanding of current MSW problems and priorities, and propose new potential solutions and benefits for MSW reduction, reuse, and recycling. To better circumscribe the theme, attention in this didactical experience was concentrated on plastic packaging, which was addressed by four working groups (more details are reported below). The relevance of this theme is clear. In 2020, generated packaging waste was estimated at 177.2 kg per inhabitant in the EU (https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Packaging_waste_statistics; accessed on 20 November 2023), the Italian individual contribution being 215.6 kg, 68% of which being recycled. The goal of the described project was to be inclusive and agile in promoting collaboration amongst people with different skills to generate new ideas.

2. Hackathon Methodology as Innovation Context for Sustainability

Higher education institutions (HEIs) play an increasingly important role in co-creating innovative pathways for sustainable territorial development [21], both for urban [22] and rural contexts [23]. This function has always been associated with the university's so-called "third mission", allowing for societal engagement and the transfer of technologies developed through research [22]. However, recently, the effort has been expanded to show how teaching also fits into this discourse [24]. The Education for Sustainable Development, as defined by the UNESCO [25], encourages a teaching path that allows for the greatest achievement of the Sustainable Development Goals (SDGs). This encourages learners to become "actors of change" by using critical thinking skills to act responsibly for both the present and the future [25].

The difficulties of this have always been related to the identification of suitable pedagogical approaches which allow the process of "learning for sustainability". Indeed, SDGs are all interconnected and, by their nature, require a multi-disciplinary approach, which, according to Kioupi and Voulvoulis [26], make it difficult to relate them to the specific educational learning outcomes. Therefore, to deal with the complexity of sustainability and to learn the transversal skills needed, many authors advocate for the use of concrete case studies which apply unconventional active-learning pedagogies [27,28], such as the hackathon, allowing first-hand experiences in the field of sustainability by responding to specific territorial challenges [29].

Hackathons are time-bound, themed events, engaging several participants with different backgrounds to work collaboratively in finding a solution to a given problem [30,31]. The term, which derives from the combination of 'hack' and 'marathon', initially referred to the programming activities conducted among the tech communities; however, over the last 50 years, they have been rapidly adopted by other fields also [32,33]. Although each hackathon is designed according to the specific objectives of the event, there are some common features which contribute to its definition [30,31]; these can include (i) the presence of the "hackathon organizer(s)" who give rise to the initiative; (ii) the presence of several participants, diverse in their background, expertise, and goals, who join the initiative for both personal and learning interests towards the treated theme(s); (iii) the subdivision of participants into different teams competing during the event; (iv) the presence of mentors, who will support the different teams throughout the initiative, according to their technical knowledge, competences, and previous experiences; and (v) the presence of stakeholders of different natures, who are mainly identified as experts of specific topics, or sponsors for the initiative itself. Their presence throughout the event might vary according to their role and type of commitment.

In terms of time, hackathons take place for a short period, ranging between 1–2 days and two weeks, marked by specific initiatives at the launching (e.g., keynote speech) and at the conclusion, where participants are asked to pitch their solutions to a jury, formed by a panel of experts of different titles and roles who then announce the winner(s) [30,31].

In terms of results, hackathons can have multiple outcomes, which can include the following [30]: (i) tangible outcomes are often the most recognized; these are generally identified as a technical artefact such as a prototype, visual product, or publication; (ii) intangible outcomes are the most difficult to quantify, since they mostly rely on the overall learning journey, such as deepening the knowledge about a current societal issue or about the use of a specific technology, acquiring both technical and transversal skills, networking with peers and other relevant stakeholders, or, more generally, fostering entrepreneurship. This classifies hackathons as a mean to generate innovation that has a positive impact on the strength and resilience of communities [34], while providing a meaningful educational experience for participants [35]. Indeed, a hackathon is an innovative and educational tool [31]. Innovation is generated from the dual working perspective of participants who combine individual work which enhances their skills and expertise with teamwork, in which skills are merged and knowledge is shared, thus making the transdisciplinary aspect the key element for the identification of an innovative solution [31]. According to Wood [35], these innovation-led features make hackathons an important educational tool. Indeed, due to the short time available, participants' work may not revolutionize the current state of our societies, but the environment generated allows participants to personally develop by testing themselves with real challenges, while also enjoying working as a team, meeting new people, and being more open to diverse fields and points of view than those usually managed [34,35].

According to Medina Angarita and Nolte [30], the hackathon approach has relevant limitations and potential pitfalls. These can include (i) a limited understanding of how participant goals impact ideation, team formation, and hacking behaviour in hackathons; (ii) uncertainty about the relationship between participant goals and the sustainability of hackathon outcomes; (iii) the hackathon organizers' goals' influence on the hackathon design and how this can potentially affect the outcomes, despite there being limited evidence on this connection; (iv) insufficient studying on the goals, background, and experience of mentors in hackathons and their impact on the outcomes; (v) the repetition of hackathons provides opportunities for organizers to learn and improve the design, but this has an unclear impact on sustainability; (vi) hackathons as part of a series of events pose unknown effects on the sustainability of hackathon outcomes; (vii) the ownership of ideas resulting from hackathons by participants, organizers, or stakeholders and its influence on sustainability is poorly understood; (viii) the lack of details on the ideation process during hackathons, despite its indirect impact on outcome satisfaction; (ix) the limited study on the impact of different hackathon durations on project quality and outcomes; and (x) the insufficient exploration of tools and methods to support the intrateam communication, interdisciplinary collaboration, and sustainability of non-technical artifacts in hackathons.

