A framework for sustainability assessment and prioritisation of urban waste prevention measures

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Chiara Magrini*[1], Anna Degli Esposti[1], Elena De Marco[1], Alessandra Bonoli[1]

[1] Department of Civil, Chemical, Environmental and Materials Engineering-DICAM/University of Bologna, Chiara Magrini, University of Bologna, via Terracini 28, 40131 Bologna, BO, Italy, chiara.magrini7@unibo.it

Abstract

Waste prevention (WP) can play a significant role in pursuing both sustainable development and decarbonization. Nevertheless, a general method to monitor and evaluate WP does not exist yet. This study proposes a framework for the sustainability assessment and prioritisation of waste prevention measures (WPMs), at consumption level. Firstly, some WPMs are selected, based on relevant criteria. Secondly, their impacts are assessed, in terms of environmental, economic, and social sustainability, in a life-cycle perspective. Then, a set of significant effectiveness and efficiency indicators are chosen and calculated. Finally, an algorithm for the prioritisation is proposed. This methodological approach might be useful to guide the financing choices of the public decision-makers, to assess and promote WPMs, and to develop WP strategies. Moreover, the results can be used in waste management planning and to motivate local actors through benchmarking.

The designed framework has been applied to 17 projects implemented by Municipalities in the Emilia-Romagna Region (Italy), as case study. The projects, whose aim is the reduction of waste from plastic disposable goods, can be grouped in three different categories: i) drinking water dispensers in towns/cities, ii) drinking water dispensers in schools and iii) replacement of disposable goods in school canteens. The project category of drinking water dispensers in towns proved to be the most sustainable one, achieving a score of 0,4265, while the other categories scored around 0,28.

The study confirms that WP should be promoted, despite being very difficult to monitor. The political institutions should invest in implementing a specific monitoring system, also able to reveal potential integration of WP strategies with other policy areas. Finally, an improved institutional framework might help the Municipalities in overcoming barriers to the identification and implementation of WPMs, by allowing for coordination and networking of individual projects and by encouraging the spread of good practices.

Keywords: Waste prevention; Waste reduction; Sustainability; Environmental assessment; Economic assessment; Social assessment.

1. Introduction

Waste prevention (WP) is an important element within the paradigm of sustainable development: in the frame of United Nations Agenda 2030, sustainable development goal (SDG) 12 (Ensure sustainable consumption and production patterns) includes targets focused on environmentally sound management of all waste through prevention, reduction, recycling, and reuse (targets 12.4 and 12.5) and reduction of food waste (target 12.3) (United Nations, 2015). At global level, WP is particularly important in urban areas, where the population is increasing, and waste generation is higher. Accordingly, the SDG 11 (Make cities and human settlements inclusive, safe, resilient, and sustainable) aims to "reduce the adverse per capita environmental impact of cities, including special attention to air quality and municipal and other waste management", and the New Urban Agenda (United Nations, 2017) commits to "environmentally sound management and minimization of all waste" too.

WP could play a significant role in emission reduction and more specifically in climate change mitigation, if implemented globally (Gentil et al., 2011): the potential greenhouse gases (GHG) savings from WP and minimisation could greatly exceed the savings that can be achieved by advanced technologies managing post-consumer waste (ISWA, 2010). In Europe, waste management (WM) sector represents the fourth largest source of GHG

emissions, accounting for 3% of total greenhouse gas emissions in 2017 (Eurostat, 2020): the implementation of best practices might boost the achievement of the 2050 European climate-neutrality target, or the intermediate goal envisaging at least -55% net GHG emissions by 2030, as stated by the European Green Deal (European Commission, 2020).

The European waste hierarchy places the greatest preference on WP, which is the most favourable WM option, above reuse, recycling, and recovery (Directive 2008/98/EC, Article 4, as amended by Directive (EU) 2018/851). Nevertheless, over the time frame between 2013 and 2018, an increase in per capita generation of municipal solid waste (MSW) occurred in the European Union.

Although the political commitment to this topic, according to literature very little is understood about how to monitor and evaluate WP particularly among local authority waste managers who are most likely to implement intervention campaigns (Sharp et al., 2010; Corsini et al., 2018; Gusmerotti et al., 2019). So far, there is no general method to monitor and evaluate the effects of waste prevention measures (WPMs) (Zorpas and Lasaridi, 2013; Zacho and Mosgaard, 2016; Yano and Sakai, 2016; Matsuda et al., 2018; Hutner et al., 2018) and only a few studies have focused on waste prevention systems (Laurent et al., 2014; Hutner et al., 2018). The success of a WP action cannot be assessed with an analysis of the evolution of waste, since waste generation depends on many factors whose effect is difficult to assess. Therefore, a completely different approach has to be led, focusing on the actual action (Bel, 2010; Hutner et al., 2018).

As Abeliotis et al. (2013) state, WP includes a variety of different actions, such as: i) reducing or even eliminating the consumption and therefore the production of certain goods; ii) substitution of products by others; iii) extending the utilization phase for items. A more detailed classification of WPMs was proposed by Nessi et al. (2013) (see Section 2 of SM): the focus is on the environmental consequences of the implementation of waste prevention

activities (i.e., the environmental impacts related to substitutive goods/packaging or to the usage phase).

Considering the increasing demand for broader sustainability assessments, where the environment, society and the economy are integrated (Hellweg and Canals, 2014), it might be stated that the impacts of WPMs have to be assessed by including also economic and social domains, given that a partial approach often delivers misleading messages for policy- and decision makers. Moreover, this conforms with Article 4 of the Waste Framework Directive (Directive 2008/98/EC) which establishes "economic viability" and "economic and social impacts" as decisive criteria for the implementation of the waste hierarchy.

Results of a literature review show that only one study has assessed waste prevention activities according to the so-called three pillars of sustainability: Bergström et al. (2020) applied Environmental Life-Cycle Assessment, Life-Cycle Costing and Social Life-Cycle Assessment to some food waste prevention activities (see Section 1 of SM for details on the literature review performed by the authors). To the best of the authors' knowledge, no studies exist about the sustainability assessment of prevention activities aiming at the reduction of other waste streams. Moreover, the study by Bergström et al. (2020) do not provide the readers with indicators assessing the success of WPMs analysed.

