SMALLDERS PROJECT

SMART **M**ODELS FOR **A**GRIFOOD **L**OCAL VA**L**UE CHAIN BASED ON **D**IGITAL TECHNOLOGIES FOR **E**NABLING COVID-19 **R**ESILIENCE AND **S**USTAINABILITY

D6.2

Identification of multi-capitals based mathematical models

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List of Abbreviation

AFSC	Agri-Food Supply chain
CI	Composite indicator or index
BoD	Benefit of the Doubt
DEA	Data Envelopment Analysis
MCDM	Multi-criteria decision making
SI	sustainability index
SMART	Simple Multi - Attribute Rating Technique
S-M-A-R-T	specific, measurable, achievable, realistic and timely

EXECUTIVE SUMMARY

This document is a deliverable of the SMALLDERS project, funded under PRIMA which is the European Union program for Research and Innovation solutions in the Mediterranean region.

This document refers to task 6.2 of WP6 of the SMALLDERS project, which is entitled "Identification of Multi-capitals". The purpose of this task is the selection of capitals that apply to the scenarios defined in the previous deliverable. Indeed, the theoretical analysis carried out in task 6.1 and presented in deliverable D6.1 helped in identifying all the capitals that can be involved in the sustainability scenario thus already defined. In fact, for each sustainability dimension, different capitals must be considered. Also, per sustainability capitals, a set of indicators must be identified. This deliverable aims at i) selecting sustainability capitals and indicators per capital and ii)defining the calculation approaches and mathematical models for them in order to assess the multi-capital sustainability of Smallholders and the other Agri-Food Supply Chain (AFSC) actors for four scenarios defined in the previous deliverable D6.1.

1. Introduction

Sustainability is a multi-dimensional concept including the environmental, economic and social dimensions. Furthermore, each dimension encompasses one or several capitals. Capitals are themselves composed of a set of indicators. The assessment of sustainability begins with selecting capitals and individual indicators per capital, calculating the individual indicators within each capital. Based on the indicators' values, capitals and dimensions could be assessed. Two questions arise in this regard:

- Q1: considering a specific sustainability scenario (as defined in deliverable D6.1), what are the sustainability capitals and indicators to retain for each AFSC actor, how could they be selected?
- Q2: what are the methods, steps, and concepts to be applied for sustainability assessment while accounting for the multi-capital and multi-dimensional aspects?

The aim of this deliverable D6.2 is to answer these questions while considering the defined sustainability scenario. Moreover, the purpose is to identify the appropriate mathematical model that allows us to effectively evaluate the multi-capital sustainability defined to design the dashboard layer of the SMALLDERS platform. As sustainability is divided into three dimensions, each one of them comprises a subset of single indicators, multiple aggregations are to be conducted: for example, aggregating groups of indicators into aggregate values of capitals, then aggregating those values into higher-level aggregates i.e., dimensions, until the final sustainability index value (Mazziotta and Pareto, 2013). Given that a composite indicator (CI) is formed when individual indicators are compiled into a single index on the basis of an underlying model, there is a consensus in literature on its use for the construction of sustainability indexes as well as dimensions and capitals indexes (Nardo et al., 2005; Mazziotta and Pareto, 2013). Based on the literature of sustainability indexes and CI constructions, a global methodology and mathematical models will be developed in this deliverable. The global methodology will be presented in section 2, then each step within the methodology will be detailed in subsections 2.1 to 2.4. In Particular, the selection approach of capitals and indicators for each AFSC actor will be described and also the Tunisian testbed in subsection 2.1 and 2.2. Subsection 2.4 focuses on the choice of appropriate calculation approaches. Finally in section 3, the proposed mathematical approach to compute the sustainability capitals for the dashboard layer will be provided and explained.

2. Global methodology of multi-capital sustainability assessment for SMALLDERS's dashboard layer

The idea behind sustainability assessment method, is that sustainability measurement is considered as a composite indicator or index (CI) which is an aggregation of individual indicators with a defined/determined participation or ponderation (Mazziotta and Pareto, 2013). In SMALLDERS project, a multi-capital approach is adopted for sustainability which is already defined on the basis of three pillars: environmental, economic and social. To assess the sustainability of an AFSC actor, a sustainability index (SI) could be calculated as a CI where the indicators are the dimensions indexes. In the same way, a dimension index is a CI where indicators are capitals 'index. A capital's index can be defined as a CI itself.

A global methodology for sustainability evaluation is defined and illustrated in Figure 1. This methodology was defined based on several research papers on composite indicators applied to sustainability indicators (Gómez-Limón and Sanchez-Fernandez, 2010; Escrig-Olmedo et al., 2017; Dasgupta et al. 2021, etc). As can be seen, 5 steps were identified. First, a final list of capitals and indicators per AFSC actor should be selected. In this process, deliverables 6.1 and 2.4 are considered respectively as inputs to capitals and indicators selection steps. Then based on defined mathematical models and formulas as well as data collection, indicators' values will be generated for each AFSC actor. A calculation approach following the CI concept is applied to compute the selected sustainability capitals and dimensions. To do so three sub-steps should be applied: data normalization; weighting of the different indicators and their aggregation. The choice of appropriate methods strongly depends on the type of indicators selected by capital and therefore on the type of data to be considered in the mathematical model. Finally, sustainability is assessed based on capitals weighting and aggregation as well. Further details for steps 1, 2, 3 and 4 are provided in the subsections 2.1, 2.2, 2.3 and 2.4 respectively. It is worth noting that this deliverable focuses on the selection of capitals and indicators as well as the definition of the mathematical approach for multi-capital sustainability assessment for each AFSC actor. Hence, only mathematical equations for both the calculation of individual indicator and CI(s) constructions will be provided throughout this deliverable. Especially the mathematical model for SI construction will be developed in section 3. The data as well as calculation results are beyond the scope of this deliverable.