3. Case Study

3.1. Master's Course on Sustainable Development and Climate Change at the University of Pisa

Due to the emergence of COVID-related sanitation rules, the one-year postgraduate MSDCC at the University of Pisa was fully delivered online (Figure 1). More than 120 teachers were involved, with most of them coming from the academic world (mostly from twelve departments at the University of Pisa); however, attention was given to ensure a strong corporate partnership through the involvement of a number of relevant companies from the private sector and public local, national, and international institutions and organizations. The MSDCC was intended as a foundational program to promote or advance the career of professionals involved in public policy, education, environmental justice, journalism, finance, insurance, international development, research science, or any other climate/sustainability-related disciplines. The program was organized under the auspices of the Italian Ministry of Ecological transition, and was of several national professional orders. Taking an interdisciplinary approach, the MSDCC focused on all the themes of the UN Agenda 2030, its 17 SDGs, and 169 related targets (https://sdgs.un.org/goals, accessed on 22 November 2023). The course equipped 43 postgraduates of heterogeneous backgrounds (no registration restrictions were set in terms of the disciplines previous studied) with the skills to analyse and model past climate variability, current trends, and causes of change, but also to deal with impacts, mitigation, adaption measures, and environmental responsibility, integrating the scientific and socio-economic aspects within a unique context. At the same time, the MSDCC focused on the ecological, social, cultural, and economic requirements in terms of the interdisciplinary knowledge, skills, values, and attitudes that empower students to face the challenges of sustainable development in a global arena, from promoting biodiversity conservation to reducing inequality. The course objectives were addressed through a warm up "foundations module", four core modules on climate change, environmental/economic/social aspects of sustainability, and a final chapter devoted to the creation of a sustainability report; also included was a curricular internship and a final independent and original dissertation (https://www.agr.unipi.it/master-in-sviluppo-sostenibile-e-cambiamento-climatico/; accessed on 12 December 2023).

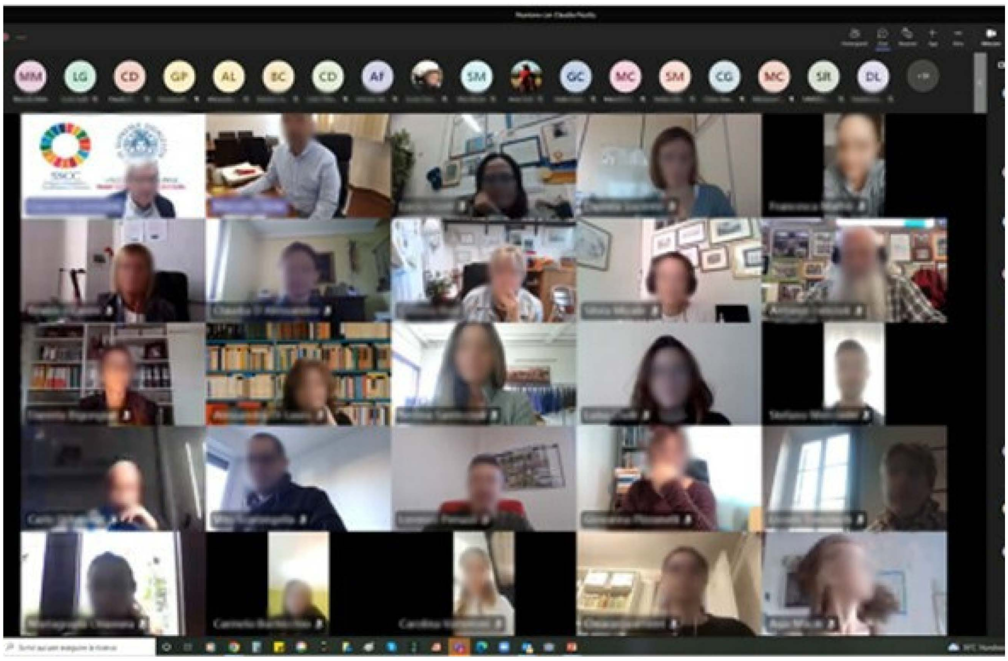


Figure 1. A screenshot of a remote class of the master's course on Sustainable Development and Climate Change at the University of Pisa. The entire lesson program was conducted online via the MS Teams platform. The interactivity between the instructor and the class population was absolute.

3.2. Hackathon Genesis and Realisation

Even if the MSDCC course was planned as a fully online project, 17 students (i.e., 40% of the classroom population) expressed a desire to voluntarily organize a face-to-face event in order to meet with other colleagues and teachers. The steering committee approved the proposal and floated the idea of a non-competitive hackathon trial, focused on the CE principles applied to MSW management, with specific attention paid to plastic packaging.