Thus, the aim of this paper is to propose a framework for the sustainability assessment, the evaluation of success, and the prioritisation of WPMs at consumption level. Firstly, relevant project categories are selected, by verifying the fulfilment of specific conditions. Adopting a life-cycle perspective, the environmental, economic, and social consequences of WPMs within the selected categories are assessed. Then, a set of indicators for the evaluation of effectiveness and efficiency of the projects is defined, as well as an algorithm to support the identification of a priority order for the project categories. The specific objectives are: i) to support the decision-makers in the prioritisation of publicly funded projects, which aim at

WP by acting at consumption level; ii) to assess the already implemented projects, in a preliminary manner, by providing insights on their success. The analysis and discussion of results gives a valuable contribution to the formulation and promotion of WP strategies, at different geographical levels.

The model is described through its application to the significant case of the Emilia-Romagna Region, in Italy. The Region has a population of 4.471.485 inhabitants (2019); with a production of urban waste equal to 3.011.354 ton in 2018. Some ongoing prevention projects implemented by Municipalities in the Region are analysed, as replicable case study.

2. Materials and method

Strategic Waste Prevention is defined as "*a long-term policy concept that concretely situates waste prevention within a longer-term resource management and sustainable development perspective. Strategic Waste Prevention works toward the reduction of absolute waste amounts, hazards and risks, and it is characterised by at least four aspects (...): a life-cycle perspective, a material-differentiated approach, integration of social and economic aspects into environmental policy discussions, and facilitating cooperation across traditional institutional structures for overall policy synergy*" (OECD, 2000). This definition is the base for the design of the framework described in this study.

WP needs actions both at production and consumption level. According to Boulanger and Mainguy (2010) "path towards dematerialized and detoxified goods and services can be summarized by 4Rs; significant benefits in Reducing, Reusing, Recycling and Repairing will not result from changes at the production level only, but from inescapable changes in consumption practices and institutions": this study focuses on this second kind of changes, enabled by the implementation of specific projects at municipal level.

Figure 1 depicts a graphical representation of the stages of the designed framework. The framework is described in detail in the next paragraphs, after an introductive description of

the Emilia-Romagna case study.

2.1 The case study of the Emilia-Romagna Region

In Italy, urban WM involves a system articulated between State, regional, provincial, and municipal competences. While the State is in charge of defining the general criteria for WM (Legislative Decree 152/2006 art.195), the Regions are responsible for planning activities (Legislative Decree 152/2006 art.196).

The Emilia-Romagna Region is committed to WP: after the approval of the Italian national waste prevention program in 2013, the Emilia-Romagna Region Council approved in 2016 the "Emilia-Romagna Region waste management plan" which defines the regional waste prevention program (chapter 17, part IV), over a time frame of 7 years (2013-2020). The plan includes some prevention measures; each measure is divided in related actions, which have impact on different product life stages (see Section 2 of SM for details). The target is to reach 20-25% reduction of per capita urban waste production by 2020, compared to 2014.

Since the implementation of a municipal WP program can be a complex process, requiring important investments and the involvement of many actors, potentially belonging to the whole supply chain of goods and services (Nessi et al., 2015), the Region established a fund to promote prevention and reduction of waste among the Municipalities (Emilia-Romagna Region, 2015). This conforms to European Directive 851/2018, which suggests the application of economic incentives for regional and local authorities, in particular, to promote WP and intensify separate collection schemes (see annex IVa, titled "Examples of economic instruments and other measures to provide incentives for the application of the waste hierarchy"). The regional fund aims at: i) reducing the cost of WM for the citizens of the Municipalities which achieved the best results in reducing production of non-recyclable waste; ii) reducing the costs of changing the collection system, to implement a pay-as-you-throw scheme; iii) financing the creation of municipal reuse centres and municipal projects

promoting reduction in waste generation. This study focuses on the third point, analysing the projects promoting waste reduction. The regional fund is managed by ATERSIR, the Emilia-Romagna territorial agency for water and waste services, which defines the criteria to allocate economic resources. Starting from 2016, every year a call for grants for the implementation of municipal waste reduction projects has been published. Section 2.1 of SM provide further information, showing a classification of the 89 waste reduction projects funded from 2016 to 2018 in Emilia-Romagna.

Since the total cost of WM system in the Emilia-Romagna Region for the 3 years (2016-18) was around 2.248 million €, the investments in waste reduction projects represent around 0,05% of this value. As for now, 81 Municipalities out of 331 Municipalities have received funds for at least one project.

2.2 First stage: Selection of the project categories and verification of representativeness of the selected projects

The first stage of the designed framework aims at the selection of project categories to be considered and of representative projects within each of them. Selection criteria ensure the reliability of the analysis and the comparability among the selected project categories. This framework was designed to analyse and compare only projects which prevent the same waste materials. Besides that, other selection criteria are the availability of reliable estimation of avoided waste imputable to projects, the replicability of projects within the territory, and their potential impacts on the improvement of consumption habits. After the selection of project categories, the representativeness of projects within each category has to be verified.

In the present case study, this results in selecting three categories of projects: i) installation of water dispensers in towns/cities (the so-called "water houses"), including 12 projects; ii) installation of water dispensers in schools, including 2 projects; iii) replacement of disposable goods in school canteens, including 3 projects.

Firstly, since plastic was defined as a priority waste stream both at European and regional level, projects tackling plastic pollution has been selected. A focus on single-use plastic waste prevention through the reduction of disposable plastic products consumption is maintained. Over the past few years, plastic has been object of specific policies, both at European and regional level, i.e., the European Union (EU) plastic strategy (COM/2018/028), the so-called "Single-use plastic products (SUP) Directive" (Directive 2019/904) and the related "Emilia-Romagna Regional strategy for reducing the impact of plastics on the environment" (Emilia-Romagna Region, 2019). Social commitment on this problem has increased as well. For example, a recent survey shows that a major part of Italian citizens (94%) are willing to stop buying plastic bottles (EIB, 2020).

The second selection criterion verifies the feasibility of a reliable estimation of avoided waste for project categories object of analysis. In this case, the availability of the involved stakeholders to provide real data has been an essential condition.

Thirdly, all the selected project categories have high replicability potential, meaning that their replication is theoretically feasible in each Municipality and each school of the Region, as they do not have specific requirements (e.g., in terms of place, because they are implemented in public spaces).