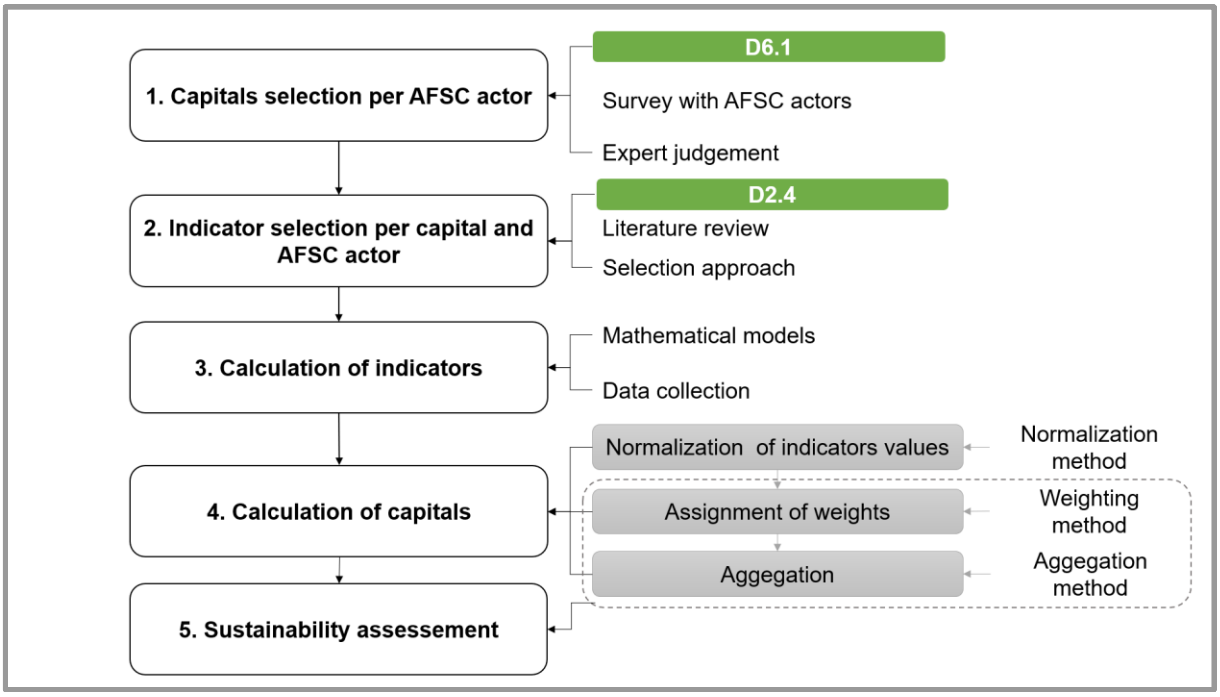

Figure 1 Global methodology for sustainability assessment of the AFSC

2.1. Selection of sustainability capitals

As a multi-capital sustainability approach is adopted in the SMALLDERS project, the first step of the methodology consists of choosing the capitals to consider per AFSC actor. This work was partially addressed in D6.1, however, only smallholders chosen capitals were presented. In this deliverable, the Tunisian scenario is considered as information on the needs and preferences of AFSC actors in terms of capitals. This information was available via expert judgment as well as surveys with AFSC actors. The Tunisian scenario is defined according to the Tunisian test bed which is presented in Table 1 below. The validation of the developed approach will be based on data collection and indicators calculation for this test bed. It is worth noting that similar data were collected via surveys with experts from the partner countries of SMALLDERS (France, Italy and Spain). However, for each of these countries, not all AFSC actors' feedback were available for this deliverable (see D6.1 for more details). For this reason, a literature review for each AFSC was conducted to study the SMALLDERS partners preferences/needs in terms of capitals and indicators. In summary, the final list of capitals for the SMALLDERS sustainability scenario was defined not only based on survey and expert judgment of Tunisian AFSC actors but also considering the state of the art by adding most important capitals addressed in literature for an AFSC actor if it is missing. The final lists of capitals are provided in Figure 2. It shows 8 capitals retained for smallholders, 5 for the transport company, 6 for critical stakeholders, 4 for both citizens and policy-maker.

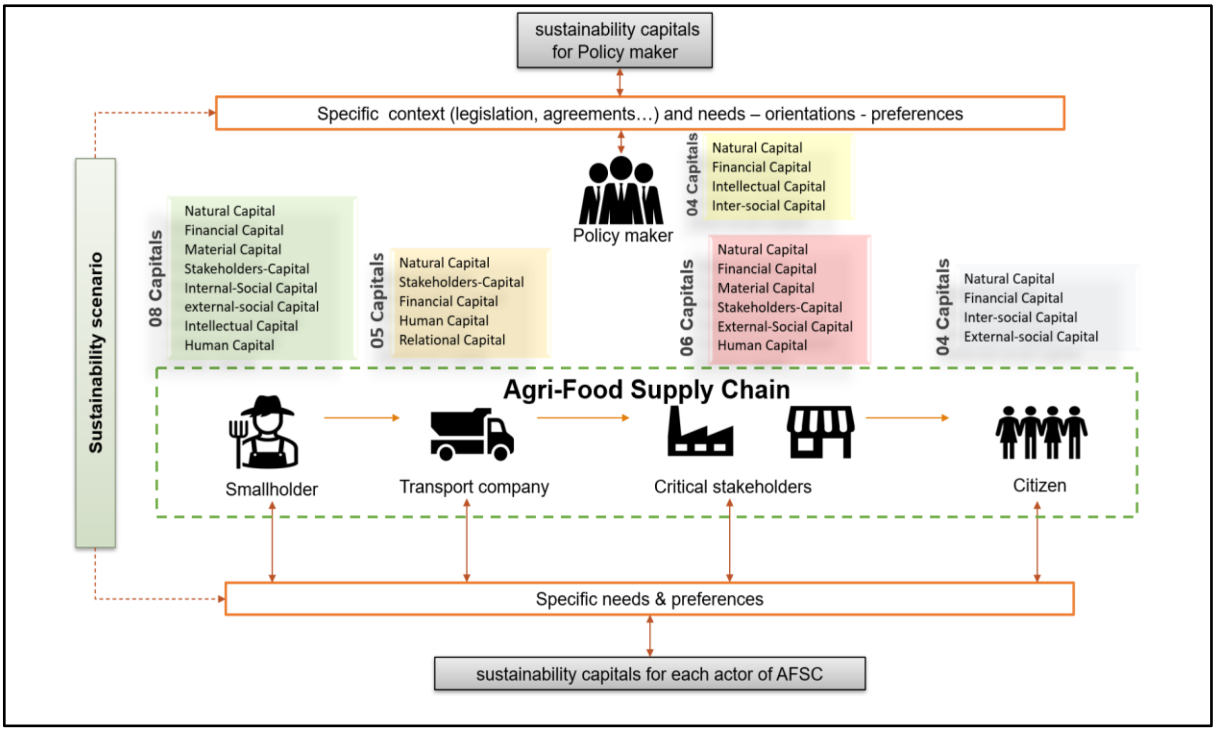

Figure 2 Sustainability capitals for AFSC actors for SMALLDERS platform

Table 1 Tunisian test bed: supply chain actors in the Tunisian scenario

Supply chain actor	***Compagny/institution in Tunisia***	***Logo***
Smallholders	*Smallholder located at El Frenine, Dar Chaaben El Fehri, Nabeul* *Activity: arboriculture (orange and lemon)*	
Critical Stakeholders	***Saveurs du Cap Bon**:* *It is a processing unit for agricultural and forest local products (Honey, peppers, spices, peanuts, dried plants) and their marketing at the level of small, medium and large supermarket*	Saveurs Du Cap Bon C'EST TELLEMENT BON !
Freight Transport Company	*"BIG BOSS" Logistics and Delivery throughout all Tunisia*	BIG BOOS
Policymaker	*CRDA (Ministry of Agriculture, Water Resources and Fisheries)*	