In July 2022, in collaboration with all participants, four working groups, assigned to specific tasks and led by as many teachers, were established as follows: (i) communication/citizen education on MSW; (ii) the reduction of MSW production; (iii) innovative solutions to recover and enhance secondary raw materials deriving from MSW processing; and (iv) the eco-design of the cities of the future, focusing on the CE principles applied to MSW recycling. In more detail, the task (i) was planned from the starting point that an informed and engaged consumer/citizen plays an important role in accelerating the transition to CE, but meaning, directive, and information on waste management may be confusing. Task (ii) was devoted to preventing waste from being generated, according to the 3Rs policy (reduce, reuse, recycle) and the pivotal role of prevention in the waste hierarchy. Starting from the concept that developing environmentally and socially sustainable products is one of the main goals of 21st century design culture, and that eco-design and CE are two key elements of a sustainable economic model, Task (iii) dealt with secondary raw materials, which face a number of challenges in competing with primary raw materials, for reasons not only related to their safety, but also to their performance, availability, and cost. To give value to waste and acquire a full understanding of the dynamics underpinning the profitable recovery of waste was the core business of this task, which was supported by the staff of Revet (https://www.revet.com/; accessed on 10 December 2023), a local plastic waste recycling facility. The final task was very ambitious. Task iv was to design the city of the future to meet the needs of CE as it applies to MSW management. The hackathon event took place on 23 September 2022, after around three months of self-organization by the working groups, where they developed their preliminary ideas and activities, with occasional support from teachers. At the end of the event, each working group presented its outcomes to a heterogeneous audience, including not only professionals, scientists, journalists, and stakeholders, but also ordinary citizens.

Outcomes produced by each working group are reported below. Only minor edits to both texts and figures were intentionally performed by teachers in order to ensure the work all adhered to a consistent structure, while trying not to alter the content of work carried out by each working group. This structure was as follows: (i) background on the topic; (ii) the composition of the working group; (iii) goals and adopted methodology; and (iv) obtained outcomes.

4. Hackathon Outcomes

4.1. Working Group 1: Communication/Citizen Education on Municipal Solid Waste

Every material in existence serves a purpose in some form, and nothing is created out of nothing. Human ignorance categorizes certain things as waste, while deeming others as useful. As the types of waste evolve, so should people's attitudes towards waste. Some hazardous substances cannot be directly reused, impacting human health. Regarding habits, behaviour, and participation, "what people think about waste" [36] is a crucial aspect of MSW management [37]. Studies indicate that 89% of participants view recycling as an acceptable method of waste disposal, and 57% support charging for waste collection per bin or bag in order to incentivize recycling. Only 34% of the population recycle some waste weekly, and 9% recycle four times a year or less. The study emphasizes how the information about MSW received at school significantly influences households, particularly those with children aged 5–14, suggesting that school campaigns focused on recycling can enhance awareness and attitudes toward MSW. Additionally, 80% believe people have a duty to recycle, and 60% suggest avoiding goods with excessive packaging [38]. Reports on MSW underscore the need to establish recycling habits for the sustainability of solid waste [39].

Working Group 1's focus on "Communication/citizen education on MSW" was chosen by five students, namely (1) a female Doctor of Agricultural Science, around 30 years old, now employed in a water management public company; (2) a female Doctor of Human Nutrition Sciences, around 30 years old, now carrying out a PhD course in the Dematerialization of Food Safety; (3) a female Doctor in Climatology and Environmental

Sciences, around 30 years old, currently unemployed; (4) a male Doctor in Economics and Management, around 50 years old, now a bank manager; and (5) a female Doctor in Biological Sciences and Dietetics, around 50 years old, now working as a dietician in a local hospital.

The "Communication/citizen education on MSW" group identified its goal as investigating citizens' perceptions and habits regarding MSW separation, and to compare the results with the strategies and initiatives of waste management companies. The collected results and evidence were then used to outline a possible communication strategy that addresses the identified gaps. To reach its goal, Working Group 1 developed two questionnaires as preliminary investigations for the hackathon event. The first, in the form of a Google Form, was an anonymous survey aimed at citizens (colleagues, family members, and friends of master's students). The second questionnaire was addressed to waste management companies. The survey aimed to gather information about the communication and education strategies and the initiatives for citizens regarding waste separation, particularly plastic waste, and to create a synthesis of the experiences of waste management companies to promote a communication strategy for the disposal of 'plastic' waste based on the needs of the population. The methodological approach used included (i) a survey of the phenomenon through various research, (ii) an analysis of the collected phenomena and data synthesis, and (iii) highlighting the best experiences to draw inspiration to improve the communicative aspect.

The waste management companies involved in the survey included three from Tuscany (Central Italy) and one from Lombardy (Northern Italy). Those from Central Italy were joint-stock companies with around 350–750 employees, 105,000–380,000 citizens as a user base, and a waste-sorting rate of 66–80%. The company from Northern Italy was a non-profit cooperative with around 240 employees, more than 700,000 citizens as user base, and a waste-sorting rate of 85%. The form provided to the waste management companies included the following questions: (i) How is your company structured? [Size, territorial scope (province, city, region)]; (ii) What are the state-of-the-art models regarding waste separation in the area you serve? (Percentage of waste separation); (iii) What is your communication and education strategy for citizens regarding plastic waste separation? (e.g., collaboration with local authorities); (iv) What initiatives have you implemented for communicating and educating citizens? (regarding plastic waste separation); (v) How is waste management conducted? (e.g., door-to-door collection); (vi) How is the disposal of plastic waste managed? (recycling/reuse, who handles the disposal); (vii) Do you believe the communication on this topic has been effective?; (viii) What means have been used? (e.g., brochures, website, app, events); and (ix) What are your upcoming communication strategies and initiatives to increase the public awareness about the 'plastic' issue?