Additionally, potential impacts on the improvement of consumption habits have been considered. Italy is the first Country in Europe for per capita consumption of bottled water (BW): in 2018 the average value was 221 litres/year, while in 1980 it was only 47 litres/year (Bevitalia, 2019). Considering packaging, in 2018, the majority consisted of single-serve polyethylene terephthalate (PET) BW, which represents the 82% of total water consumption, while the 16 % consists of glass bottles (Bevitalia, 2019). This implies that wide margins of improvement exist in BW consumption habits. The same considerations are valid for single-use tableware: in Italy, around 114.200 tonnes of single-use tableware are sold every year,

used both in big events and in public or private canteens (Eco dalle città, 2010). In Italy, 432,3 million of meals in school canteens were consumed in 2016 (ORICON, 2017). Assuming that half of them is served in disposable tableware whose weight is 200 g, 43.230 tonnes of waste would be generated every year.

Finally, the representativeness of projects within each project category has to be guaranteed. To check that, the average and the standard deviation of the population of Municipalities implementing projects in category 1 has been calculated and compared to the average and standard deviation of the population for all the Municipalities in the Region. Results show that the values are acceptable. The schools involved in projects within category 2 are representative of schools in the Region as far as the number of potential users is concerned. As a matter of fact, the average number of scholars in each school in the Region is equal to 1024 (School office of the Emilia-Romagna Region, 2020), a value close to the average number of students involved in the selected projects. Moreover, since a specific group of citizens is targeted, the average usage rate can be assumed as more uniform, with the variation of the school. On the other hand, the three projects within category 3 are representative of a small, medium, and large school canteens, respectively.

2.3 Second stage: Impact assessment methodology and system boundary

According to the "European better regulation guidelines" (EC, 2017), the impact assessment (IA) process is about gathering and analysing evidence to support policymaking as well as the advantages and disadvantages of available solutions. Hence, the IAs must compare the policy options on the basis of their economic, social, and environmental impacts (quantified costs and benefits whenever possible). Thus, the second stage of the framework aims to assess the environmental and economic impacts of each project.

Environmental benefits of waste prevention activities may not be simply considered as proportional to the amount of waste prevented (Nessi et al., 2013). The assessment of

environmental impacts of WPMs is complex, as it requires determining the environmental impact of: i) the avoided production of the material that becomes waste; ii) the avoided or additional upstream life-cycle stages that are affected by the prevention measure; iii) the avoided WM (JRC, 2011).

Considering the classification of WPMs by Nessi et. al (2013) (reported in Section 2 of SM), the analysed projects can be included in the typology "Development and/or use of less-waste-generating goods or services to provide a given function", as they imply the "development and/or use of a reusable good or of a good provided in a reusable packaging instead of a disposable good or of a good provided in a disposable packaging". Therefore, the substitutive goods generated as additional MSW to be managed and the increase of impacts in the usage phase have also been assessed, in order to include the rebound effects generated by WPMs (Hertwich, 2008).

The same considerations are valid when other dimensions of sustainability are considered. For this reason, the system boundaries set by the design framework are in common to environmental, economic, and social analyses. The geographical boundaries are regional.

The system object of the analysis includes all the activities starting from the purchase of single-use products and substitutive products to their end of life (e.g., the consumption of oil in the production of plastic bottles and the emissions to air from the vehicles that transport single-use bottles are not included). It should be noted that production, placement, and end of life of water dispensers and dishwashers are out of system boundaries, such as the life-cycle of preliminary water purifying and distribution systems. Even if the projects have a multi-year life-cycle, the assessment has been limited to the first year of project life.

Table 1 shows a brief overview of the impacts evaluated, split into: i) avoided impacts; ii) impacts related to substitutive goods and additional MSW; iii) additional impact of usage stage. Categories 1 and 2 are merged, as they are modelled in the same way.

2.3.1 LCA and LCC

Life-cycle assessment (LCA) methodology has been used to evaluate environmental sustainability of waste prevention activities, since it is a well-established methodology for this purpose (Cleary 2010; Gentil et al. 2011; Nessi et al. 2012).

Environmental consequences have been assessed in terms of Global Warming Potential (GWP), according to the Intergovernmental Panel on Climate Change (IPCC) values for a 100-year time horizon (IPCC, 2015). The amount of carbon dioxide equivalent (CO_2-eq) imputable to each project of the selected categories (drinking water dispensers in towns/cities and schools, replacement of disposable goods in school canteens) has been calculated, considering a time frame of one year.

In accordance with ISO 14040 standard (ISO 14040:2006), the LCA methodology and the impact assessment baseline performed by the Institute of Environmental Sciences of the Leiden University (CML) in version 3.05 have been applied.

Hence, for the impact assessment phase, primary data have been provided by ATERSIR, coming from the financing requests and the project descriptions elaborated by the Municipalities themselves; other information has been gathered by directly contacting the Municipalities, the water providers, the schools, or the waste collection providers involved in the projects.

To make the assumptions on the amount of waste which would have been generated without the WPM as plausible as possible, data about litres of water delivered have been gathered for the first two categories of projects, while for the last one the amount of waste prevented is foreseeable to a good approximation before the operational phase. As far as the projects of drinking water dispensers installed in the towns/cities and in schools are concerned, the Municipalities or the water providers and the schools have been asked for information about litres of water delivered by each dispenser, in a specified period. Analysing the projects of

replacement of disposable goods in school canteens, the Municipalities have been asked for information about the number of meals in one school year, the number of plastic plates and glasses used in every meal and the weight of disposable products. Furthermore, the avoided impacts, due to the avoided WM and transport of single-use products have been modelled by using secondary data gathered from the Emilia-Romagna Region WM plan, as well as the WM of substitutive goods. Material composition and life expectation of reusable solutions have been assumed by the authors, in case information on that was not available in the project descriptions. The additional impacts related to energy consumption of drinking water dispenser, and energy, detergent, as well as water consumption to wash reusable have been modelled.

The source of data related to the impacts of transportation, energy, water, and detergent is the "Ecoinvent 3.5" database. Further details on the assumptions can be found in Section 3 of SM.

The potential environmental impacts have been evaluated using the software SimaPro® 8.