2.2. Selection of sustainability indicators per capital

The selection phase is based on deliverable D2.4 where required, recommended and optional indicators were defined per AFSC actor. Hence most of the required indicators were systematically included. In fact, after the completion of D2.4, several questionnaires were carried out with the AFSC actors about required indicators within each sustainability capital. Based on their feedback as well as predefined criteria, we refined our selection such that most of the required indicators were mainly considered and some were modified according to the need given via surveys carried out with the stakeholders. We notice that optional as well as recommended indicators were also reviewed and were included not only based on the predefined selection criteria, but also considering sustainable development goals. Five criteria were defined based on (Kharrat et al. 2022; Nathan and Reddy, 2011; Mascarenhas et al., 2015) and S-M-A-R-T rule (Selvik et al. 2021) :

- *criterion 1* - Specificity and understandability: simplicity and clarity of the indicator. It must be easy to understand, clear parameters and purpose (what the indicator measures)
- *criterion 2* - Measurability: the quality of being measurable (- quantified) and comparable to other data,
- *criterion 3* - Availability: the data on the indicator's parameters should be collectable and available in the required quality.
- criterion 4 - Relevance: the indicator should be relevant with sustainability concepts and be important for sustainability assessment.
- *criterion 5* - Time-bound: covering a predefined and relevant time period.

It should be also noted that the list retained of indicators was enriched via systematic literature review which aimed to identify the indicators that were used and defined in literature related to AFSC sustainability as well as mathematical approaches applied to calculate them. A data analysis phase was also conducted in order to prevent redundancy in the choice of indicators. Once an exhaustive list was established and classified according to sustainability capitals and AFSC actors. The same selection approach was applied to choose the additional indicators to retain.

2.3. Mathematical models of selected indicators for SMALLDERS' dashboard layer

To conduct this step, mathematical models for calculating indicators were determined and defined based on a review of literature . Then for each AFSC actor,

data needed for calculation will be collected. In this deliverable, only mathematical models are presented.
The final list of indicators per capital and per AFSC actor as well as their mathematical models are presented in Appendices 1-5.

2.4. Identification of mathematical models for sustainability capitals calculation

Assessing each sustainability capital involves several steps from choosing individual indicators, their normalization to their weighting and aggregation. In this section, the focus is on normalization, weighting, and aggregation sub steps. Mazziotta and Pareto (2013) provided some directives and guidelines for the construction of a CI. The choice of the most suitable method (involving all these steps) depends on four main factors: substitutability of indicators, type of normalization, kind of weights of the indicators (subjective /objective) and the complexity of the aggregation method. These factors were taken into consideration in choosing the methods to be applied. In the following subsection, only chosen methods are presented.

2.4.1. Normalization methods

Normalization allows bringing indicators' values onto comparable scales or transforming them into a-dimensional variables so that they can be aggregated. Three main categories of normalization methods could be distinguished: distance, linear transformation and non-linear transformation. Distance (e.g., distance to target, ratio) and Linear transformation (e.g, Z-score or standardization, Min-Max transformation) normalization methods were used and/or recommended by several research papers on CI construction in general and for sustainability assessment specifically (Nardo et al. 2005; Pollesch and Dale, 2016; Mazziotta and Pareto, 2013; Talkuder et al. 2017).
In our case, Linear transformation will be applied. The principle of this category is that the transformation does not change the shape of the distribution, it simply shrinks or expands it, and moves it. The most popular methods include: i) standardization or z-scores (permits only to do 'relative' comparisons (Mazziotta and Rivista, 2013)) which is illustrated by equation (1) and ii) the min-max normalization or re-scaling (rescales the indicator to have a minimum or a maximum value) which is illustrated using equations defined below based on data available for normalization. In fact, 2 cases of normalizations could be distinguished as depicted in Figure 3:

- **Case 1**: only one measurement is available for indicator i (x_i). The normalization of the indicator is conducted considering the other indicators values by applying the min max method (see equation (2)) .
- **Case 2:** T values or measurements are available for indicator i (x_{it}; $t = 1..T$) which is the case of indicators that are directly measured using sensors (e.g., water use). In this case, the normalization of the indicator is realized based on its proper or internal measurements (Pollesch and Dale, 2016). The normalized value of the indicator i (X_i) is calculated by aggregating the normalized measurements of that indicator (X_{it}; $t = 1..T$). One of the common applied aggregation methods in this case is the arithmetic mean method. In this case, both normalization methods (Z-score and Min-max) could be applied (see equations (1) and (3)).

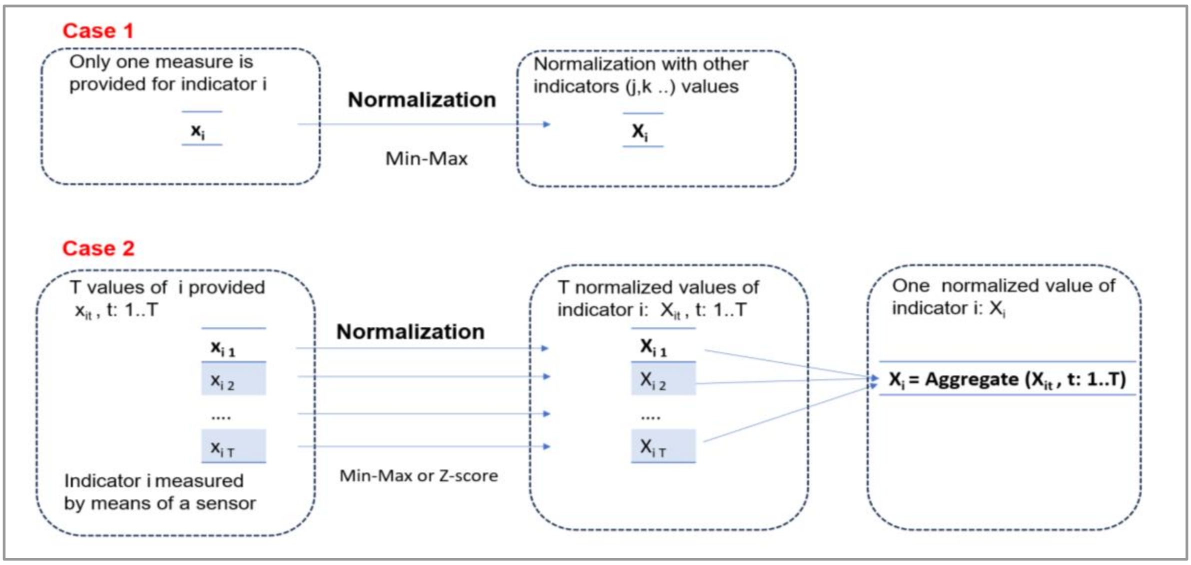

Figure 3 Illustration of both cases of normalization based on the availability of data of an indicator

