wasteless

Waste Quantification Solutions to Limit Environmental Stress

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Executive Summary

Our project, Waste Quantification Solutions to Limit Environmental Stress (WASTELESS), aims to develop and test innovative tools and methodologies for measuring and monitoring food loss and waste (FLW). A key objective is to create a decision support toolbox that helps food actors across the entire supply chain, including consumers, select the most suitable method for measuring and monitoring FLW. To achieve this, the first step is to classify FLW measurement tools and identify their characteristics. This is the aim of the present deliverable.

We begin by reviewing related work on FLW measurement and describing prominent methods and practices, along with their characteristics. We also provide examples of specific practices that employ particular methods. Additionally, we describe FLW measurement tools being developed as part of WASTELESS, including three already settled tools that can be put into the broader context of FLW measurement methods. Finally, we outline the process for developing a full-fledged decision support model based on structured descriptions of FLW methods, practices, and tools.

To achieve this, a two-way approach will be used, where FLW measurement methods are taken as a starting point to derive more specific practices and tools, which are then classified according to their attributes. Conversely, specific tools or practices will be analysed to determine the method(s) they are an instance of. This approach provides users with practical descriptions of FLW measurement methods, suggesting particular tools, and making the toolbox extendable and open to new practices and tools that can be easily integrated using a structured description and decision model. The plan is to finalize an ontological representation of FLW measurement methods, practices, and tools in cooperation with other work packages and bring them together in a decision support toolbox.

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List of Acronyms

Abbreviation / acronym	Description
D	Deliverable
DEX	Decision expert (method)
FAO	Food and Agriculture Organization of the United Nations
FLW	Food loss and waste
FSC	Food supply chain
HoReCa	Hotels, restaurants, and cafés
ISIC	International Standard Industrial Classifications of All Economic Activities
NACE	Statistical Classification of Economic Activities
NUTS	Nomenclature of Territorial Units for Statistics
Q	Question
VFG	Vegetable, fruit, and garden
WP	Work Package
WRAP	Waste and Resources Action Programme

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1. Introduction

Our project *Waste Quantification Solutions to Limit Environmental Stress* (WASTELESS; https://wastelesseu.com/) is designed to develop and test a mix of innovative tools and methodologies for food loss and waste (FLW) measurement and monitoring. One of the tasks of Work Package (WP) 6, Task 6.2, aims to create a decision support toolbox. It should help all profiles of food actors, i.e. across the whole food supply chain (FSC) including consumers, who want to measure and monitor their FLW to select the most appropriate method. As a prerequisite of building such a system, tools for measuring FLW first need to be classified and the characteristics that determine their relevance identified. In the early phase of this task, this deliverable, D6.2, is a collection of FLW measurement methods and particular practices and their characteristics.

We first review related work on this topic in Sections 1.1 and 1.2, and describe the most prominent methods of FLW measurement and monitoring in Section 2. We then extract the characteristics that will determine the process of deciding which one to use in Section 2.11. We also give examples of three specific practices that employ a particular method for methods in Sections 2.1, 2.4, and 2.7. They have been previously identified in our Deliverable 1.1 (Qian et al., 2023) and we refer the reader back to it for a broader discussion of these FLW measurement practices.

In Section 3, we then describe FLW measurement tools that are being developed in WASTELESS as a part of WP2. We briefly describe three tools that are already developed at the time and place them in the context of the more general methods covered in Section 2.

Finally, we operationalize the process for going from structured description of FLW methods, practices, and tools towards a full-fledged decision support model in Section 4.

1.1. Related standards

There have been several attempts to harmonize FLW measurement methods. The *Food loss and waste accounting and reporting standard* (FLW standard; Hanson et al., 2016a) stands out as a good structured attempt. It was produced by the Food Loss & Waste Protocol, a multi-stakeholder partnership with the cooperation of Food and Agriculture Organization of the United Nations (FAO) and World Resources Institute among others.