Economic impacts have been assessed by applying Life-Cycle Cost (LCC) methodology. LCC can be considered as a useful complement to LCA: it exceeds the ordinary costs calculation of a process, summarizing all costs associated to each phase in the whole life-cycle (e.g., raw materials and energy supply, production, use and end-of-life). The costs must be related to money flows, i.e., investment costs, operating costs, and hidden costs (Kloepffer, 2008).

For all projects, ATERSIR have been asked for some information about investment costs sustained by the Municipalities and about funds allocated to each project. For the first two project categories, investment costs include the purchase and installation of water dispensers, and potentially cost for communication campaigns (up to 10% of the total cost). Moreover, investment cost of the second project category includes the costs for the purchase of reusable

aluminium bottles, which are provided for free to students, while for the first category of projects, the costs related to substitutive goods have been estimated, since they are covered by users and therefore not directly available. For the third project category, investment costs include the purchase of dishwashers and of reusable tableware.

In the first project category, information on the cost paid by users for water supplied by the dispensers were gathered, in order to include this cost item in the assessment.

Additional costs related to the WM of substitutive goods and to the usage phase (i.e., cost of energy consumption of water dispensers, cost of washing reusables covered by users) have been estimated. Avoided cost for SUP purchase have also been considered.

Moreover, reducing the quantities of waste produced means that it should be possible to reduce the budget required for the collection, transportation, and treatment of waste products (Zorpas et al., 2017). Therefore, avoided cost for WM of SUP has been calculated, considering the average cost in the Emilia-Romagna Region. Other externalities were not included in the LCC, to avoid the risk of double-counting. Further details on the assumptions can be found in Section 3 of SM.

2.4 Third stage: Social impact assessment methodology

The third stage of the framework aims at assessing the social impacts of WPMs. Given the availability of information, the social analysis has been carried out by category of project (water dispensers in towns/cities, water dispensers in schools and replacement of disposable products in school canteens) and not for each single project.

For the design of the social impact analysis, the "Product Social Assessment Methodology Report 2018" (Goedkoop et al., 2018) has been used as inspiration as it is in consonance with the SDGs, agreed upon by 193 Countries in 2015. The Product Social Impact Assessment method described in the manual includes four key parameters: i) stakeholder groups (small entrepreneurs, workers, users, and local communities); ii) social topics; iii) performance

indicators; iv) reference scales to assess the impact. Social topics for users and related indicators are of interest to the authors because the stakeholder group considered in the study are the users, i.e., the citizens, who benefit from the use of the infrastructures installed thanks to these projects. All citizens are potential users of projects implemented within category 1, while projects within categories 2 and 3 target specific users, i.e., the students at the involved schools. Thus, the indirect effects on other stakeholders associated with the consumption reduced/induced by the different projects have not been analysed.

Hence, social sustainability has been evaluated based on the following social topics: health, safety, responsible communication, privacy, inclusiveness, effectiveness and comfort. One indicator per topic was evaluated, using reference scale with relative scores (from -2 to +2).

"Health" indicator is meant to assess the extent to which the project maintains or improves the health status of the users. "Safety" indicator considers the extent to which the project maintains or improves safety of the users. "Responsible communication" assesses the extent to which transparency enables users to make informed choices. The fourth indicator concerns the extent to which a project respects and protects users` privacy. "Inclusiveness" is defined as the extent to which the project affects affordability and accessibility of products or services to different groups of people (e.g., disabled persons, the elderly, persons with low income). Finally, "effectiveness and comfort" of projects aims to evaluate the extent to which the projects affect the efficiency and comfort of users.

2.5 Fourth stage: Waste prevention observation, identification and selection of indicators

Waste prevention observation consists in setting up indicators describing and monitoring the resources allocated to the action or policy, the results of this action or policy, and to assess its efficiency regarding sustainable development (Bel, 2010).

In the fourth stage of the framework, impact-oriented and result-oriented indicators have been

assessed with the aim to monitor both effectiveness and efficiency of the selected project categories in a life-cycle perspective. Facing the huge number of possible prevention measures that theoretically could be taken by the public sector, and, taking into account limited financial resources and also organizational capacities, indicators allow comparison of the effectiveness of different measures, and thus to select and prioritise (Wilts, 2012).

In collaboration with ATERSIR, some indicators to perform the analysis have been identified, starting from the results of the environmental, economic, and social assessment. The focus was not on the monitoring of every single project, but on the analysis of the project categories, in order to assign priority order for future allocation.

As far as the environmental aspect is concerned, some waste reduction indicators have been assessed, as well as some impact indicators, which stem from the LCA assessment. Waste reduction indicators always include the estimations of additional waste from substitutive goods. Besides indicators assessing the total avoided waste and total avoided CO_2-eq emissions, the indicators "per capita avoided waste" and "per capita avoided CO_2-eq emissions" have been calculated, by applying two different methodologies for the estimation of users. The first one considers the diffusion factor (DF), defined as the percentage of population/producers that effectively changes its consumption behaviour as a consequence of the prevention policy (JRC, 2011), while the second one considers all the potential users. The indicators calculated with the first methodology are part of the final set of indicators, as they are more representative of reality. Moreover, they are constant within each project category. Further details about the DF for each project category are provided in Section 3 of SM.

As far as the economic aspect is concerned, the economic impact resulting from the LCC assessment has been parametrized to avoided waste and avoided CO_2-eq emissions. Moreover, a comparison between the funds allocated by ATERSIR and the economic impact has been performed, together with an analysis of the grant received by each project in

function of the avoided waste. Nevertheless, the indicators referring to the grant have been excluded from the final set, to guarantee the objectivity of the analysis. As the decision on the fund's allocation is notified by ATERSIR to the Municipalities after the start of projects, it is assumed that the economic efficiency is not influenced by the grant amount. Moreover, the payback period of each investment has been calculated, considering all the additional and avoided costs for the society: this indicator has not been included in the final set, because the time required to recoup the funds expended is not considered relevant.