Z-score normalization (Case 2)

$$X_{it} = \frac{x_{it} - mean_t(x_{it})}{std(x_{it})} \quad (1)$$

Min-max normalization or re-scaling (Case 1)

$$X_i = \frac{x_i - min_j(x_j)}{max_j(x_j) - min_j(x_j)}$$ (indicator to minimize i.e., the smaller the better)

Or

$$X_i = \frac{max_j(x_j) - x_i}{max_j(x_j) - min_j(x_j)}$$ (indicator to maximize i.e., the larger the better) (2)

Min-max normalization or re-scaling (Case 2)

$$\square_{\square\square} = \frac{\square_{\square\square} - \square\square\square_{\square}(\square_{\square\square})}{\square\square\square_{\square}(\square_{\square\square}) - \square\square\square_{\square}(\square_{\square\square})}$$ (indicator to minimize i.e., the smaller the better)

Or (3)

$$\square_{\square\square} = \frac{\square\square\square_{\square}(\square_{\square\square}) - \square_{\square\square}}{\square\square\square_{\square}(\square_{\square\square}) - \square\square\square_{\square}(\square_{\square\square})}$$ (indicator to maximize i.e., the larger the better)

Where

- *i: the index of indicators i = 1..□ where □ is the number of indicators*
- *t: the index of measurement of an indicator i; t=1..T where T is the number of measurements*
- $\square_{\square\square}$: [illegible]
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The normalization based on min-max transformation is generally more sensitive to outliers than Z-scores since the standard deviation is less dependent on an outlying value than the maximum or minimum . For re-scaling, the definition of extreme values could be either internal to the indicator's measurements (min and max of the measurements: internal values of the indicator) which allows relative comparisons (Mazziotta and Rivista, 2013) or independent from the data, which allows sto perform 'absolute' comparisons (Mazziotta and Rivista, 2013).

2.4.2. Aggregation and Weighting methods for sustainability index design

After the normalization of indicators, the design of a CI encompasses two main steps: i) affecting a weight to each indicator and ii) aggregating them into a single CI (Nardo et al., 2005). Weighting in composite indicators refers to the relative importance attributed to each indicator relative to the others (Greco et al., 2019). While aggregation can be defined as the combination of multiple indicators into one value. In the state of the art, there are two different aggregation approaches: direct and indirect. The last one is considered when the former steps are conducted separately, by applying separate methods, and in a sequential manner (Zhou and Ang, 2009). However, a direct approach conducts aggregation without the predetermination of weights. In this case, weighting and aggregation are conducted using the same approach (Zhou and Ang, 2009). The quality and reliability of the calculated index depend mainly on the type of aggregations and weights assignment (Saisana et al., 2005; Nardo et al., 2005; Greco et al., 2019).

As can be seen, the choice of the weighting method depends on the aggregation approach. That is why, first the aggregation method is selected.

- **The choice of the aggregation method**

Multi-criteria decision making (MCDM) approaches have been widely applied as aggregation methods to CI construction in general and SI building in particular. El Gibari et al. (2018) proposed a classification of these approaches as presented in Figure 4. Five classes of methods have been identified: elementary (the weighted additive and product aggregation methods), value-utility (Azapagic and Perdan, 2005; Belton and Stewart, 2002), distance function (Díaz-Balteiro et al., 2017), data envelopment analysis (DEA) (Charnes et al. 1978), and outranking relation (e.g., ELECTRE (Roy 1968; 1991), PROMETHEE (Brans et al., 1986)) - based methods. The classification of MCDM aggregation methods according to this distinction is illustrated in Figure 4. Aggregation methods could be also categorized as 'compensatory' or 'non-compensatory' (Greco et al., 2019, Mazziotta and Pareto, 2013, Munda 2005). Compensatory aggregation methods allow compensability or tradeoffs between indicators meaning that an alternative or a scenario can compensate for a deficiency in one criterion by performing well in others (Nardo et al., 2005; Greco et al., 2019). However, in non-compensatory methods preference relations between indicators are considered instead of tradeoffs (Greco et al., 2019). Non-compensatory approaches are especially preferred when different criteria are equally important and legitimate. In fact, these methods can help ensure that scenarios meet certain minimum standards on critical criteria, even if they perform exceptionally well on others. Each method is mostly appropriate for a different objective or purpose and involves some advantages and shortcomings accordingly. That is why, a comparative table between both approaches is elaborated based on several studies on aggregation methods for CI construction (Greco et al., 2019; El Gibari et al., 2018; Cinelli et al., 2014; Munda, 2005; Attardi et al., 2018 etc)(see Table 2). As can be seen, the choice of an aggregation method depends on the extent to which trade-offs or compensation are allowed within the assessment engines and therefore on the paradigm of sustainability (strong vs weak). Non-compensatory MCDM should be applied if there exists a value threshold that cannot be exceeded for sustainability assessment. In this case, these methods operationalize the concept of strong sustainability (Polatidis et al., 2006).

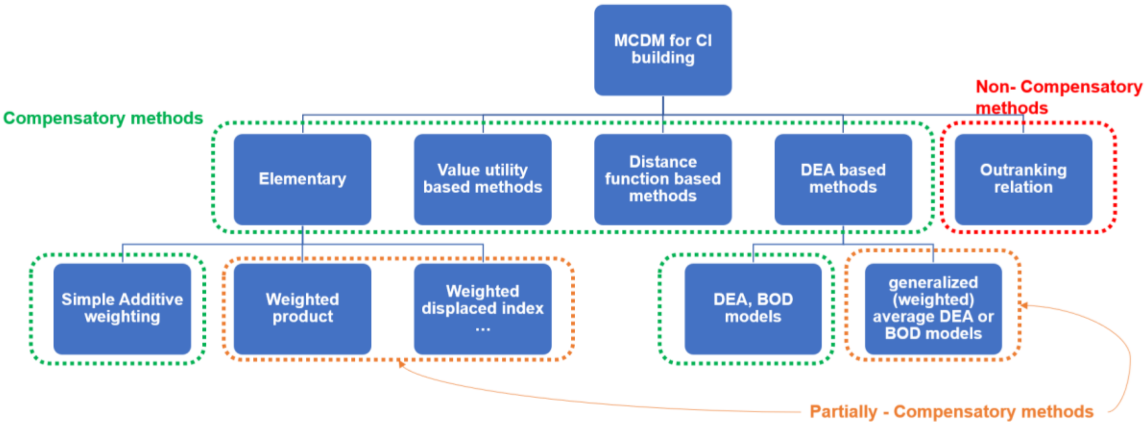

Figure 4 Classification of MCDM as aggregation methods for CI construction

Table 2 Properties, advantages and drawbacks of compensatory vs non-compensatory aggregation methods

