WESTE methodology for holistically evaluation of the waste management chain

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Abstract

The quantification of the sustainability degree of the waste management chain in a municipality or a region is essential to move forward a more sustainable scenario. This paper presents the WESTE methodology for holistically evaluation the waste management chain under an environmental, social, technical and economic (ESTE) perspective. The methodology allows benchmarking the sustainability degree of a case study, making comparisons among different case studies and tracking the developments over the time. As a result, 12 high level sustainability indicators have been defined and more than 50 intermediate and low-level indicators. 70% of the indicators are technical indicators describing the performance of the system such as the amount of waste collected or the kilometres per route. Social indicators cover the 14% of them describing mainly the behaviour of the citizens. Environmental and economic indicators account for the 16% of indicators describing the environmental impact and cost of the system.

Key Words

Indicators, Sustainability, Methodology, Waste management assessment

1. Introduction

Municipal waste accounts for about 10% of the total waste generated in the European Union (EU-28), meaning that 243 million tonnes were generated in 2015 [1]. This represents an average of 475 kg per person per year. Waste generation varies greatly from place to place due to differences in consumption and production patterns and economic wealth, as well as due to its high political profile. Even though the European Waste Framework Directive states the waste management hierarchy (prevention, preparing for reuse, recycling, recovery and disposal) [2], on average 26% of municipal waste is still sent to landfills, 27% is incinerated and only 47% is composted or recycled. Currently and according to the best practices available, 80 million tons of recyclable materials are disposed of or wasted every year, regardless the wastes coming from industrial sector. Among recyclables, the management of biowaste (and especially food waste) is considered the backbone of a good waste management system [3]. However, biowaste is only selectively managed in a few Member States. The sector that most contributes to the food waste are households (47 million tons every year). About 80% of food waste is avoidable [4]. In addition to the economic cost to municipalities, waste management represents more than 3% of total greenhouse (GHG) emissions in Europe (more than 100 million tonnes of GHG).

The public authorities have the responsibility of assuring the transparency of the system providing verified high-quality information. Furthermore, they have a key role in the fight against climate change since many of the GHG emissions are attributable to production, management and consumptions activities among the cities [5- 6]. Additionally, the urban waste management service (UWMS) causes environmental and health impacts all through its life cycle. Likewise, UWMS could breed some environmental and health benefits due to material recovery and virgin material extraction avoidance. Thus, the quantification of the sustainability degree of the waste management chain in a municipality or a region is essential to move forward a more sustainable scenario.

The success of the UWMS lies in the knowledge of the problem as well as in the accuracy and reliability of the data used. Decisions taken without a proper supportive information may result into an inappropriate management with direct consequences on human health, financial security, efficiency of facilities, use of resources as well as on the environmental impact of the system at local and global level [7]. Hence, it is important to have mechanisms that facilitate to draw out the essential information of each stage of the UWMS for subsequently be capable of quantifying the impacts along with tracking of strategic objectives.

The use of indicators capable of communicating complex results in an understandable way either for experts or for non-expert public, has shown its suitability to ease the decision process [8]. The use of indicators enables the evaluation of the system, to conduct a follow-up of the actions deployed, to pinpoint breakdowns in the system identifying improvements possibilities or to allow the benchmarking. The indicators could be classified into four categories: environmental, technical, social and economic indicators. Technical or performance indicators determine whether system objectives are being met indicating progress towards the objective. The objectives of the waste management service come in line with the objectives set by the legal framework such as the separate collection rate for recyclables or the landfill diversion rate of residual waste. Environmental impact indicators are based on Life Cycle Thinking and Assessment [9]. Life Cycle Assessment means quantifying all physical exchanges with the environment, whether these are inputs (resources, materials, land use and energy) or outputs (emissions to air, water and soil) attributed to a specific product or service over their entire life cycle. The results are classified according to the different environmental impact categories such as the climate change or the resource depletion. Economic indicators report cost information attributed to a specific product or service. While social indicators try to catch citizens' performance towards the systems such as the acceptance or the potential use of the system in terms of the accessibility of the system.