The indicators finally selected include five environmental indicators, three economic indicators and one social indicator. In particular, the environmental indicators encompass two waste reduction indicators: i) "Avoided waste" [kg/year] and ii) "Per capita avoided waste, considering DF" [kg/(user year)], and three LCA indicators: i) "Total avoided CO_2-eq emissions"[kg CO_2-eq/year], ii) "Per capita avoided CO_2-eq emissions, considering DF"[kg CO_2-eq /(user year)], and iii) "Avoided CO_2-eq emissions per avoided waste" "[kg CO_2-eq /(kg year)]. They are complemented by three economic indicators: i) "Economic impact" [€], ii) "Economic impact per avoided waste" [€/(kg year)] and iii) "Economic impact per avoided CO_2-eq emissions" [€/kg CO_2-eq], and one social indicator, the sustainability assessment score resulting from the social impact assessment. While some indicators can only be calculated by experts or researchers (e.g., LCA indicators, economic impact per avoided CO_2-eq), the waste reduction indicators as well as the social indicator do not require the same experience. Hence, the local administrators might be always able to evaluate the majority of the indicators.

2.6 Fifth and sixth stages: Normalisation and definition of the priority order

After the calculation of the indicators, the results have been normalized. This normalization step is usually regarded as a sensible matter which requires careful judgement based on experience (Rigamonti et al. 2016; Wilson et al. 2015). Following Fernández-Braña et al.

(2019), for the sake of simplicity, in this analysis it was decided to give the same weight to each indicator as a first assessment, leaving the question of a more accurate weighing procedure for future studies. The following mathematical formulae were applied to calculate the final score of each project category:

$$Normalised\ value_{ijp} = \frac{ind_{ijp}}{\sum_{j=1}^{3} ind_{ijp}}$$

$$Average\ of\ normalised\ value_{jp} = \frac{\sum_{i=1}^{n} Normalised\ value_{ijp}}{n}$$

$$Total\ score_j = \frac{\sum_{p=1}^{3} Average\ of\ normalised\ value_{jp}}{3}$$

Where:

j represents the project category (from 1 to 3, indicating installation of water dispensers in towns/cities, installation of water dispensers in schools, replacement of disposable goods in school canteens); p represents the sustainability pillar (from 1 to 3, indicating environment, economic and social aspects); ind_{ijp} is an effectiveness and/or efficiency indicator i, for the project category j, referred to the sustainability aspect p.

As final result, a priority order for the analysed project categories is extrapolated.

3. Results and discussion

3.1 Results of the environmental, economic, and social impact assessment

Table 2 shows a comparison of the total impacts related to the drinking water dispensers in towns/cities, drinking water dispensers in schools and replacement of disposable goods in school canteens, considering environmental, economic, and social aspects. Section 4 of SM shows the detailed results of LCA and LCC, for each project; additionally, it describes the reasons of the scores, for each social indicator and for each project category.

As far as environmental impacts are concerned, interestingly no significant differences can be found between the three categories: the avoided impacts associated with the use of disposable goods overcome the impacts related to the additional WM and the additional consumption of

energy, water, and detergent, resulting in an overall negative environmental impact. Therefore, the additional energy consumption item has the highest environmental impact.

From an economic perspective, the investment cost is the highest cost item for the categories 1 and 2, while for category 3 the cost for washing reusables is the most significant one. Consequently, for categories 1 and 2 the economic impact is lower than the total cost of the projects, while for category 3 this does not happen. As far as avoided costs are concerned, for all the categories the avoided expense for SUP purchase is the most relevant economic benefit.

The social impact assessment has resulted from evaluations made by the authors. In three out of six social topics, each project category gets the same score. The third project category has no impact on safety and on inclusiveness, while the first two categories have a positive impact on these topics, since they offer an essential goods, in a safe manner and at very low costs. Moreover, the effectiveness of the second and third project categories is increased by the fact that they are implemented in schools, given that education plays an important role in generating the awareness essential to effectively promote WPMs.

3.2 Effectiveness and efficiency indicators

As far as the environmental aspects are concerned, the waste reduction indicators (i.e., the average per project avoided waste and the average per capita avoided waste) for each project category are shown in Figure 2. LCA indicators, i.e., the average values of both total environmental impact and per inhabitant impact in terms of avoided CO_2-eq emissions for each category, are shown in Figure 3, together with the avoided CO_2-eq emissions per kg of avoided waste. This last indicator links the two classes of indicators. Section 5 of SM shows the values of indicators for each single project.

On the base of waste reduction indicators, the first category (water dispensers in towns/cities) is the most effective one in terms of WP: the total annual amount of avoided waste is around

six times bigger if compared to the same indicator for categories 2 and 3. Nevertheless, per capita avoided waste is higher for category 3 (replacement of disposable goods in school canteens): this is due to the fact that in this case the diffusion factor is equal to 100%, as the application of this prevention measure does not depend on consumer choices. The same consideration is valid as far as per capita avoided CO_2-eq emissions are concerned. Hence, the category 3 has the least per capita environmental impacts, in terms of CO_2-eq emissions. The third category performs better than the others also in: i) the average value of total avoided CO_2-eq emissions, since it reaches a value slightly higher than the first category; ii) the amount of avoided CO_2-eq emissions per kg of avoided waste.

It should be considered that waste reduction indicators and LCA indicators do not result in the same ranking of project categories, both taking into account the total and the per capita indicators. Thus, it was decided to maintain a double focus by selecting indicators of both classes, in order to mirror the targets set by legislation.

As far as the economic aspects are concerned, Figure 4 shows the average indicators for each category, while Section 5 of SM shows the values of indicators for each single project.

Overall, these results indicate that the third category of project reports in the first year an average economic impact which is much higher than the grant received by ATERSIR: the reason can be found in the high value of operating costs associated to dishwashing of reusable dishes/glasses. The opposite can be said of the first category: in this case, the cost item "Savings for citizens for not buying BW" has a big relevance: thus, the grant received by ATERSIR covers just a small portion of the economic impact in the first year.

The third category has the highest cost per kg of avoided waste, resulting in a value almost seven times bigger than category 1. The gap between categories decreases when the cost per avoided CO_2-eq emissions is assessed.

Finally, the payback period was calculated (in Section 5 of SM, the average values for each

category is shown). It should be noticed that the first 2 categories of projects have a pay-back period, while the third category prove to be not profitable.

3.3 Selected indicators and comparison of project categories

The three types of projects (water dispensers in towns/cities, water dispensers in schools and reduction in consumption of disposable products) have been compared, for each aspect analysed (environmental, economic, and social), by assessing the average value of selected indicators. Hence, the results are shown in Table 3.