The online survey (provided by social networks) aimed to citizens included the following questions: (i) How does your hometown manage waste collection? (Door-to-door collection/Street recycling bins/'Smart' street bins for residents only/Mix of door-to-door and traditional bins/Mix of door-to-door and 'smart' bins/All three/Other); (ii) Do you practice waste separation at home? (Yes/No); (iii) If YES, Why do you think it is important to separate waste? (For a lower environmental impact/For social reasons/For economic reasons); (iv) Which type of waste do you think you produce the most? (Plastic/Organic/Paper+cardboard/Glass/Non-recyclable); (v) Provide examples of items you would place in the plastic waste bin; and (vi) If the answer to question (ii) is 'No', Why do you believe you do not separate waste? Within 6 days, 1596 responses to the online survey were collected, all coming from citizens living in Central and Northern Italy. Some outcomes of this survey are shown in Figure 2.

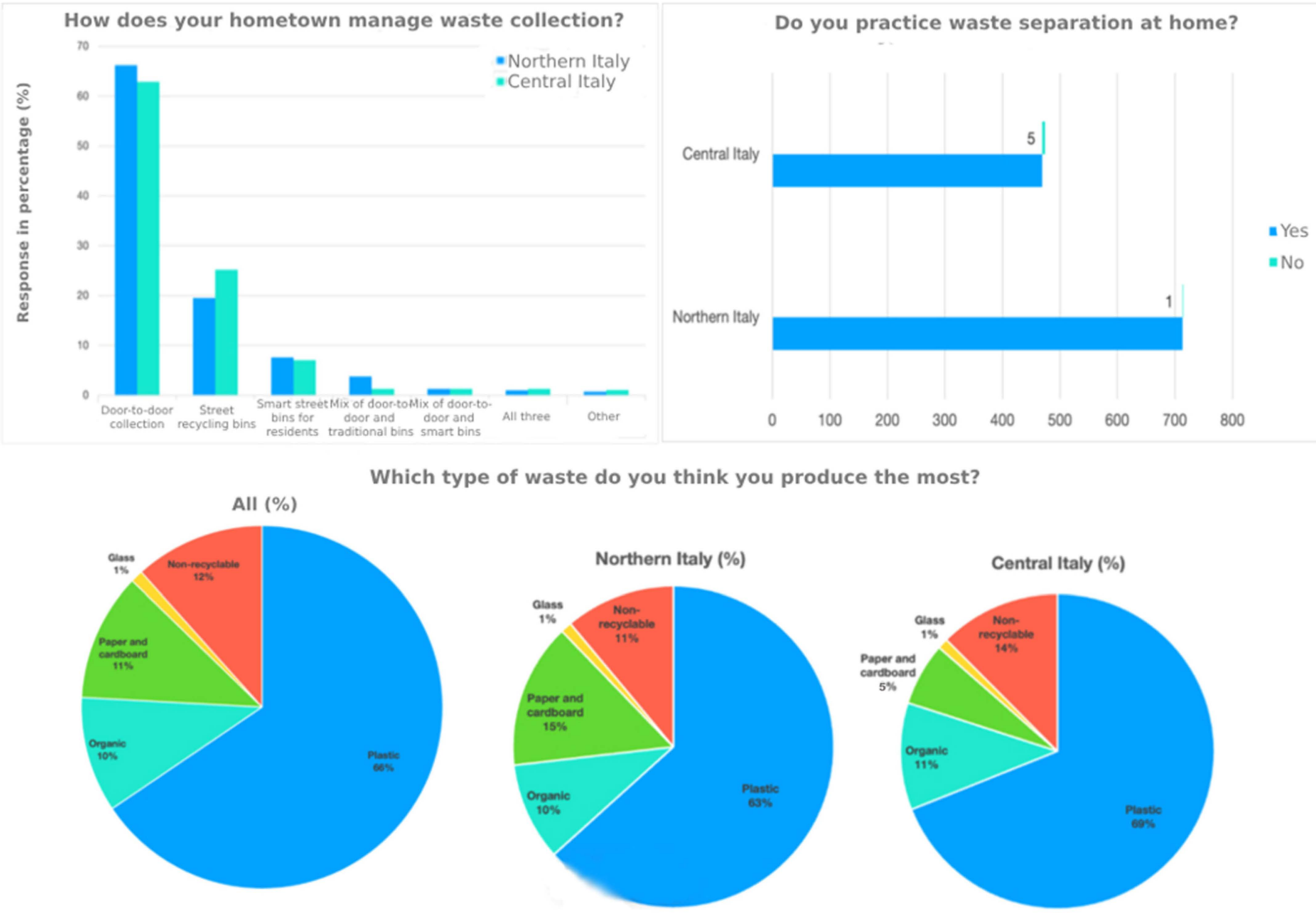


Figure 2. Outcomes of the survey developed by Working Group 1, aimed to citizens from Northern and Central Italy.