The literature has thoroughly work in the definition of an evaluation tools to assess the UWMS. Each stage among the waste management chain should be evaluated, considering that when taking decisions about the design of infrastructures or the implementation of management policies, experts worldwide have recognized the importance of considering the whole system in a holistic manner [10]. Prevention of the generation is the top priority of the waste hierarchy set by the European waste framework for which it is asked to set proper specific qualitative or quantitative benchmarks for waste prevention measures adopted. The most used indicator to measure the impact of the prevention actions is the evolution of the generation. However, is not easy to state the individual impact of each action [11]. The efficiency of a collection system has been usually determined by the separate collection rate which reflects the gross amount of waste collected separately over the total generation. However, some other indicator are needed to evaluate the effective separate collection rate, that is, the amount of clean waste available for its recycling [12]. The treatment stage has usually been evaluated according to percentage of waste send to different management alternatives such as recycling (organic and inorganic), incineration or landfill. Due to the lack of framework to quantify the waste effectively recycled, a new definition to quantify the real amount of waste that is sent effectively to recycling treatments called Destination RECcyling (DREC) has been set [13]. Over time, new innovative indicators have stood up to evaluate the transition towards zero waste ecosystems [14], [15], to foster reduce-reuse-recycling politics [16], to evaluate the potential of a region to become a circular economy [17], to account for the self-sufficiency of the waste management system [18] or to define new resource efficiency indicators [19]. By the same token, different softwares have arisen to quantify the main impacts of the UWMS. EASETECH is a life cycle assessment (LCA) model for the assessment of complex materials flows modelling the resource use and recovery as well as environmental emissions [20]. CO2ZW tool is also a LCA-model focusing on measuring the carbon footprint of the UWMS [21]. SIMUR is an analysis tool to develop environmental profiles to diagnosis how urban system are managing their waste and to help to develop plans for future from a life cycle perspective [22]. Wasteaware indicators have been built to allow the comprehensive performance measurement of the physical components of the UWMS and the governance aspects [23].

The main shortcoming of the application of these mechanisms and tools is twofold: a lack of consistent data, and a lack of a common framework that allows benchmarking of a city's performance, comparing among cities and monitoring developments over time. This work presents the WESTE methodology for holistically evaluation the waste management chain from an environmental, social, technical and economic (ESTE) perspective. WESTE methodology will be tested in 4 real pilot sites within the Waste4Think (W4T) project. The main objective of W4T project is to move forward the current waste management practices into a circular economy motto, demonstrating the value of a set of 20 technological and non-technological eco-innovative solutions that cover all the waste value chain integrating them into a common waste data management methodology [24].

2. Methodology

2.1. Indicator tree

WESTE methodology allows benchmarking the sustainability degree of a site, making comparisons among different places and tracking the developments over the time. The methodology is a top-down methodology (Fig 1). The methodology begins by setting the main objectives of the waste management strategy. The objectives are defined as the goals for which the waste management strategy is defined for such as social satisfaction or high sorting rate. For each of the objectives at least one quantitative indicator is defined. These main indicators are defined as high-level indicators (HLI). Subsequently, it is begun to weave an indicators tree looking for intermediate indicators until concluding on low-level indicators (LLI) . HLI are the aggregation of different intermediate and LLI, while LLI could be used to calculate more than one HLI. The more reliable LLI the more accurate quantification of the HLI.