The FLW standard establishes the scope of an FLW inventory. It requires definitions of:

- timeframe: start and end date of measurement,
- material type: either food only, inedible parts only, or food and associated inedible parts,
- destination: where FLW ends up,
- boundary: food category, lifecycle stage, geography, and organization,
- related issues: packaging material, water added or removed from FLW, pre-harvest losses.

Furthermore, it provides definitions of boundary elements and recommendations for classifications that should be used to describe them. For classifying food into categories, it suggests the FAO's and World Health Organization's Codex General Standard for Food Additives (Food and Agriculture Organization of the United Nations & World Health Organization, 2019). We might add that alternatively, Annex II might also be used. For lifecycle stage, the International Standard Industrial Classifications of All Economic Activities (ISIC) should be used or Statistical Classification of Economic Activities (NACE) (European Parliament & Council of the European Union, 2006), in the case of Europe. Finally, for geographical boundary classification UN region or country codes should be used or Nomenclature of Territorial Units for Statistics (NUTS) (European Parliament & Council of the European Union, 2003) in the case of the European context.

1.2. Related tools

The FLW standard also provides guidelines on how to decide which quantification method to use for FLW measurement or monitoring. The *FLW Quantification method ranking tool* was prepared by the Waste and Resources Action Programme (WRAP) and includes eleven questions.

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Most of the questions (Q) serve as exclusion criteria. For example, a negative response to either "Do you have existing records that could be used for quantifying FLW?" (Q9) or "Do you have access to those records?" (Q10) excludes the method of records (see Section 2.5). As another example, a negative response to "Can you get direct access to the FLW being quantified" (Q3) immediately excludes direct weighing, counting, assessing volume, and waste composition analysis (see Sections 2.1, 2.2, 2,4, and 2.4), since these all need such access to be feasible.

The answers to other, more general questions are quantified on a scale from 0–1. For example, the question "How important is it to have a low level of uncertainty?" (Q1) has three possible answers: "very important", "important", and "I don't know". The accurate methods, such as direct weighing, get a score of 1 for any answer. Less accurate methods get a lower score: for example, since surveys are not a very accurate method (see Section 2.7), they get 0.25 if the answer to the question was "very important", 0.5 if the answer was "moderately important", and 1 if the user answered "don't know".

Once the methods are scored according to user's answers to individual questions, the final score is the multiplication of all individual items' scores. This has the effect of excluding methods that were scored 0 on any question since this means the method is inappropriate for the user's use case. Furthermore, multiplying fractional quantities quickly diminishes the total score of a method, so that it gets ranked lower. Only methods that perfectly fit all of the user's answers would have a final score of 1 and would be ranked the highest.

2. Methods for measuring and monitoring of food waste and loss

This section follows the outline of methods as provided in the *Food loss and waste accounting and reporting standard* by Hanson et al. (2016a), specifically in the *Guidance on FLW quantification methods* (Hanson et al., 2016b), which is a supplement to the standard. It describes ten methods of FLW measurement and monitoring, some of which are direct measures while others are approximations or inferences.

Direct weighing, counting, and assessing volume are the most direct methods of measuring FLW since they deal with FLW material directly. They can be enhanced by waste composition analysis which takes measurement a step forward by considering specific components of FLW. Where direct access to FLW is not possible, the data can still be collected either by asking about it in surveys or diaries or by leveraging the data collected for other purposes if access to them is provided. When even indirect data based on measurement or approximation are not available, it might still be possible to calculate FLW. Three methods are inferential in their nature in that they calculate FLW by considering other types of data that can shed light on FLW: mass balance, modelling, and proxy data.

The methods described differ in their costs, either expertise, work, or equipment costs, their accuracy, and the FSC stage they can be applied to. Some are also better suited for specific types of food: assessing volume, for example, is best done when dealing with liquid FLW.

2.1. Direct weighing

Possibly the most direct method of measuring FLW is weighing of the actual waste. Assuming a good sampling strategy, this method is very accurate and requires no special expertise. The most important drawback of this method is its cost since sufficient weighing equipment needs to be purchased, possibly for multiple measurement sites. To reduce cost, only a sample of the whole FLW generated is usually weighed and the total FLW is then inferred analytically.