Category of Aggregation approach	Compensatory	Non-compensatory
Case of utilization	- Assuming compensability between indicators or criteria i.e., decision-makers are willing to consider trade-offs and make more flexible decisions. - Useful in complex decisions where a balance between various factors is essential.	- In situations where there are critical criteria with strict minimum requirements (i.e., strict requirements or constraints must be met), - For a ranking problem of options or alternatives: evaluate and rank alternatives or options based on multiple criteria without allowing trade-offs or compensations between criteria.
Advantages or desirable properties	- Simplicity - Flexibility: in many real-world decisions, decision-makers are willing to trade off strengths in some criteria for weaknesses in others. - Consider the degree of performance on each criterion, allowing for a more nuanced evaluation of alternatives. This can help avoid the loss of valuable information present in the data. - Allow for the assignment of different weights to criteria to reflect their relative importance, which can align with decision-makers' preferences.	- Allows equitable consideration of different objectives that need to be legitimated at the same level . - Allow decision-makers to explicitly model their preferences and requirements. This can be especially useful when there are certain "must-have" criteria or minimum performance standards that need to be met. - Robustness

Drawbacks	- Sensitivity to the choice of weights which can be subjective and may vary between decision-makers. The choice of weights can significantly impact the results. - Compensability propriety allows an alternative with significant weaknesses in one or more criteria to be ranked highly if it excels in others. This can lead to suboptimal or risky decisions. - admitting an unequal consideration of different objectives which need to be legitimated in an equal manner (due to compensability) - The Assumption of Linearity (Oversimplification) between criteria may not hold true in all situations. Non-linear relationships may not be adequately captured.	- Rigid and potentially less nuanced evaluations as trade-offs between criteria is not allowed, which may not reflect real-world decision-making where trade-offs are often necessary. - Can lead to the exclusion of alternatives that perform well on most criteria but fail to meet the minimum threshold on one or two criteria. This may result in the rejection of valuable options. - Setting the minimum thresholds for each criterion can be a subjective process and may vary from one decision-maker to another. - May discard valuable information about the quality of the alternatives. - Complexity of the methods (Not intuitive and easy-to-use). - Computationally costly to calculate. - final scores could not be determined, which makes it impossible to calculate the distance between the performance of two options on the basis of the CI.
Sustainability paradigm	Weak sustainability	Strong sustainability

Our objective is to develop a tool that assesses sustainability (involving its capitals and dimensions) for the SMALLDERS defined scenarios. In this deliverable, we are interested in both approaches. In fact, according to Mazziotta and Pareto, 2013, environmental, economic and social dimensions in sustainability are non-substitutable which require the use of non-compensatory aggregation approaches. As we are in the very early steps of this process, the choice of aggregation methods is based on the following criteria:

i) minimum complexity and computational effort are required;

ii) Type of data needed to apply a given method: In our case, information about threshold limits for indicators is not yet available. In addition, as different scenarios (countries) are to be considered, threshold limits for each indicator depends on the AFSC actor as well as the considered country. Hence, collecting data for all AFSC and all scenarios is a really difficult and complex task;

iii) Since our aim is to evaluate sustainability rather than ranking scenarios. The chosen method should allow calculating sustainability scores.

Based on these criteria, the following approach (illustrated in figure 5) is proposed:

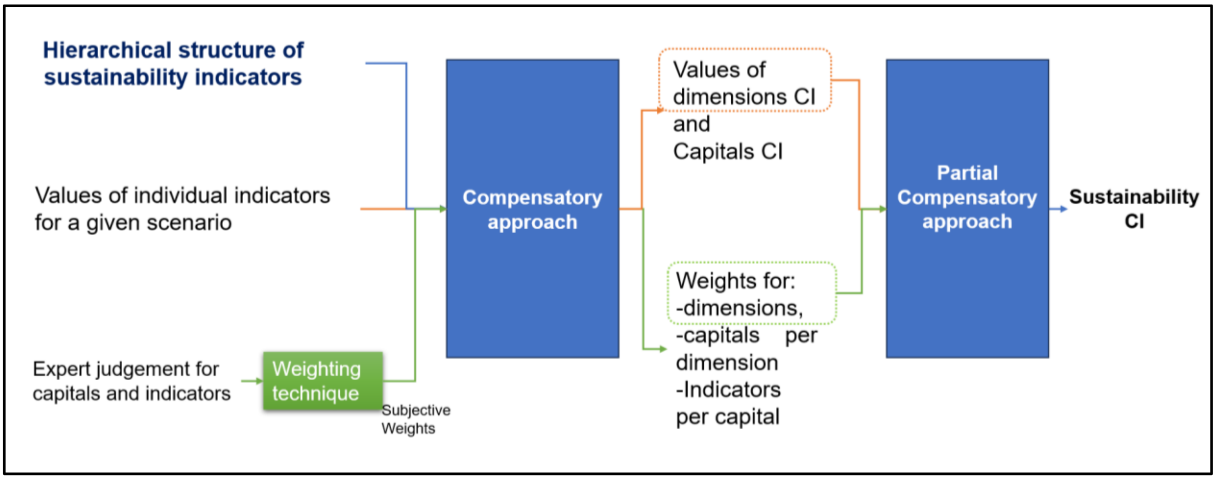

Figure 5 The proposed aggregation-weighting approach to calculate the sustainability CI for a given scenario

According to this figure, the 1st-block which defines a compensatory aggregation method can be used for aggregating indicators for indexing a sustainability dimension and capital or a category of indicators within a capital. However, a careful consideration of weight assignments is required. DEA-based models, a direct aggregation approach (Zhou and Ang, 2008), allocate the optimal set of weights to individual indicators and then aggregate them into a CI with a score (the maximum possible) without using a priori knowledge on finding the weights. Hence it is recognized as a data-driven or objective weighting method (Greco et al., 2019) that determines the best possible weights directly from the data related to indicators values for each scenario or country (i.e., each decision-making unit DMU). Moreover, to limit the flexibility in weights, weighting restrictions based on expert judgements could be incorporated. Hence, the DEA method presents a valid choice. In this regard, the DEA-based method is chosen while i) incorporating weighting restrictions based on expert judgment for the relative importance of indicators and capitals and ii) considering the hierarchical structure of sustainability (see figure 6). A brief theoretical background on DEA for CI as well as subjective weighting methods that could be used to incorporate weighting restrictions are presented in the following subsections.