Each indicator was normalized (see Section 5 of SM). Then, the average value for each aspect was calculated. Table 4 shows the results: the total score for each project category is calculated as the average of the scores in each sustainability pillar.

The total score is a result of the environmental, economic, and social contributions. The water dispenser project category whose total score is 0,4265 ranks first, resulting the best one, whereas the water dispenser in schools and the replacement of disposable goods in school canteens get an approximately equal total score.

3.4 Discussion and considerations

The application of the designed framework to the case study allowed the comparison of three different categories of project. The first two categories (i.e., water dispensers in towns/cities, water dispensers in schools) aim to promote sustainable consumption practices. With a strategy of de-commoditization, they both pursue at decreasing the influence of goods and products and, more generally, of the market institution in the way in which people satisfy their needs and desires (Boulanger and Mainguy, 2010). The third measure (the replacement of disposable goods in school canteens) represents a procurement decision made by the public sector.

The criteria of selection guarantee the comparability of the different project categories and the reliability of the result.

Starting from the results of the environmental, economic, and social assessment, the proposed algorithm for the prioritisation allows the decision-maker to objectively evaluate the project categories. The analysis is also strongly supported by the effectiveness and efficiency indicators, selected in collaboration with the public decision-maker.

As preliminary evaluation after one-year from the project start date, the total amount of avoided waste thanks to the implementation of the 17 analysed projects has been estimated as approximately equal to 88 tons: this accounts for the 0,03% of the total plastic waste production in the Region in 2018 (ARPAE, 2020). Even if this value seems low, it should not be neglected that only few projects, demanding limited economic resources, have been analysed: the investment cost for the implementation of these projects is equal to the 0,873 % of the WM cost paid by the involved Municipalities in 2018. Thus, increasing the investments for WP might allow to unlock the high potential of replicability of the selected projects.

Considering the impact assessment phase, the geographical boundaries of the system coincide to the regional ones: this implies that the analysis is limited to the purchase, the use and the WM of avoided single-use products and related substitutive goods. Furthermore, another limitation of the analysis is the fact that only projects in an initial stage of their life-cycle are considered. An evaluation of success in the long-term could benefit, as it is crucial that WP behaviour are sustained beyond cessation of the active campaign (Cox et al., 2010). Moreover, it should be considered that the unsuccessful projects were excluded from the analysis. Further research might investigate the reasons of their failure, to develop a learning process.

A careful analysis of the single projects can be the starting point to identify the success factors within each project category. For example, within the first project category, the smallest Municipality is the one that achieves the best performance in terms of per capita

avoided impacts: a more detailed analysis of the specific characteristics of each Municipality should be performed to understand if the Municipality size has indeed influence on the success of this kind of projects.

Thus, future research might focus on an accurate assessment of the impacts of every single WP project, in a particular geographical context, with a lower number of assumptions. Furthermore, a sensitivity analysis might be performed. Economic analysis might also be enlarged, by considering the monetization of externalities. Moreover, the social assessment might be performed at project level, allowing a more detailed analysis of impacts (e.g., water quality can vary from a Municipality to another), on a larger number of stakeholders. The use of a life-cycle approach might allow designers to identify any critical points of a WPM, possible improvements, and the way a WPM can be best designed and implemented in a particular geographical context to achieve the expected benefits (Nessi et al., 2014; Magrini et al., 2020).

Monitoring prevention and reuse activities is crucial for policy and decision-makers.

To effectively allocate financial resources, the results of this study should be integrated with an analysis of waste generation patterns in the regional territory, in order to promote and implement WPMs where per capita waste generation and/or littering rate (if available, both limited to the waste stream tackled by the WPMs) are high. Moreover, the framework should be applied to projects which target other waste streams: the comparison of the results can provide policy and decision-makers with a more complete picture.

The Emilia-Romagna Region has not implemented a specific monitoring system for prevention activities yet. The annual monitoring of WM plan does not evaluate the success of waste prevention activities, but it only considers the quantity of waste generated. Indeed, the LCA study of regional WM plan considers WP only for the definition of the functional unit, as waste in input (Magrini and Bonoli, 2019). The monitoring system should oversee WPMs

implemented in the territory, not only at consumption level, but also at other stages of the value chain, promoting synergies to pursue strategic waste prevention.

If the monitoring activity is complemented by an improvement of coordination and networking of individual projects, good practices could spread and learning effects regarding innovation approaches could realize (Wilts et al., 2013). Additionally, benchmarking between different spatial entities motivates local actors to invest more time, effort, and responsibility in the objectives (OECD, 2004; Wilts, 2012).

Furthermore, the analysis of the indicators assessing the average environmental impact (both in terms of amount of avoided waste and in terms of avoided CO_2-eq emissions) and the economic impact might be useful in planning activities, as in the definition of a waste prevention program or in making projection about waste composition in the future years.

On the one hand, the indicators can provide a benchmark value for ATERSIR, in the phase of screening of the funding requests, in order to validate the projections on waste reduction and the economic estimations made by Municipalities; on the other hand, they might be useful for Municipalities, for an ex-ante assessment of the environmental and economic benefits related to specific WPMs.

Moreover, social impact assessment helps in evaluating the achievement of long-term sustainability goals: education and knowledge are considered to be one of the most powerful, well-known, and proven drivers for sustainable development and behavioural change must be done starting from young ages to move the agenda forward on prevention (Zorpas et al. 2016).

To effectively promote WP, its potential integration with other policy areas should be considered. Thus, institutional mechanisms can help in linking efforts to promote sustainability in various issue areas, thus representing one crucial element of an integrated approach to sustainable development (Spangenberg et al., 2002).

Hence, policies must have a systemic perspective, including considerations on life-cycle perspective, production systems and raw material in use, consumer behaviour, direct and indirect environmental impacts as well as economic and social ones, trade-offs between environmental, economic, and social sustainability. In this sense, the use of indicators can facilitate cooperation across traditional institutional structures.

The analysis indicated that till now few Municipalities of the region have presented fund requests for the implementation of WPMs: an improved institutional framework might help the Municipalities in overcoming barriers to the identification and implementation of WPMs. Financial incentives offered by the region can cover the investment costs for the implementation of WPMs. Nevertheless, in some cases, the need for additional longer-term incentives arises, in view of the high operating costs (e.g., category 3).