This method can be used across the whole food supply chain and throughout all lifecycle stages. A special case of weighing across a food supply chain is *load tracking* where the same product is weighed at several points of processing so that it is possible to pinpoint sources of FLW (for an example, see Box 1.3 in Hanson et al., 2016b; p. 9).

One of the practices of weighing identified in D1.1 was a "Smart Scale System" (Qian et al., 2023, p. 67). Hotels, restaurants, and cafés (HoReCa) employed weighing using a smart scale. In addition to providing a measurement, it also generated analytics and reports automatically so that the users could track their FLW for each specific food commodity.

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2.2. Counting

Counting can be considered an approximate method of weighing. It involves counting the items of known weight, either manually, by scanning, or by using visual scales. When the product is packaged with low deviation from the stated net weight, it is a very straightforward and accurate method. Accuracy decreases when using it with "loose products" such as grain. In this case, the number of items can be converted to weight loss using approximate conversion factors.

Hanson et al. (2016b) include scanning and using visual scales under this category, in addition to basic counting. Scanning bar codes can significantly reduce the work required when counting products in standard packaging. At the other end, when only a part of the smallest unit is considered wasted or lost such as with insect damage of (individual) grains, visual scales can be helpful. These are reference photographs that show different degrees of damage to the grain. By visually comparing these photographs to actual product, FLW due to damage can be estimated.

While basic counting and scanning do not require any expertise, visual scales need to be developed by agricultural experts and raters using them need to be trained. Still, this is an inexpensive method. It is appropriate for foods that have a clearly defined unit and cannot be used for mixed waste either composed of different food products or mixed with non-FLW waste. It could, in principle, be used at any stage of FSC, but is mostly appropriate for farming, manufacture, processing, and transportation and storage, rather than in households since these rarely produce FLW with clearly defined units.

2.3. Assessing volume

The second method to approximate weight is volume assessment. It is typically used for liquid FLW, but can also be applied to solid and semi-solid material. Volume can be converted to weight when multiplied by density, but sometimes this is done using "bulk density", which is an average density for several mixed components. Accuracy of this method is therefore variable as well as its cost; if volume assessment is done in a laboratory such as with chemical oxygen demand (see below), it can quickly become costly because of requiring specialized equipment and high expertise.

Assessing volume can be done with five basic approaches:

- pre-calibrated containers or measuring jugs are especially well-suited for household use,
- measuring dimensions of containers of FLW material, particularly efficient in transport where containers are already used and well packed,
- visual assessment, when containers are only partially full,
- water displacement technique,
- flow meter, where FLW is disposed of through pipes, such as into sewage.

A special case of assessing volume in liquid waste streams is chemical oxygen demand technique which can be used when FLW is mixed with waste water. This measures how much chemical oxidant is needed to oxidize an organic compound and compares the value to known values of typical FLW materials such as milk. The volume of waste product in the mixture can then be estimated.

2.4. Waste composition analysis

Waste composition analysis refers to physically separating components of FLW which are then weighed and might also be categorized. It therefore shares its high accuracy with direct weighing but is much costlier in comparison. It is mostly used by governments or other large agencies which are not producers of FLW themselves but have other interests for its measurement. It requires high level of expertise and a great deal of organization since it must be done before FLW degrades. When used correctly, however, it can produce very precise measurements accounting separately for packaging and producing categorizations which are as detailed as desired.

Since sampling is almost unavoidable with this method, analysis of data collected requires statistics expertise. It is important to take into account collection-related context (e.g., how often the waste is collected), special

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periods such as holidays or festivals, and socio-demographic variables such as household size or economic sector. The scope of the sampling method is also an important consideration: whether sampling individual units (e.g., households), a small area (e.g., a street), or bulk sampling (i.e., in a collection vehicle).