As a 2nd-step, once dimensions' indices are calculated, they will be aggregated via a method that limits the compensation among dimensions without necessarily requiring a threshold or benchmark values for indicators/ dimensions. Knowing this, only an elementary MCDM method could be applied (see Figure 4) which is partially compensatory such as weighted product. In fact, the degree of compensation is high for additive models, partial for product-type models (Zhou and Ang, 2009). Unlike the linear or additive versions, the weighted product does not allow poor performance in one of the sub-indicators to be linearly compensated for by higher performance in other sub-indicators. This means that a low relative performance value of a sub-indicator is directly reflected in a lower CI (Rogge, 2018). Also these methods are indirect aggregation approaches which require information about weightings prior to applying them. Some examples of applications of these methods can be found in (Dobrovolskiien and Tamošiūnienė, 2016; Kaldas et al., 2020).

- **Theoretical background on the DEA method**

DEA is a nonparametric approach that was first introduced by Charnes et al. (1978). It uses linear programming to assess the relative performance of multiple units (countries, companies, institutions, companies, etc.), called decision-making units (DMUs), and evaluates them based on "efficiency values." (Cooper et al., 2000). This score is calculated for each unit based on a developer-specified maximization/minimization function, dividing the weighted sum of outputs (e.g., profit, performance metric being maximized) by the weighted sum of inputs (e.g., cost). It is obtained by: Starting from this linear programming, a set of weights (one per unit) is endogenously determined such that its "efficiency" is maximized under certain predetermined constraints (Hermans et al. 2008).

In the context of CI, the formulation of the classic DEA can be applied in two different ways (El Gibari et al., 2018). In the first approach, the sub-indicators are considered as input or output variables, depending on whether they are indicators of the "less is better" or "more is better" type, and the classical DEA method is used. Then the CI will be calculated. The second approach is to create dummy inputs (or outputs) and consider all sub-indicators as outputs (or inputs). This approach is known as Benefit of the Doubt (BoD) (Melyn and Moesen, 1991).

According to Rogge (2018), "the conceptual starting point of the BoD-approach is that, in the absence of detailed knowledge on the correct weights for the sub-indicators, information on the weights can be retrieved from the observed sub-indicator data themselves". BoD is increasingly applied for constructing CIs. According to Nardo et al. (2005), CI values based on BoD range between the lowest possible value (zero) and 1 (the benchmark), where indicators are usually based on the normalized values from min-max transformation.

The popularity of this method comes from the fact that each DMU chooses its proper weights in such a way as to maximize its performance (Cherchye et al. 2007, 2008). However, this flexibility in selecting the weights may lead to: compensability of indicators and unfairness in assigning weights (Hatami-Marbini and Toloo, 2016; El Gibari et al., 2018, Greco et al., 2019). This consists of assigning an extreme value (very high/low or unrealistic) to a weight. For instance, in some cases DEA models may assign all the weighting capacity ($\simeq$ *1*) to the indicator that has the highest value, and zero weights to certain indicators, indicating that they have no impact on CI, which is counterintuitive and may lead to the neglect of important single indicators, hence in contrast to decision-makers' beliefs.

To address these shortcomings, weighting constraints can be added to the BoD model, taking into account the judgment of the decision maker, for example, controlling the lower and upper bounds of the weights of each indicator or group of indicators. Various weight restriction techniques have been proposed in the DEA literature. Absolute weight limit (Roll et al., 1991). ordinal weight constraints and virtual weight constraints (Wong and Beasley, 1990; Cooper et al., 2007; Cherchye et al., 2007); "Assurance region" or relative weight constraints (Thompson et al., 1986), scaling factors (PAKKAR, 2016), and indirect restriction constraints (Zhou et al., 2007, 2010, Cherchye et al., 2008). These restrictions can be identified using one of the subjective weighting methods based on interviews with experts (in this case the AFSC actors). The selection of subjective weighting methods is discussed at the end of this section.

Another shortcoming of the traditional BoD model or the basic DEA-CI based model is that it treats all indicators as if they are part of a single layer. Yet, when creating a sustainability or dimension index, it's important to consider the hierarchical structure of these indicators. They may actually belong to different categories and have connections between them, forming a multi-layered hierarchy (see Figure 6 and Appendices 1-5). In such cases, using a basic DEA model that treats all indicators at a single level means that valuable information about their hierarchical arrangement is lost. To address this limitation, a layered hierarchy DEA approach has been proposed by Meng et al. (2008) where: i) the weights between categories or sub-groups of indicators are determined by the DEA model, ii) the weights within each category (

i.e., internal weights) are established using the weighted-average approach embedded in the DEA approach. However, the latter model of Meng et al. (2008) is nonlinear and is only applicable to situations with a two-layer hierarchy. Subsequently, a linear version has been developed by Kao (2008) using variable substitution. A generalized multilayer DEA model is then introduced byShen et al. (2012). Their model considers a multi-level hierarchy of indicators without limiting the number of layers. However, the weights obtained from these methods may not be consistent across all decision-making units (DMUs) and may lack fairness and uniformity, which can pose challenges in evaluation processes such as rankings and benchmarking.

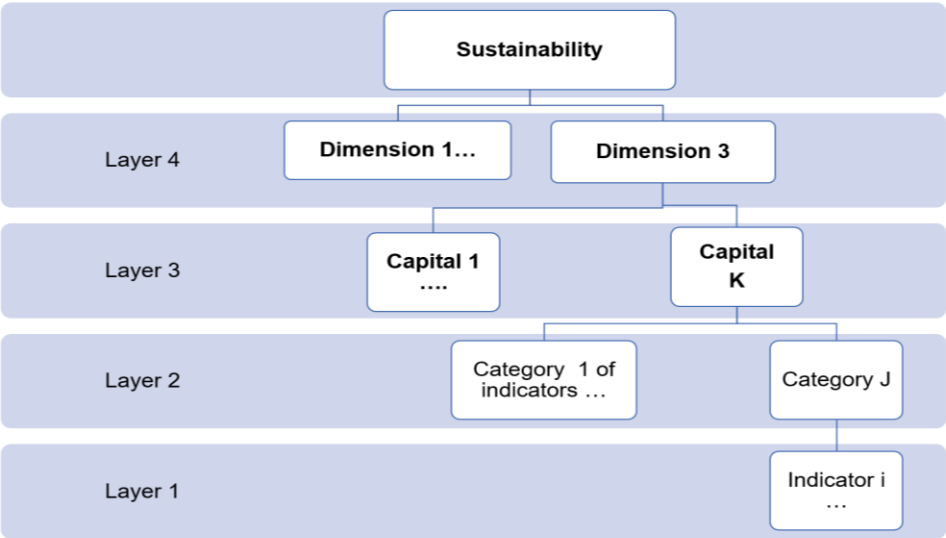

Figure 6 The hierarchical structure of sustainability indicators

In summary, since DEA-based models are used to determine the efficiency or CI of different DMU(s), we propose applying this method by considering only one DMU at the beginning (Tunisia) and then 4 DMUs (Tunisia, France, Spain, and Italy). A Multi-level DEA-based CI model is developed while considering weight restrictions based on expert judgment. The question now is how to include expert judgment for weight restrictions. In the next subsection, the choice of a subjective weighing method is discussed. The incorporation of weights obtained from expert judgment in the Multi-level DEA based CI model is presented in section 3.