As far as the participation of citizens is concerned, it should be noticed that the first category of project has an average DF equal to 13%, while the second category scores 24%. Certainly, there can be several different drivers to determine the social approval of a WP action. In promoting the participation of citizens, it should be considered that citizens all over the world, regardless of what category their countries are (low or high incomes), need motivation (mainly less taxes or to receive extra money somehow) to react to anything and specially to participate in environmental performances actions (Zorpas et al., 2017). As example, in case of project category 1, the price for water supply paid by users can influence the success of these projects.

Moreover, as barriers to engaging householders include both modern consumer culture and a genuine confusion that WP is equivalent to recycling (Cox et al., 2010), communication campaigns are fundamental.

4. Conclusions

In this research, waste prevention is investigated within the framework of sustainability, in

accordance with the SDG 12 of UN Agenda 2030, by focusing on WPMs promoting sustainable consumption.

In compliance with the definition of strategic waste prevention, a framework for the assessment of WPMs implemented by Municipalities is proposed, to evaluate their success and support the financing choices of public decision-makers. The designed framework evaluates impacts, effectiveness, and efficiency of some selected WPMs. The framework designed by authors was tested on three categories of projects: as case study, the impacts of 17 projects already ongoing in the Emilia-Romagna Region were assessed. As outcome, a priority order for future allocation of financial resources can be defined. Moreover, the contribution of WPMs to the achievement of waste prevention targets and sustainable development is quantified.

In the present study environmental considerations are complemented by an evaluation of economic and social impacts. LCA and LCC methodologies have been applied, limiting the explored system to the phases of consumption and WM.

This study has the ambition to give a contribution in waste prevention field. Literature highlighted the need of developing reliable methods to monitor, measure and evaluate benefits of waste prevention, as means to overcome potential barriers to the spread and to the success of WPMs. Moreover, monitoring the effects of waste prevention is a mean to integrate the evaluation into environmental policy strategy, thereby mainstreaming sustainability into policymaking.

As above discussed, the study confirms that institutional mechanisms, such as action and economic leverage, are fundamental for channelling the behaviour of individuals and the actions implemented by Municipalities towards WP, contributing to the evolution of societies towards sustainable development.

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Table 1. Impacts considered for each project category.

Project category	Object of analysis	Avoided impacts	Impacts related to substitutive goods and additional MSW	Additional impact of usage stage
Drinking water	**Products**	PET bottles (primary	Glass bottles, aluminium	

dispensers in towns/cities and schools (Categories 1 and 2)		packaging, secondary packaging, transport packaging)	bottles and water dispensers	
	Environmental impacts	Transport, waste management of bottles, starting from the purchase, over one year.	Transport, waste management of reusable bottles, starting from the purchase, over one year.	Energy consumption of drinking water dispenser. Energy, detergent, and water consumption to hand-wash reusable bottles, over one year.
	Economic impacts	Avoided cost for the waste management of disposable bottles, over one year.	Annual cost of substitutive goods (dispensers, glass bottles and aluminium bottles). Annual cost for additional waste	Cost for annual energy consumption of drinking water dispenser. Annual cost paid by citizens for supplied water. Annual cost for

		management.	energy, detergent, and water consumption to wash reusable bottles.
	Social impacts	Included	-	Included
Replacement of disposable goods in school canteens (Category 3)	**Products**	Disposable plates/glasses	Multi-use plates/glasses and dishwashers	
	Environmental impacts	Waste management of plastic plates and glasses, starting from the purchasing, over one year.	Waste management of reusable plates/glasses, starting from the purchase, over one year.	Energy, detergent, and water consumption to wash reusable dishes/glasses (in the dishwasher).
	Economic impacts	Avoided cost for the waste management of disposable goods, over one year.	Annual cost of substitutive goods (dishwashers, multi-use plates and glasses). Annual cost for additional waste management.	Annual cost for energy, detergent, and water consumption to wash reusable dishes/glasses (in the dishwasher). Annual cost of labour.

	Social impacts	Included	-	Included

Table 2. Results of IA. Total impacts for each project category.

	Drinking water dispensers in towns/cities	Drinking water dispensers in schools	Replacement of disposable goods in school canteens
Environmental items	**Environmental impacts [kg CO2-eq.]**		
Avoided waste management	-109.000	-3.090	-14.800
Additional waste management	429	189	139
Additional energy consumption for washing reusables and for water dispensers	39.500	266	3.890
Additional water and detergent consumptions for washing reusables	35.500	233	2.160
Total environmental impact	**-33.571**	**-2.402**	**-8.611**
Cost items	**Economic impacts [€]**		
Investment cost (covered by Municipalities)	357.655	37.931	57.259
Cost paid by users (for water supplied by the dispensers)	22.520	-	-
Cost of energy consumption (water dispensers)	1.088	21	-
Cost of substitutive goods (covered	79.286	(included in	(included in

by users)		investment cost)	investment cost)
Cost of washing reusables	46.904	265	57.664
Additional cost for WM of substitutive goods	1.159	14	2,68
Avoided cost for SUP purchase	-428.316	-11.139	-11.381
Avoided cost for SUP WM	-22.747	-572	-1.070
Total economic impact	**57.548**	**26.520**	**102.474**
Social topics and indicators	**Score**		
Health	1	1	1
Safety	1	1	0
Responsible Communication	2	2	2
Privacy	0	0	0
Inclusiveness	2	1	0
Effectiveness and Comfort	0	1	2

Table 3. Comparison of average values of the selected indicators, for each project category.