Additionally, collection of FLW samples needs to follow health and safety procedures and might require specialized equipment. Local legislation should also be consulted as it might not be legal to sort through someone's waste without their informed consent. Furthermore, the process of actually obtaining samples of FLW might also be very complex. For example, waste management company needs to be contacted, a sorting centre set up, delivery vehicles rented etc. Finally, actually sorting the samples is also challenging. There need to be clear categories defined and some FLW is virtually impossible to classify (e.g., whole meals).

One of the practices of waste composition analysis identified in D1.1 was a "Supplementary memorandum Food waste in Dutch households in 2016" (Qian et al., 2023, p. 72). CREM, a waste management company collected residual waste and vegetable, fruit, and garden (VFG) waste from 13 municipalities, sampling 10 households from each one. They sorted waste manually on a table at a central location and differentiated between 16 categories of food waste and 7 categories of unavoidable food losses.

2.5. Records

Sometimes FLW can be measured by leveraging existing data that have been collected for other purposes. As an example, if a food processing company needs to pay for their waste removal by weight, their waste transfer receipts could be analysed to determine their FLW. Even though this data might have served another purpose (as a confirmation of payment in the previous example), they can still be useful for measuring or at least estimating FLW. This makes the method cheap apart from possible data analysis costs. It also requires no particular expertise and could be used throughout FSC, but such data is rarely available for households.

The main drawback of this method is that it may not always be clear how the original data have been obtained. It might also mean that the entity providing the data might not be the same one that FLW data pertain to.

2.6. Diaries

Diaries rely on reports of participants regarding their FLW. They are not an independent measurement method since they need to be combined with a way to estimate FLW such as direct weighing, volume measurement, or another type of approximation. They are most often used in households and commercial kitchens.

Diaries require social and market research expertise to be developed and the diarists themselves need to be briefed, helped, and kept motivated. As such this method is usually expensive. However, the data can be collected in real time and as such do not suffer from recall bias (as compared to surveys described below). They can also include types of FLW that would otherwise be missed such as food fed to pets that some people might not consider FLW. On the other hand, data can be inaccurate because of social desirability of respondents.

2.7. Surveys

Surveys can be compared to diaries in the sense that they can be used to approximate FLW and measure participants' perceptions of FLW and can also include additional data such as reasons for and attitudes towards FLW. They are much cheaper, but suffer from recall bias and usually only include one respondent per household. They also require high level of expertise both for their development and administration.

They are also prone to misunderstandings of concepts mentioned in the survey. This can be overcome to some extent by face to face interviews but the cost increases rapidly in this case.

One of the practices of weighing identified in D1.1 was "Analysing household food waste in the Maltese islands" (Qian et al., 2023, p. 72) in which 212 households provided data on the volume and type of food waste disposed per week.

2.8. Mass balance

Mass-balance method includes measuring inputs such as ingredients in a factory and outputs such as products made while keeping track of changes during processing like water evaporation. By calculating differences

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between outputs and inputs while accounting for stock (i.e., food still on the shelves), we can infer FLW. This method is also called material flow analysis or substance flow.

The method is very versatile and can be applied at various levels of analysis (e.g., ingredients, products). It is well established and standardized with specialized software developed for this purpose. It is most often employed by national and international agencies such as the US Department of agriculture and FAO. While simple in essence, it requires careful consideration of non-FLW outputs such as donations, weight changes due to evaporation, drying, and cooking, and changes in stock levels including due to other flows such as theft. This can increase its cost and introduce uncertainties.

2.9. Modelling

We can also try to infer FLW by considering factors that directly and indirectly affect FLW. In building predictive models, we might be able to use scientific literature, local data, and agricultural and marketing practices. This is a method that has a relatively low cost of admission, but it requires high level of expertise to develop the models. The most important challenge is the access to high quality data to train and validate the models.