- **The choice of subjective Weighting method**

Weighting can be divided into objective and subjective weightings (Mazziotta and Pareto, 2013). The subjective weights are based mainly on expert judgment presenting the preferences of a 'plurality of individuals' regarding the importance of indicators within a CI (Greco et al., 2019). These approaches could be referred to as "Plurality of

Weighting Systems" as presented by (Greco et al., 2019) or exogenous methods. These approaches present some limitations. For instance, judgements can be hard to collect and time consuming (especially for a great number of indicators) as well as inconsistent (within the same context, two experts may deliver contradictory opinions), which may lead to biased results (Greco et al., 2019; Nardo et al. 2005). In addition, CI are very sensitive to the assigned weights and hence to subjective judgements (Greco et al., 2019; Lindén et al., 2021). Despite these limitations, As AFSC sustainability is highly context-dependent, the opinions of AFSC stakeholders are critical to indicator weighting (Talukder et al,. 2017). Ezell et al. (2021) presented a taxonomy of subjective weighting methods used in MCDM problems. From the presented methods, the Simple Multi Attribute Rating Technique (SMART) was chosen for this deliverable. SMART (Ezell et al., 2021; Edwards, 1977) determines weights indirectly by systematically comparing attributes with attributes assumed or selected as least (or most) important according to expert opinion.

The SMART technique is conducted in four steps for each layer of the hierarchical structure of sustainability indicators (dimension> capital> categories of indicator> indicators). The first three steps are related to collecting expert judgment. Three types of information are demanded from the expert. First, he or she ranks the indicators according to their relative importance in order to choose either the most (or least) important attribute. Once chosen, this latter will be considered as a reference point and is assigned a reference score of 10 points for example. Then, the expert will assess how less or more important other indicators are compared to the reference point. Once these data are collected, the fourth step "calculate weights" can be performed. This is done by normalizing each indicator's score (obtained in step 3) against the total score among all indicators as shown in Equation (4).

$$w_i = score\ of\ the\ indicator\ i / \sum_i score\ of\ i \quad (4)$$

Where: w_i is the weight of an indicator i regarding the other indicators belonging to a given category or layer of indicators.

3. Mathematical models for multi-capital sustainability assessment for the SMALLDERS's dashboard layer

Based on methodology defined in section 2 and the choice of the methods for the normalization; aggregation and weightings steps, a four-level DEA based approach with weights restriction based on expert judgment is developed for sustainability assessment for SMALLDERS's dashboard layer. The developed approach will be applied for each AFSC actor as the set of capitals and individual indicators per capital vary according to each actor (see Figure 2 and Indicators tables in Appendices 1-5). The proposed mathematical model is defined based on a hybrid approach which includes a multi-level DEA and SMART method as illustrated in Figure 7. This section details the mathematical models defined for this approach. First a four-level DEA model is proposed where the hierarchical structure of sustainability indicators is taken into account. Then, a formulation of weighting restriction constraints based on expert judgment is proposed to be included in the developed four-level DEA model.

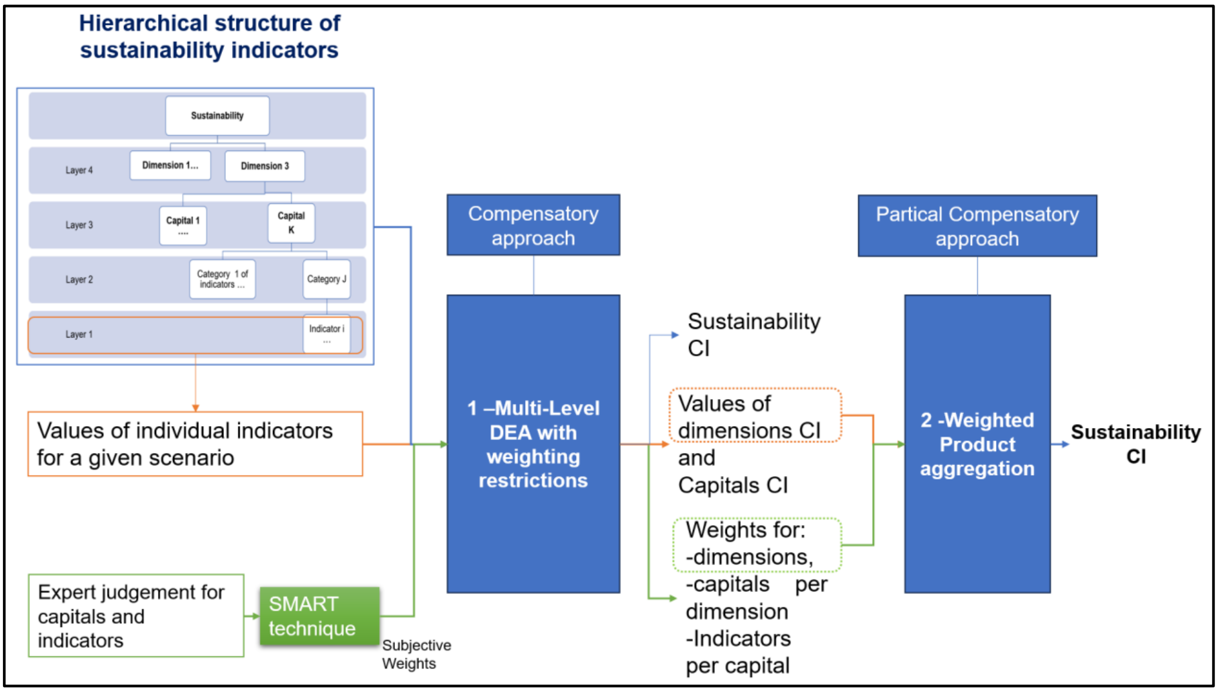

Figure 7 The proposed approach for multi-capital sustainability assessment

3.1. Four-level DEA model with weighting restrictions

3.1.1. Four-level DEA model without weighting restrictions

The model notations and decision variables are presented as follows:

Indices:

- l : dimension index, $l\epsilon\{1,\dots,L\}$
- k: capital index, $k\epsilon\{1,\dots,K_l\}\ \forall\ l$
- j: category index, $j\epsilon\{1,\dots,J_{kl}\}\ \forall\ k\ ,\ l$
- i: indicator index, $i\epsilon\{1,\dots,I_{jkl}\}\ \ \forall j,\ k,\ l$
- c: scenario index c$\epsilon\{Tunisia, France, Italy, Spain\}$

Parameters:

- L : the number of dimensions
- K_l : the number of capitals belonging to dimension l
- J_{kl} : the number of categories belonging to capital k of dimension l
- I_{jkl} : the number of indicators belonging to category j of the capital k of the dimension l
- $x_{ijkl,c}$: the normalized value of indicator i of the category j of the capital k of the dimension l for the scenario c

Decision variables :

- w_{ijkl} : the internal weight of indicator i of the category j of the capital k of the dimension l, such that $\sum_{i=1}^{I_{jkl}} \quad w_{ijkl} = 1\forall j,k,l$
- w_{jkl} : the internal weight of category j of the capital k of the dimension l, such that $\sum_{j=1}^{J_{kl}} \quad w_{jkl} = 1\forall k,l$
- w_{kl} : the internal weight of capital k of the dimension l, such that $\sum_{k=1}^{K_l} \quad w_{kl} = 1\forall l$
- w_l : the internal weight of dimension l,

The value of each index in layer m is measured as the weighted sum of connected normalized indicators in the previous layer m-1.