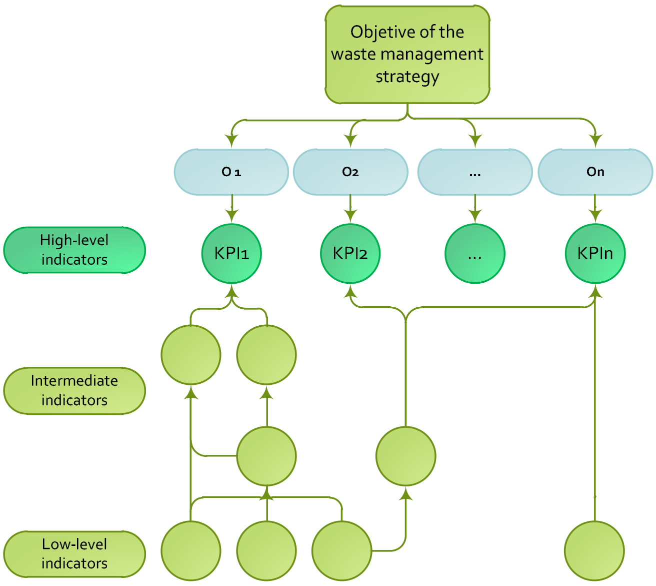

Fig 1. WESTE integral waste management assessment methodology

2.2. Waste-data

WESTE methodology is based on the waste-data available which is defined as all the ESTE data used to describe the waste management strategy implemented in a case study [25]. Waste-data comprehends data concerning waste generation, collection and management, data related to the kind of resources used, context defining data and data from external sources (Fig 2). Waste generation, collection and management data refers to the amount of waste generated, collected and managed in the pilot site. Waste-resource data relates to the characteristics of the technological resources used and their efficiency, such as the collection and transport means' characteristics, the deposit points used or the features of the treatment plants. When applying internationally recognized methodologies, such as the Life Cycle Thinking methodologies [26], inventory data is compulsory as well as verified characterization and normalization factors. Finally, context-defining data concerns all cultural, social, legal, demographic, environmental and economic characteristics of the case study.

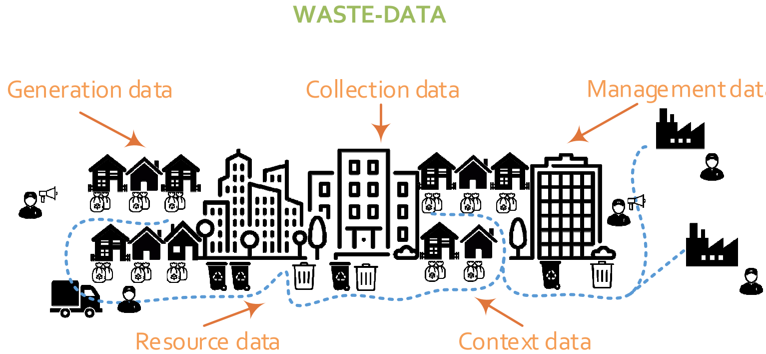

Fig 2. Waste data sources

The cornerstone of the methodology is the waste generation, collection and management data. Technical data about the waste generation is the mass quantification of the kind of waste streams generated in a fix place and time. Whereas the amount of waste collected are the figures about the distribution of the previous generation. Management data refers to the mass managed by the treatment and disposal facilities either inside or outside the case study. To quantify the first two terms, generation and collection, it is essential to define the sorting matrix. While for quantifying management, it is needed to clarify the nature of each treatment, that is the management scheme.

2.3. Indicator hierarchical system

The indicators are hierarchised according to a four-tier system [8] (Fig 3). Tier 1 represents direct measures from the collection points, treatment facilities or other data sources such as the waste tonnages collected. However, these data do not provide information on how these tonnages relate to the total amount of materials managed. Thus, indirect indicators are defined. To this extent two type of indirect indicators are defined depending in the supplementary data used. The indirect indicators that show the relative effect of each waste management strategy do not need supportive data (Tier 2), whereas indirect indicators that reflect the relative effect in terms of other variables do need this type of data, such as socio-economic characteristics (Tier 3) and life cycle sustainable assessment data (Tier 4). The indirect indicators provide a better understanding of the actual impact of each waste management strategy implemented. Tier 2 utilizes tonnages managed, but measured by percent to provide a better understanding of the relative effect of each waste management strategy. Tier 3 indicators are ratios indicating the amount managed in specific categories relative to the inherent characteristics of the site such the population or the gross domestic value. Finally, Tier 4 represents the outputs from a LCA analysis.