Project category	Number of projects	Environmental analysis					Economic analysis			Social analysis
		Average «Avoided waste»	Average «Avoided CO2-eq	Average «Per capita avoided waste,	Average «Per capita avoided d CO_2, -eq	Average «Avoided CO_2 -eq	Average «Economic impact » [€]	Average «Economic impact per	Average «Economic impact per	Sustainability assessment score

		[kg/year]	emissions» [kg CO_2-eq/year]	considering DF» [kg/user]	considering DF» [kg CO_2-eq/user]	per avoided waste» [kg CO_2-eq/kg]		avoided waste» [€/kg]	avoided CO_2-eq emissions » [€/kg CO_2-eq]	
Water dispenser in towns/cities	12	6.518	-2.798	8,877	-3,79	-0,429	4.796	5,77	13,45	6
Water dispenser in schools	2	1.011	-1.201	4,436	-5,29	-1,189	13.260	14,07	11,83	6
Replacement of disposable goods in school	3	1.290	-2.870	5,162	-12,08	-2,300	34.158	35,15	15	5

canteen s										

Table 4. Final results

Project category	Environmental analysis	Economic analysis	Social analysis	Total score
Water dispenser in towns/cities	0,383	0,544	0,353	**0,4265**
Water dispenser in schools	0,217	0,292	0,353	**0,2872**
Replacement of disposable goods in school canteens	0,400	0,164	0,294	**0,2863**

Figure 1. Graphical representation of the stages of the proposed framework

Figure 2. Average values of environmental indicators in terms of avoided waste for each project category

Figure 3. Average values of environmental indicators (in terms of avoided CO_2-eq emissions) for each project category

Figure 4. Average values of economic indicators for each project category

Declaration of competing interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Credit Author Statement

Chiara Magrini: Conceptualization, Methodology, Validation, Formal analysis, Data curation, Writing- Original draft preparation, Reviewing and Editing, Visualisation.

Anna Degli Esposti: Conceptualization, Methodology, Validation, Formal analysis, Data curation, Writing- Original draft preparation, Reviewing and Editing, Visualisation.

Elena De Marco: Conceptualization, Validation, Investigation, Writing- Original draft preparation.

Alessandra Bonoli: Conceptualization, Validation, Reviewing and Editing, Supervision.

Graphical abstract

Highlights
- No general methodology for the assessment of prevention initiatives exist
- Environmental, economic, and social sustainability in a life cycle perspective
- Impacts, effectiveness, and efficiency of 17 waste prevention projects are assessed
- An algorithm for prioritisation is proposed
- Monitoring waste prevention activities is crucial for decision-making

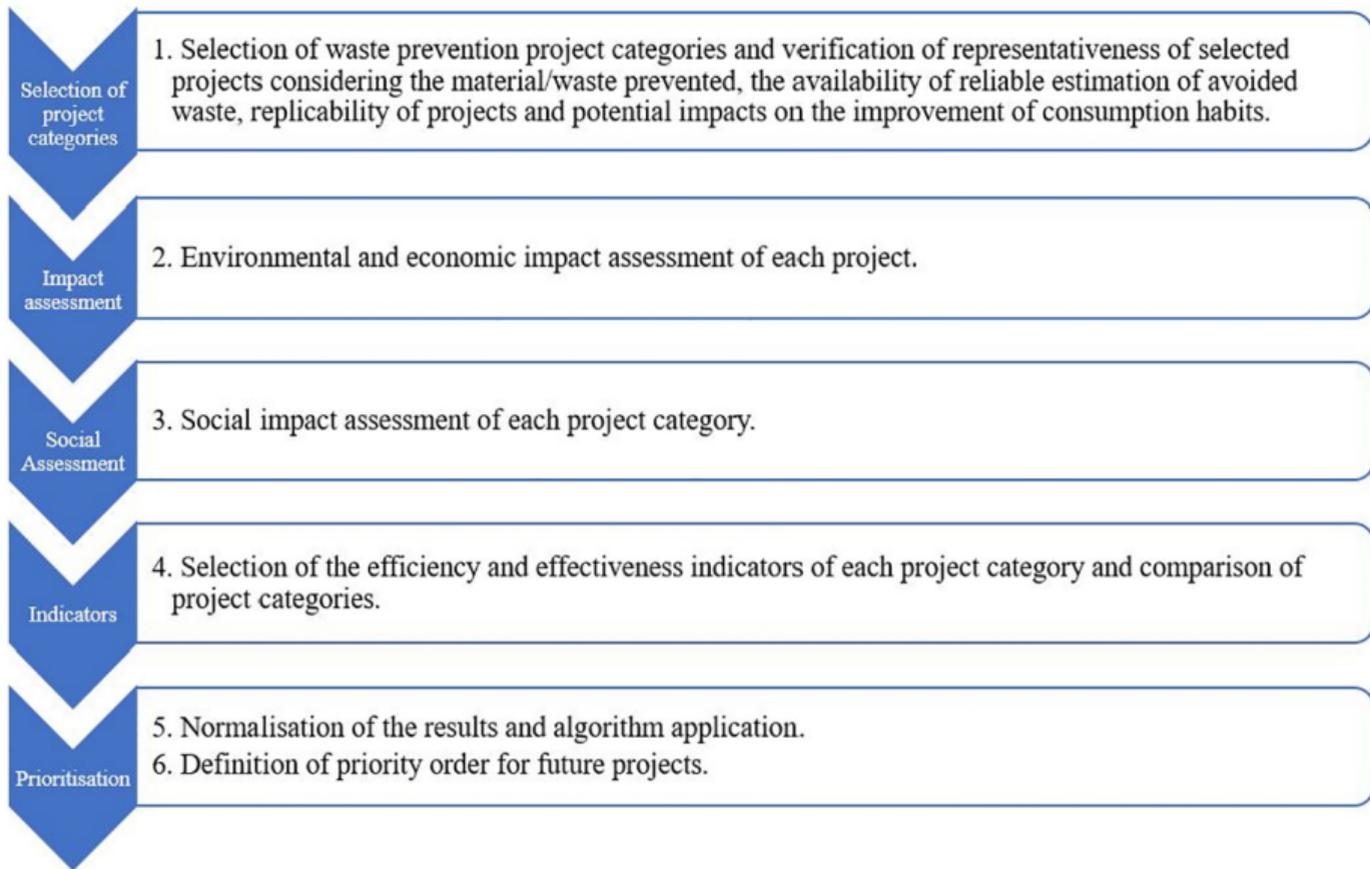|	
Selection of project categories	1. Selection of waste prevention project categories and verification of representativeness of selected projects considering the material/waste prevented, the availability of reliable estimation of avoided waste, replicability of projects and potential impacts on the improvement of consumption habits.
Impact assessment	2. Environmental and economic impact assessment of each project.
Social Assessment	3. Social impact assessment of each project category.
Indicators	4. Selection of the efficiency and effectiveness indicators of each project category and comparison of project categories.
Prioritisation	5. Normalisation of the results and algorithm application. 6. Definition of priority order for future projects.

Figure 1

Figure 2

Figure 3

Figure 4