Overall, the survey provided to citizens (responses from the waste management companies cannot be made public here) highlighted that (i) door-to-door collection is mostly performed, (ii) almost all citizens practice waste separation at home, and (iii) plastic is the waste that is mostly produced. Furthermore, no differences were reported between Northern and Central Italy. However, it is important to mention that the responses to the online survey questions could be influenced by the fact that the survey was firstly proposed to the master's students who are particularly aware of the plastic waste separation issue. Actually, the response to the last online survey question "Provide examples of items you would place in the plastic waste bin" finally highlighted a general confusion of citizens for some plastic packaging. Indeed, although several "correct answers" were reported (i.e., *plastic beverage bottles*, *plastic packaging*, *plastic grocery bags*, *plastic wrappers*, *plastic bottle caps*, *plastic jars*, *drink cans*, and *aluminium packaging*), some 'confused' (i.e., *polystyrene food containers*, *plastic cups*, *lids*, *utensils*, *tetra pak*, and *toothpaste tube*) and 'incorrect' answers (i.e., *plastic pieces of objects that can be disassembled such as pen and correction fluid*, *toothbrush*, and *toys for kids*) also occurred. Working Group 1 also reported some "infrequent answers", i.e., *all packaging*, *food containers or bottles with PET or PVC plastic recycling symbols*, and *plastic fruit nets*.

4.2. Working Group 2: The Reduction of Municipal Solid Waste Production

The waste hierarchy principle, existing for approximately 40 years, originated with a focus on prioritizing waste reduction, recycling, and reuse over treatment or disposal, as noted by van Ewijk and Stegemann [40]. Introduced by the private company 3M [41] in the United States, and proposed by Dutch politician Ad Lansink in 1979 [42], it was formally incorporated into the Waste Framework Directive 2008/98/EC (WFD) [43] in 2008, and subsequently integrated into the national laws of European Union (EU) Member States. The WFD outlines the waste hierarchy as the preferred sequence in waste management as follows: prevention, preparation for reuse, recycling, other recovery (including energy recovery), and disposal. The CE Strategy from the EU COM/2015/0614 [44] advocated for waste management based on the waste hierarchy as the optimal approach for environmental outcomes and material reintegration. Hultman and Corvellec [45] highlighted the potential of recycling sites to transform materials, effectively 'unblackboxing' material management. By 2016, the waste hierarchy was included in the 12th SDG of the 2030 Agenda for Sustainable Development [46], titled "Responsible consumption and production", aiming to substantially reduce waste through prevention, reduction, recycling, and reuse by 2030. Waste prevention stands as the central tenet of the waste hierarchy [47].

Working Group 2's aim of the "Reduction of municipal solid waste production" was picked by five students, namely (1) a female Doctor in Law, around 30 years old, now employed in a regional agency for environmental protection; (2) a female Doctor in Biology, around 40 years old, currently working as Aquaculture Researcher at the Food and Agriculture Organization of the United Nations; (3) a female Doctor in Agricultural Sciences, around 25 years old, now working in the Administrative Office of an Italian University; (4) a female Doctor in Environmental Engineering, around 30 years old, employed in the Sustainability Group of an Italian luxury fashion house; and (5) a female Doctor in Chemistry, around 50 years, now working in an environmental consultancy firm.

After a legislative overview, Working Group 2's activities focused on three case studies, respectively, from the plastic, beverage, and fashion/textile sectors (Figure 3), with the aim of contributing to the CE by extracting high-quality resources from waste as extensively as possible, and to demonstrate that sustainable waste management is an important step to promote growth by transitioning to a modern, resource-efficient, and competitive economy, in the realm of the European Green Deal. After a comparison of the different work experiences, the group decided to present the best practices adopted by companies specialized in sectors with high environmental impact, but with the common objective of waste reduction. The first part of the work focused on the analysis of the current legislation, in particular on the European Directives related to the Green Transition, in order to identify the following key areas for green transitions: the Eco-friendly design, the single-use plastic and the CE, and circularity in the textile sector.

Figure 3. The three case studies addressed by Working Group 3, reducing the use of foamed polystyrene in the fishery and aquaculture sectors; solutions adopted by the beverage industry to reduce packaging and the dispersion of waste (e.g., by tethered caps); some realities of the textile sector contribute to the reuse of wasted materials and the application of the highest technologies for recycling.

The first case study identified existing solutions for reducing the use of foamed polystyrene (EPS) in the fishery and aquaculture sectors, given this material represents one of the most recorded components of marine litter. Foamed polystyrene is inexpensive to produce, waterproof, lightweight, and has good insulating properties. These characteristics make it particularly suitable for aquatic activities and the production of fish boxes, buoys, floats, and pontoons, with fish boxes having the most significant impact at the environmental level [48]. A promising solution to the use of polystyrene boxes has been recently identified and developed, and consists in the use of polypropylene (PP05) boxes. Compared to EPS boxes, which are single-use, PP05-based boxes can be re-used many times; additionally, these boxes can be equipped with a scannable microchip for the traceability along the entire value chain, from the fish harvesting to the selling point.

The second case study described the solutions adopted by many companies in the beverage industry, which have promoted the transition to a CE with innovative and sustainable business models, products, and materials by reducing packaging and the dispersion of waste into the environment. The first example is the introduction of the "tethered cap", meaning caps which remain firmly attached to the bottle once they are opened and also during use, complying with a European directive (Single Use Plastic, SUP) on the reduction of the impact of certain plastic products on the environment, which requires that beverage containers with lids attached to the relevant containers must be marketed by 2024. Another important action aimed to help reduce CO_2 emissions in the atmosphere is to reduce the amount of PET and rPET used in the bottle-manufacturing process.