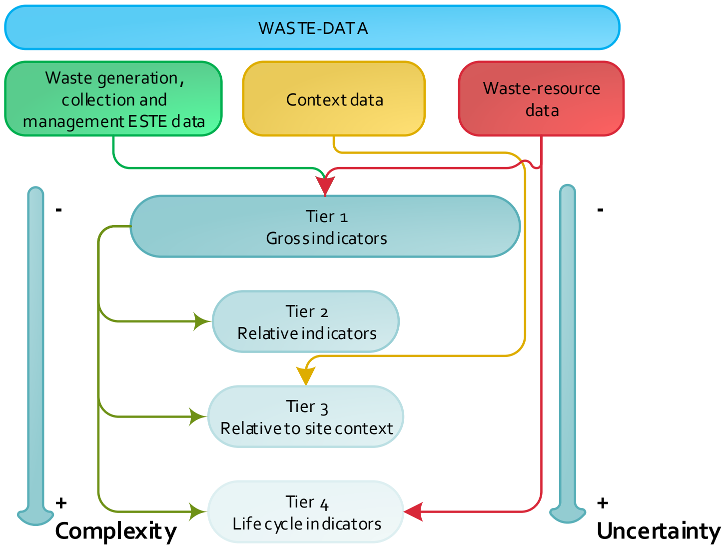

Fig 3. Relation between waste -data and indicator tier

Each tier implies higher data requirement and consequently greater calculation complexity. The accuracy of the results strongly relies on the quality of the low-level indicators (Tier 1). Thereby, the usage of local data is advisable but when this is not possible three aspects are highlighted to evaluate the accuracy of the data and assess the alignment with the case study: the geographical, time and technological correlation of the external data compared to the case study. Conversely, because an increase in tiers indicates an increase in computational complexity, more data are needed for the higher tiers which lead to more sources of error and potential inaccuracy in calculations which turns into higher uncertainty of the results.

2.4. Indicator description template

Each indicator is described according to the template on Table 1. Firstly, the name of the indicator, a unique code and the tier must be indicated. In the general description, the type of variable measured by the indicator (environmental, economic, social, technical) must be indicated. In stage field, it must be indicated which is the waste management stage described by the indicator (generation, collection, treatment, global). Finally, the type of indicator must be indicated. Direct indicators are quantified without any other data, while indirect indicators need supplementary information to be quantified.

Secondly, a broad description of the calculation methodology should be done. A detailed description of the indicator specifying whether the indicator comes from a standardized methodology. A standardized methodology is one that it is internationally recognized, such as the IPCC methodology for the calculation of GHG [27]. Then the calculation formula whereby the indicator is calculated and a detailed description of the necessary variables and data for its calculation must be done. Each indicator must have a unit of measurement. In the calculation procedure, the necessary information flows for the calculation of the indicator must be identified. Here two kinds of data are identified. On the one hand, primary data which are data related to the information obtained from the monitoring systems. On the other hand, the secondary data which are related to the information obtained from external databases. Finally, the frequency of calculation must be specified, as well as it should be identified whether a preliminary indicator is needed to quantify it, and the subsequent indicators.

Table 1. Indicator description template

{name of the indicator}		{tier}	{indicator code}
1 GENERAL DESCRIPTION			
VARIABLE	{to specify which variable measures the chosen indicator: • ENVIRONMENTAL • SOCIAL • ECONOMIC • TECHNICAL}		
STAGE	{to specify which stage of the waste management the indicator: • GENERATION • COLLECTION • TREATMENT • GLOBAL}		
TYPE	{to specify whether it is the DIRECT or INDIRECT indicator}		
2 CALCULATION METHODOLOGY			
DEFINITION	{detailed description of the indicator}		
STANDARDIZED METHODOLOGY	{to indicate whether the indicator comes from a standardized methodology and specify which methodology is}		
FORMULA	{to indicate the formula whereby the indicator is calculated and a detailed description of the necessary variables and data for its calculation}		
UNIT OF MEASURE	{unit of measure of the indicator}		
CALCULATION PROCEDURE	{to describe necessary information flows for the calculation of the indicator identifying for the primary data • Information source • Alternative source • Measurement location And for the secondary data • Reference source • Alternative sources}		
ACCOUNTING PERIODICITY	{To indicate the frequency of calculation of the chosen indicator: daily-monthly-yearly}		
3 OBSERVATIONS			
PRELIMINARY INDICATORS	{To indicate the required preliminary indicators to calculate the chosen indicator}	*SUBSEQUENT INDICATORS*	{To specify indicators where the chosen indicator is used}
{To specify any NOTES regarding the chosen indicator}			

3. Case study

WESTE methodology is applied to holistically assess the sustainability degree of the waste management strategies implemented in the municipalities of Cascais (Portugal), Halandri (Greece), Seveso (Italy) and Zamudio (Basque Country) (Fig 4).