We can use indirect data such as national economic and trade data to estimate FLW or model specific processes. For example, a model simulating discrete events in milk deterioration was used to infer FLW in households (Quested, 2013). The authors explored different factors at the stages of purchases (e.g., how much milk was bought, what its shelf life was at the time of purchase), storage (e.g., how often milk stocks were monitored by checking the fridge), and consumption (e.g., purposefully using up milk approaching its use-by date, the way milk is consumed). They related these factors to predict FLW of milk and make suggestions on how to reduce it.

Regardless of how they were built, the models should be critically evaluated, first by theoretical considerations of the variables included in the model and second, if possible, validated by real-world measurements.

2.10. Proxy data

When all else fails, we can always try to infer FLW from data collected elsewhere, either in a different geographical area, different time frame or another sector. This has significantly lower cost than any other method but results are less accurate and should only be used for approximate measurement and not for monitoring FLW reduction targets. While not much skills are required for this method, the analysts should nevertheless have basic familiarity with the data so that the relevance of the scenario can be evaluated.

2.11. Summary

Following the FLW standard, we described the methods above according to the lifecycle stage they can be used with, their accuracy, and their cost (see Table 1). These three dimensions can help us decide which method is the most appropriate for a given scenario.

Note, however, that these are not the only decisive factors. Some methods are only applicable when specific conditions are met, that is, they have some exclusion criteria. For example, when direct access to the FLW being quantified cannot be obtained, none of the direct methods of FLW measurement can be used: direct weighing, counting, assessing volume, and waste composition analysis are impossible to do in this case. Previously mentioned Quantification method ranking tool takes these constraints into account by assigning 0 to the method when an exclusion criterion is fulfilled. Since the final score for the method is the product of all subscores, this puts such a method at the very end of the list.

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Table 1

Methods for FLW measurement and their related cost, accuracy, and life cycle stage (a stage in the food supply chain, FSC) relevance.

Method	FSC stage	Accuracy	Cost
Direct weighing	any	high	medium
Counting	not households	medium or high	low
Assessing volume	any	medium or high	low or medium
Waste composition analysis	any	high	high
Records	not households	medium	low
Diaries	households, restaurants	medium	high
Surveys	any	low	low or medium
Mass balance	any	medium	low or medium
Modelling	any	medium	low
Proxy data	any	low	low

3. Digital tools and methodologies from Work package 2

In WASTELESS' WP2, a set of digital tools and methodologies for measurement and monitoring of FLW are being developed. These are innovative solutions not yet captured in the list of the previous section. They do, however, include elements of various other measurement methods.

In Task 2.2, a computer vision-based image analysis system is being developed. This system can be integrated into a smart fridge and takes photographs of food stored in it. Changes in colour of fruit and vegetables or meat can be related to the process of their degradation. This method can be used in households or meat processing plants.

This method is related to visual assessment which was mentioned under Counting in Section 2.2 where comparison of grain to reference photographs was used to estimate food loss due to insect damage. The system that Task 2.2 is developing, however, differs from this importantly since it aims to be an automatic method. While counting often uses visual scales to guide the estimation, machine-learning models are used in the computer vision-based system to predict the degradation of food. Provided a good training dataset, this can make for a more accurate method which could provide data in real time and continuously.

In Task 2.4, a surplus measurement and management tool is being developed. This is a clear example of using existing records that retailers use to manage their stock for FLW measurement. It also implements the mass balance method since it allows for tracking inputs, outputs, and (unwasted) stock. This particular method is aimed at retailers, that is actors in the "Accommodation and food service activities".

Task 2.5 aims to develop an automatic system for FLW assessment in households. It includes a digital weighing scale and a phone holder that can take a photograph of the food weighed. It therefore employs direct weighing as a measurement method, enhanced with an image-based diary. Since it also asks the user to categorise the waste sample, it can also be seen as a type of waste composition analysis method.

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4. Outline of a decision support system

We can suggest which method of FLW measurement is the most appropriate based on their characteristics described in previous sections. To use such a system a user would answer a series of questions and then get a list of measurement methods ranked by their relevance. This system needs to consider both characteristics described in Table 1 as well as exclusion criteria mentioned in Section 1. It could suggest any of the method from Section 2 as well as those developed in WASTELESS, three of which were mentioned in Section 3.