The third case study presented the current issues of the textile sector, underlining the operational difficulty in components' materials separation and, therefore, the important role of the design. Some realities of the sector were presented, which contribute to the reuse of wasted materials and the application of the highest-existing technologies for recycling. One example is the process that allows for the recovery of precious metals through separation, precipitation, and, therefore, the reuse of these metals in the galvanic industry. Finally, some examples of regenerated yarns were presented as follows: the creation of these articles is possible thanks to the recovery of waste, such as fishing nets and carpets, to create yarns, which can be used for the production of clothes; these can be fully recyclable if designed appropriately.

4.3. Working Group 3: Innovative Solutions to Recover and Enhance the Secondary Raw Materials of Municipal Solid Waste Production

There is a growing consensus that an environmentally sustainable approach to waste management necessitates the advancement of landfill diversion strategies and the development of markets for secondary raw materials (SRM) [49]. The European Environment Agency (EEA) underscores this consensus by promoting a CE in Europe, which includes endorsing waste-as-a-resource business models [50]. The significance of SRM markets lies in their role within a circular economy, enabling recyclables to re-enter the production value chain and reducing the reliance on primary resources. The EU's CE action plan in 2020 recognises this pivotal role [51]. Specifically, the recycling of polyethylene terephthalate (PET) bottles not only holds the potential to conserve fossil fuels, but can also result in reduced energy usage and greenhouse gas emissions. Studies indicate that using one pound of reclaimed PET flake reduces energy consumption by 84% and decreases greenhouse gas emissions by 71% [52,53].

Working Group 3's "Innovative solutions to recover and enhance secondary raw materials from MSW production" was targeted by four students, namely (1) a female Doctor of Engineering, around 30 years old, freelancer in the sustainability sector; (2) a male Doctor of Economics and Management, around 30 years old, currently involved in a company aimed to define taxonomy and sustainability in the financial system; (3) a female Doctor of Architecture, around 30 years old, freelancer in architectural renovation; and (4) a male Doctor of Engineering, around 40 years old, now employed by a public water management company.

Working Group 3 developed the project titled "Creation and Implementation of a 3D Lab Printing Point for the Use of Recycled Plastic Filaments". The aim of this project was to propose the implementation of a 3D lab printing point to the partner company (i.e., Revet), where new objects will be designed and produced using 3D printers that use filaments obtained from granules of recycled PET, which the partner company produces as part of its core business. The project encompassed several aspects of sustainability. Firstly, environmental sustainability, as it reintroduced secondary raw materials (plastic) into the production system in the form of granules, reducing the production of environmentally harmful waste and the impact of their disposal, through a technology that operates in additive manufacturing, thus producing zero processing waste and low energy consumption. Secondly, economic sustainability, as the use of 3D printing technology leveraged the concepts of "Just in Time Production", optimizing both the resources used in the production process (e.g., filaments obtained from granules, energy) and production times, as well as the impact of storage and transportation. Lastly, but of equal importance, is social sustainability, as the project also aimed to raise awareness and place citizens, schools, industry, and its production processes at the centre, ensuring that they feel actively involved in and promote the circular economy. Active involvement will initially be achieved through the recycling of secondary raw materials and the best practices, and, secondly, through the understanding and knowledge of the transformation process and the creation of new objects through 3D printing.

Presentation contents during the hackathon include (i) Project Title and Objective (e.g., definition of the Innovative Solution, target audience, empirical data); (ii) Definition of Secondary Raw Materials (examples, advantages/disadvantages) and Circular Economy; (iii) Revet (role of the Project partner); (iv) Just in Time Production and SWOT analysis; (v) Case Studies and Benchmarking; (vi) 3D Printers (e.g., positive impacts of usage, opportunities, and risks) and types of plastic filaments; (vii) The Implementation of the 3D Lab Printing Point (Figure 4); (viii) video of the 3D Printing of the Master's Logo (Figure 5).