Zamudio (3200 inhabitants, Basque Country) is characterised by a big enterprise ecosystem with a highly disperse population. It has a four bins collection system for the separate collection of lightweight packaging, paper and cardboard, glass and biowaste, and another one for the residual waste which resulted in a 14% sorting rate in 2016.

Halandri (70000 inhabitants, Greece) is considered the largest suburban city of the capital of Athens with a wide range of business activities. The current collection system comprises a two-bin system collecting 5,000 tons/year of all recyclables in a blue bin and the rest is collected as commingled waste in a green bin, being nearly all send to Athens landfill. Currently, there are 4,500 green and 1,200 blue containers. This system results in a 11% of sorting rate in 2016.

Fig 4. Pilots sites within the Waste4Think project

Seveso (22000 inhabitants, Italy) is a town and municipality located in the Lombardia region. The municipality has a door to door collection of not recyclable waste, food waste, paper and cardboard, glass and lightweight packaging with different timetables. Additionally, Seveso has implemented a RFID residual waste collection system in bags with an electronic tag in order to identify each user, which allowed reaching 70% recycling rate.

Cascais (206479 inhabitants, Portugal) is one of the richest municipalities with a very touristic area. The collection is organised in residual waste, Recycled, gardening and bulky waste. All the bins are equipped with RFID transponders and the underground containers are equipped with bin level sensors. These data are integrated in an optimization software. This system results in a 11% of sorting rate in 2016.

4. Results and discussion

The main objective of the municipalities is to move forward the current waste management practices into a circular economy for which a set of specific objectives have been defined:

- O.1: Reduction of the 8% the municipal waste generation
- O.2: To eliminate the primary waste deposited into landfills and to maximize waste reuse and recycling increasing an average of the 20% of the waste sorted
- O.3: To promote the long term behavioural changes of waste generators
- O.4: To improve the integral waste management service reducing the GHG (10%) and service cost (10%)

The translation of these objectives and their classification into the indicator tree is depicted in Fig 5. Purple boxes are the main objectives of the pilot sites. Pink boxes are high-level indicators while green boxes are the intermediate indicators. Finally, blue boxes are the low-level indicators. Additionally, there are two main data flow used in different indicators. On the one hand, the amount of waste collected (T1.2) which is referred with a red line. And on the other hand, the primary waste destination (T.3.5) specified with a green line. These two indicators are the cornerstone of the final results.

As a result, 12 high level indicators have been defined and more than 50 intermediate and low-level indicators (Table 2). 70% of the indicators are technical indicators describing the performance of the system such as the amount of waste collected or the kilometres done per route. Social indicator accounts the 14% of them describing mainly the behaviour of the citizens. Environmental and economic indicators account for the 16% of indicators describing the impact and cost of the system.

Table 2. Classification of the indicator set of Waste4Think project

Indicator type	Quantity	Environmental	Social	Technical	Economic	Tier 1	Tier 2	Tier 3	Tier 4
High-level indicators	12	1	6	4	1	6	4	1	1
Intermediate-level indicators	26	3		20	3		19	4	3
Low-level indicators	33		4	26	3	33			
Total	**71**	**4**	**10**	**50**	**7**	**39**	**23**	**5**	**4**