Figure 1 illustrates an example of decision that is guided by answers to some of the possible questions. This is a user-centric view that refers to the user experience of using such a system.

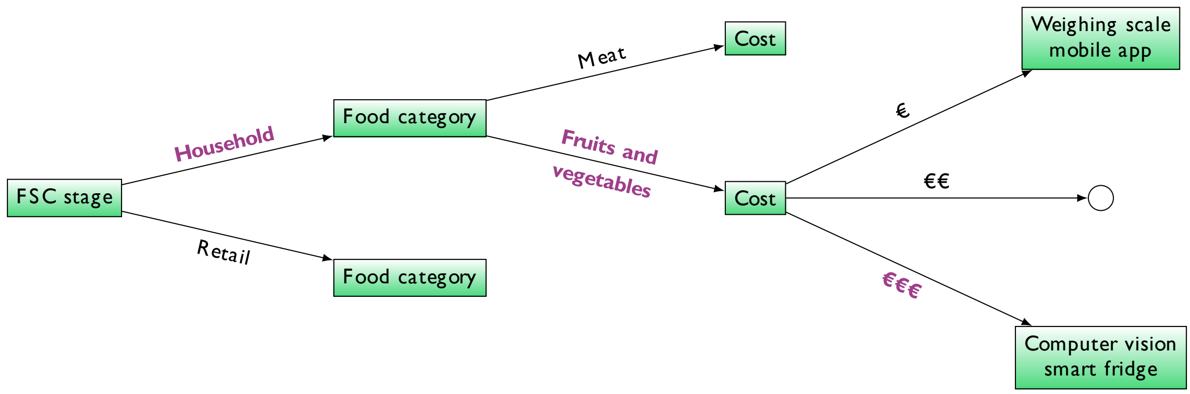

Figure 1

An illustration of decision support. A household might want to measure FLW of fruits and vegetables with sufficient funding available to suggest a computer vision-based image analysis system.

4.1. Structured descriptions of methods

To build a decision support system, we need a computer-readable representation of methods presented in Table 1 or practices presented in Section 3 and related information. For example, we can describe each FLW method or practice in terms of the FSC stage and food category it is applicable to, its accuracy and its cost. We present such an example for one practice in Table 2.

Table 2

A structured description of a particular FLW measurement practice.

		Computer vision-enabled smart fridge
FSC stage (NACE)	Most suitable	Activities of households for own use (U98)
	Conditionally suitable	Retail sale of meat and meat products (G47.22)
		Food and beverage service activities (I56)
Food category		Fruit and vegetables; meat
Accuracy		High
Cost	Equipment	High
	Work or upkeep	Low
	Expertise	Medium

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One way of systematically representing such data is with an ontology, for example using the Web Ontology Language. We already mentioned some classifications in Section 1.1 which can easily be transformed into ontologies. There also exist ontologies that are specific to food waste, such as the FoodWasteEXplorer (Stojanov et al., 2019).

We are also exploring an automatic way of creating an ontology, specifically applicable to FLW measurement and monitoring methods. One of avenues to explore is the recently presented relation extraction model called Multilingual relation extraction by end-to-end language generation (mREBEL; Cabot et al., 2023). It works by finding triplets such as "Primary production is an *instance of* Economic Sector", "Agriculture is a *part of* Primary production", "Food industry is a *part of* Economic sector", "Food is a *product or material produced* of Food industry", and "Meat is a *subclass of* Food". These triplets work both with the text provided (e.g., the FLW standard) and Wikipedia pages and Wikidata. In this way, we might be able to find relations between different, seemingly unrelated classifications or ontologies.

4.2. Decision support model

To be able to help a user decide which FLW measurement method is the most appropriate for their scenario, we need relate the methods' or practices' descriptions such as the one in Table 2 to the user specified criteria represented in Figure 1. One way of doing this is using the Decision expert method (DEX) (Bohanec, 2022). With this method, we first define attributes which are important for decision process and their scales. These attributes can also be hierarchical and we can represent them as a tree.