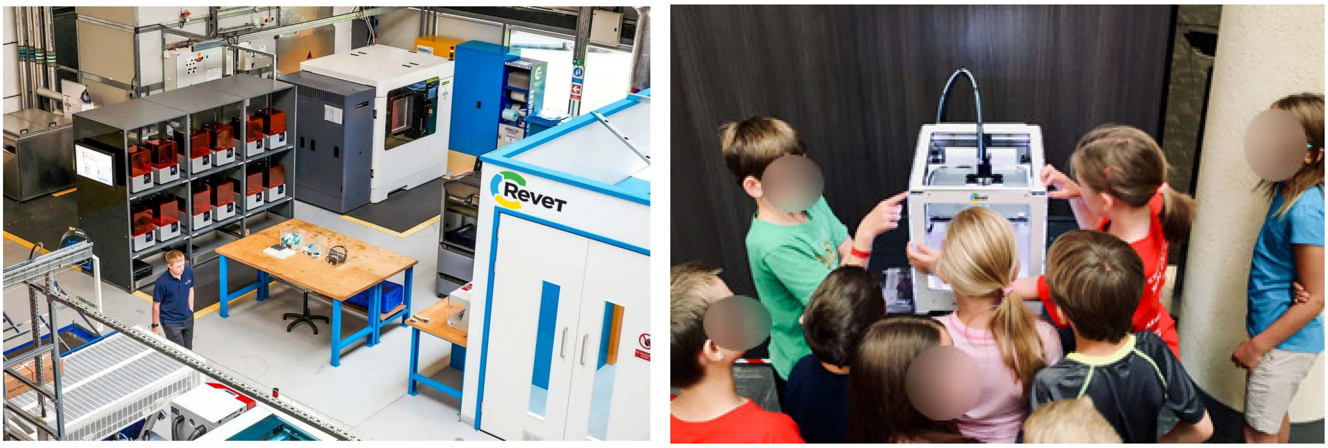


Figure 4. Renderings showing the idea developed by Working Group 3 for the implementation of the 3D Lab Printing Point.

4.4. *Working Group 4: The Eco-Design of the Cities of the Future with a View to the Circular Economy Principles Applied to Municipal Solid Waste Recycling*

Urban centres worldwide are experiencing rapid growth, with over half of the global population residing in cities since 2007. It is projected that 70 out of every 100 people will inhabit urban areas in the near future [54]. While metropolitan expansion holds potential for a new era of development, the challenge lies in achieving sustainable growth that aligns with the UN SDGs. This includes promoting inclusive economic growth, ensuring employment, and decent work opportunities, preserving environmental quality, and maintaining social balance. Future cities aim to prioritize environmental care and resident well-being through initiatives such as sustainable mobility, green space creation, the reduction of greenhouse gases, the adoption of renewable energy, and commitment to the CE. Smart cities are dedicated to employing efficient technologies that transform them into eco-cities, demonstrating respect for both the environment and residents. In 2022, Arcadis, a prominent eco-design and consulting firm, conducted a study to identify the world's most sustainable cities. The assessment considered various metrics, converging into the following three fundamental pillars which aligned with the UN SDGs: social, environmental, and economic. The study recognized one hundred cities, each paving the way for green urban development. Barnett and Beasley [55] emphasized that a sustainable built and natural environment can be achieved through eco-design. Eco-design integrates planning and urban design with environmental conservation, aligning with normal business practices, capital programs, and existing regulations. This approach facilitates adapting the built environment to a changing climate and a rapidly growing world, creating more desirable places in the process. Eco-design thinking is relevant to anyone influencing the future of cities, including designers, public officials, and politicians.

Figure 5. Digital project, realization, and the final product of the logo of the postgraduate master's course on Sustainable Development and Climate Change at the University of Pisa, produced by Working Group 3 with recycled plastic filaments.

Working Group 4's "Eco-design of the cities of the future with a view to the circular economy principles applied to MSW recycling" was targeted by three students, namely (1) a female Doctor in Law, around 45 years old, currently a freelance lawyer, (2) a female Doctor in Architecture, around 45 years old, now freelance architect, and (3) a female Doctor in Engineering, around 45 years old, now a municipal employee.

In Europe, 2.2 billion tonnes of waste are produced each year, of which, 27% consists of municipal solid waste (source: Infographic on waste management statistics in Europe, updated as of 28 June 2023). When looking at previous years, the data show a continuous increase. According to Eurostat, for example, in 2020, European citizens generated 225.7 million tonnes of MSW, with a constant, albeit modest, increase compared to 2019. The management of these waste materials is left to municipalities, which must meet the targets set by the EU for individual states. On one hand, if there is an increase in the recycling rate, it must be considered that the quantities of waste generated continue to rise. A significant issue is the cost of these services, which falls entirely on the citizens.

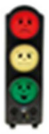
The so-called "door-to-door" separate collection system is certainly an effective way to achieve significant collection rates for homogeneous fractions and subsequent recycling, but it is also the most expensive method. Thus, combining optimal collection and recycling rates, while optimizing costs appeared particularly difficult. From an empirical analysis conducted in three Italian regions (Apulia, Campania, and Tuscany), the tender processes for the management of waste collection are standardized, and the relative services are determined according to the discretion of the winning company, who often has little interest in reducing the comprehensive costs. The main issue is that these tender processes specify only a single collection method for an entire municipal territory. Even in rural areas or the countryside, despite being surrounded by greenery and therefore having the potential to manage organic waste differently, the collection system only differs in terms of the collection frequency compared to urban or peri-urban areas. In residential areas, which may have more space, but may also have numerous apartment buildings, the waste collection system is basically the same as in the historical city centres. This non-selective organization negatively impacts costs.

The solution proposed by Working Group 4 consisted of creating a modular tender specification, based on a differentiated collection system, according to the type of zone (not neighbourhood by neighbourhood), which takes advantage of the urban and anthropic characteristics of the various areas within a city, such as the historic centre (small houses, narrow streets), the commercial area (presence of typical waste-producing commercial activities, wider streets), residential areas, suburban areas, etc. Considering that a city is composed of zones with unique characteristics, Working Group 4 developed a model for a modular tender specification (named "Differentiate the differentiated"), designed for any municipality. This model takes into account the heterogeneity of the zones and waste contributions of a "typical city" used as a reference model, identifying different collection methods for each zone type, with the aim of providing a replicable model for all cities (Figure 6).