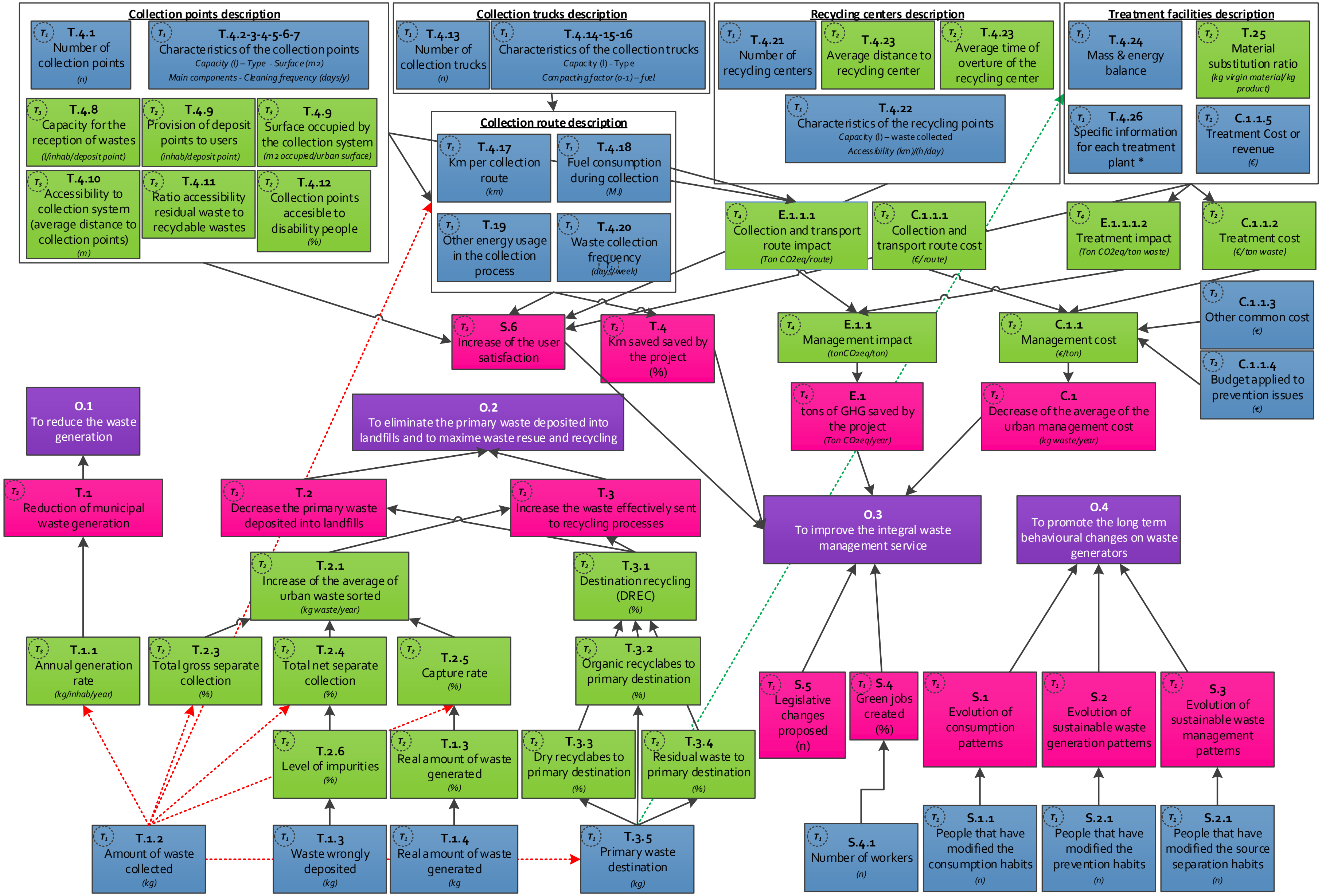

Fig 5. Indicator tree within Waste4Think context

Concerning the hierarchical system, it could be see that the 55% of the indicators belong to Tier 1, meaning that the row data use in the quantification of the sustainability degree of the system is higher than its transformation. The indicators modified to express the relative effect accounts for the 32%, that is Tier 2. Indicators using external information sources is just the 13%. As mentioned earlier, the higher the tier the higher the probability of having uncertainty among the results.

5. Conclusion

When seeking for comparison among different systems it is not straightforward setting the comparison framework. Within the objectives of W4T project it is the transferability to the market of the different eco-solutions proposed as well as the promotion of the best practices in waste management. Thus, it is necessary to set a clear framework in which the quantification procedure for the different specific objectives is defined.

In this work, the bottom-up WESTE methodology has been proposed. Firstly, the goal sought by the UWMS are defined. Secondly, at least one quantitative or qualitative high-level indicator is defined per goal. Subsequently, a, indicator tree is weaved until low-level indicators are found, that is row data gathered directly from the system either from sensors or by direct contact with the management staff.

As a result, 71 environmental, social, technical and economic indicators have been defined to quantify the sustainability degree of the UWMS among W4T pilot sites. Each indicator is defined according to a description template in which the main features and procedure are set.

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