Figure 2 shows how a method's attributes can be scored in relation to user's preferences. For example, if the user indicated they want a method for to be used at an FSC stage which was previously indicated as the most suitable (see Table 3), this would indicate a "Perfect match" for this attribute.

Table 3

An illustrative decision table which shows how we can arrive from decision factor values to the final method's suitability assessment. For simplicity, we only show combinations of two factors: accuracy and FSC stage. In general, we need combinations of all possible values of decision factors.

FSC stage	Accuracy	Method's suitability
Perfect match	Higher than OR equal as desired	High
Perfect OR acceptable match	Higher than desired	High
Acceptable match	As desired	Medium
Not applicable	ANY	Unsuitable
ANY	Lower than desired	Unsuitable

Finally, once we know all of the values of decision factors, we can arrive at the final grade of method suitability. In a DEX model, we need decision tables for this, such as the one illustrated in Table 3. These encode expert knowledge about relationships between various decision factors to guide the decision-making process.

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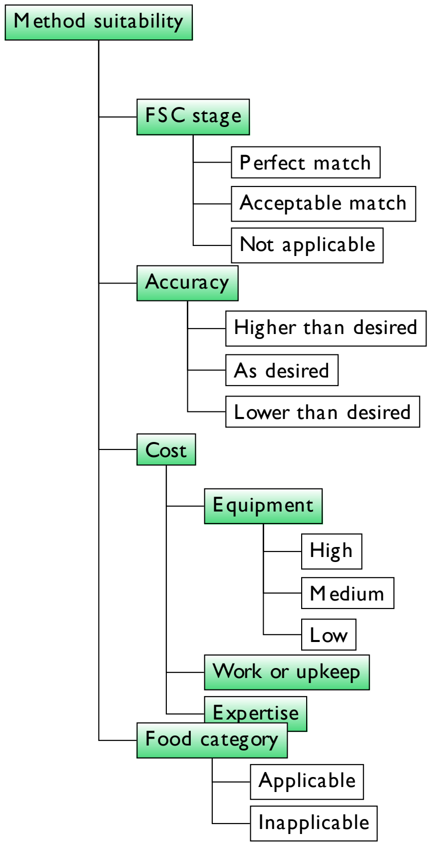
5. Conclusions

In Task 6.2 of WP6, we are aiming to create a decision support toolbox that can also be updated with descriptions of FLW measurement tools and practices. The first step of the subtask 6.2.1 has been presented in this deliverable.

Figure 16



A DEX model structure to represent a match between an FLW measurement method and user's preferences. The decision factors are shown in green and their possible values on white background. For cost, only the equipment cost's possible values are shown with the other two categories of expenses sharing the same scale.

We can take the list of FLW measurement methods presented in Section 2 as a starting point, from which we can derive more specific FLW measurement practices and tools and classify them according to their attributes such as illustrated in Tables 1 and 2. From the other end, we can build bottom up, starting from a specific tool or a FLW measurement practice and determine which method(s) it is an instance of.

This two-way approach serves two purposes. On one hand, instead of just suggesting the user a very general method of FLW measurement or monitoring, we can give them several descriptions of practical use of these methods. When they exist, we might even be able to suggest particular tools and further empower the user to be able to start FLW measurement. On the other hand, the toolbox becomes extendable and open with this approach. To further enrich the decision support system with new practices and tools as they are identified in the literature or developed elsewhere, we simply need to assess them according to criteria such as the ones presented in Table 2. Once we have such a structured description, we can employ the same decision model, such as the one illustrated in Figure 2, without much modification of the tool.

Our plan is therefore to finalize an ontological representation of FLW measurement methods, practices, and tools in cooperation with WPs 2, 3, and 4, as well as actions for FLW reduction from WP6, and bring them together in a decision support toolbox.

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