The "Differentiate the differentiated" model combines both traditional and more innovative or smart systems, which, if more widely adopted and appropriately distributed, can optimize and streamline the system of separate waste collection. In the overall management of municipal solid waste, a list of "best practices" should be incorporated and adapted to contribute to the "prevention", i.e., reducing the generation of waste at the source, such as shopping centres or small neighbourhood businesses dedicated to repairing, restoring, and reselling used items (e.g., reuse centres with sale per kilogram of recovered materials), or sharing them in the so-called "library of things". The apparent simplicity of this solution could support the limited resources of municipalities in the organization of tender processes, while also serving as an effective tool to achieve the recycling rates required by the EU through optimizing costs.

4.5. Theoretical and Practical Implications

According to Reis et al. [56], the present work showed that the ongoing discourse surrounding CE and MSW is expanding, and indications strongly suggest an inherent connection between them. At the theoretical level, developing effective strategies necessitates collaboration, not only among public authorities, but also with relevant businesses, and society at large. Initiatives, such as targeted waste collection, reverse logistics, environmental education, and the application of CE principles, are proving effective in addressing waste generation and its associated challenges. However, to achieve viable solutions, increased integration among the various social actors involved in the process is imperative. At the practical level, the findings underscore the importance of exploring innovative alternatives that can seamlessly integrate the principles of the CE and MSW management. Decision makers and policymakers are encouraged to channel their efforts into creating novel models for circular waste management through collaborative efforts among social actors. This approach can enhance the visibility of the CE as a compelling and feasible pathway forward.



No waste collection system is the absolute best for all areas of the city, so HOW TO CHOOSE?

old town	• traffic criticity • urban decorum criticity • emissions criticity • hygienic criticity	• traffic criticity • urban decorum criticity • emissions criticity	• traffic criticity • urban decorum criticity • emissions criticity	• traffic criticality • emission criticality	• traffic criticality • urban decorum criticality • emissions criticality	• waste collection efficiency • accumulation waste reduction • traffic reduction
residential area	• traffic criticity • emissions criticity • hygienic criticity	• traffic criticity • urban decorum criticity • emissions criticity	• traffic reduction • emissions reduction • suitable for temporary events	• urban decorum • emissions reduction • traffic reduction	• urban decorum • zero emissions • zero traffic	• waste collection efficiency • accumulation waste reduction • traffic reduction
suburbs and expansion area	• hygienic criticity • emissions criticity • distance criticity	• emissions criticity • distance criticity • costs criticity	• traffic reduction • emissions reductions • suitable for temporary events	• urban decorum • emissions reduction • traffic reduction	• urban decorum • zero emissions • zero traffic	• waste collection efficiency • accumulation waste reduction • traffic reduction
rural area	• hygienic criticity • emissions criticity • distance criticity	• emissions criticity • distance criticity • costs criticity	• traffic reduction • emissions reductions • suitable for temporary events	• urban decorum • emissions reduction • traffic reduction	• urban decorum • zero emissions • zero traffic	• waste collection efficiency • accumulation waste reduction • traffic reduction
	roadside waste collection bin	household waste collection bin	eco station	retractable bin	pneumatic system	Smart system (IoT)

Figure 6. The waste collection model "Differentiate the differentiated", developed by Working Group 4 for a "typical city".

4.6. Future Research

The findings of this study underscore the hackathon's effectiveness as a tool for immersive sustainability experiences, particularly in addressing territorial challenges related to MSW. As we move forward, there are several promising avenues for future research that can build upon these insights, and contribute to the broader discourse on sustainability, CE, and waste management, such as (i) exploring the factors that influence citizen engagement, and understanding how educational initiatives can be optimized to enhance awareness and behavioural changes; (ii) assessing the tangible outcomes and effectiveness of implementing CE practices in mitigating environmental challenges on a larger scale; (iii) exploring the economic and environmental implications of steering manufacturing and product utilization toward sustainability, with a focus on evaluating the success of these endeavours in reducing societal and environmental pressures; (iv) understanding the roles and responsibilities of various stakeholders, including businesses, governments, and individual citizens; (v) investigating innovative technologies, policies, and practices that facilitate systemic change in order to guide the transition towards a sustainable future; and (vi) evaluating the scalability of such events, their impact on community engagement, and their effectiveness in fostering sustainability awareness and action.

5. Conclusions

The present study confirms how the hackathon represents an effective tool to experience sustainability first-hand by responding to specific territorial challenges, also in the context of MSW, where citizen participation and education are two interrelated approaches needed to engage and inform people about waste and its impacts. Overall, the following messages emerged from the hackathon event and can potentially influence and be integrated into the average household. Developing a CE strategy will contribute positively to the fight against the planetary crisis related to climate change, biodiversity loss, and pollution. A crucial goal of the CE is to steer Europe's internal market toward the manufacturing and utilization of products that are more sustainable, thereby lessening environmental and social pressures, while still preserving value. Effective ways of tackling environmental problems are to "change the way we consume", as well as to "change the way we produce and trade", with responsibility shared by businesses, governments, and the EU, as well as citizens themselves. In this scenario, research and innovation play a key role to drive the necessary systemic changes to reach climate neutrality and ensure an inclusive ecological and economic transition. Further experiences, like the hackathon presented here, are encouraged to engage citizen participation and education.

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