- $x_{jkl,c}$: the value of category j of the capital k of the dimension l for the scenario c, where: $x_{jkl,c} = \sum_{i}^{I_{jkl}} \quad w_{ijkl} \times x_{ijkl,c}\ \forall j,k,l$,c
- $x_{kl,c}$: the value of capital k of the dimension l, where : $x_{kl,c} = \sum_{j}^{J_{kl}} \quad w_{jkl} \times x_{jkl,c}\ \forall\ k,l$,c
- x_l: the value of dimension l, where : $x_{l,c} = \sum_{k}^{K_l} \quad w_{kl} \times x_{kl,c}\ \forall l$,c
- SI_c : the sustainability index for a scenario c, where

$$SI_c = \sum_{l}^{L} \quad w_l \times x_{l,c}\ \ \forall c$$

As a result, from a sequential substitution system, the objective function is denoted by:

$$SI_c = Max \sum_{l=1}^{L} \quad w_l \left(\sum_{k=1}^{K_l} \quad w_{kl} \left(\sum_{j=1}^{J_{kl}} \quad w_{jkl} \left(\sum_{i=1}^{I_{jkl}} \quad w_{ijkl}\ x_{ijkl,c} \right) \right) \right)$$

To avoid the nonlinearity of the resulting model, a new decision variable $\widehat{w}_{ijkl}$ which denotes the multiplier weight for the indicators in the first layer (individual indicators) as defined in Shen et al., (2012).

$\widehat{w}_{ijkl}$ is measured based on internal weights as follows:

$$\widehat{w}_{ijkl} = w_l \times w_{kl} \times w_{jkl} \times w_{ijkl}\ , \forall\ i,j,k,l \tag{5}$$

The multiplier weights for the other layers are also defined as follows:

$$\widehat{w}_{jkl} = w_{kl} \times w_{jkl} \times w_{ijkl}\ \forall\ i,j,k,l \tag{6}$$

$$\widehat{w}_{kl} = w_l \times w_{kl} \tag{7}$$

The correspondence of Multiplier weights to the hierarchical structure of indicators is illustrated in Figure 8.

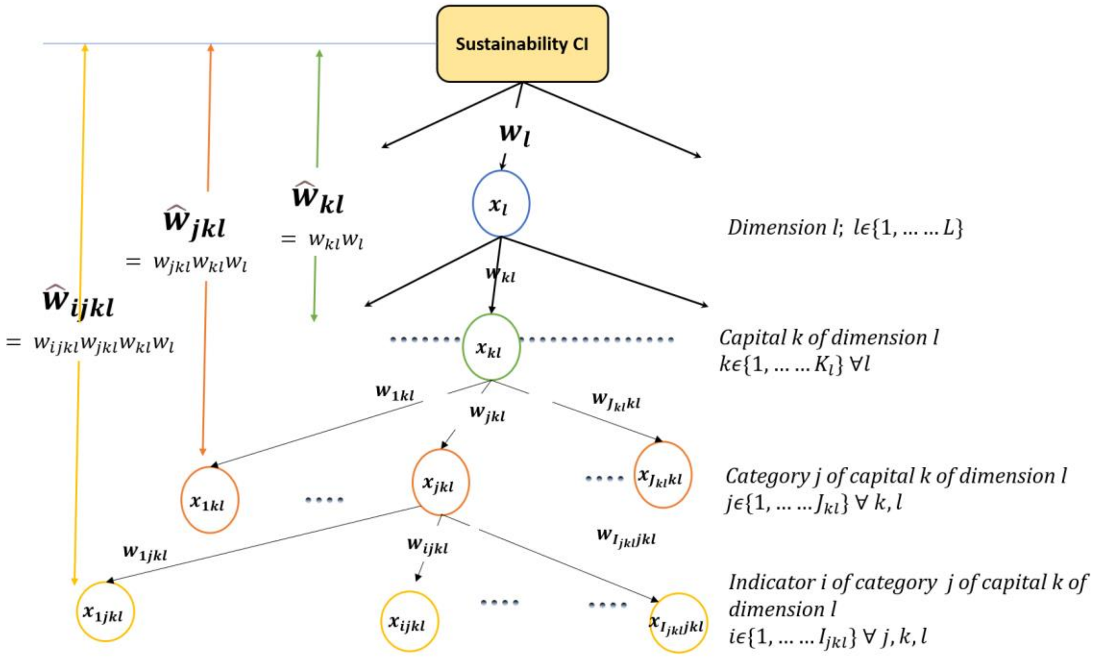

Figure 8 Illustration of internal and multiplayer weights according to the hierarchical structure of sustainability indicators

Using the multiplier weight, the sustainability index for a scenario c becomes:

$$SI = Max \sum_{l=1}^{L} \sum_{k=1}^{K_l} \sum_{j=1}^{J_{kl}} \sum_{i=1}^{I_{jkl}} \widehat{w}_{ijkl}\, x_{ijkl,c} \tag{8}$$

Consequently, a linear four-level DEA model can be developed as follows:

Objective function

$$SI_c = Max\left(\sum_{l=1}^{L} \sum_{k=1}^{K_l} \sum_{j=1}^{J_{kl}} \sum_{i=1}^{I_{jkl}} \widehat{w}_{ijkl}\, x_{ijkl,c}\right) \tag{9}$$

Constraints (10a)

$$\sum_{l=1}^{L} \sum_{k=1}^{K_l} \sum_{j=1}^{J_{kl}} \sum_{i=1}^{I_{jkl}} \widehat{w}_{ijkl}\, x_{ijkl,c} \le 1\ \forall c$$

$$w_l = \sum_{k=1}^{K_l} \sum_{j=1}^{J_{kl}} \sum_{i=1}^{I_{jkl}} \widehat{w}_{ijkl}\ \forall l \quad (10b)$$

$$\widehat{w}_{kl} = \sum_{j=1}^{J_{kl}} \sum_{i=1}^{I_{jkl}} \widehat{w}_{ijkl}\ \forall k,l \quad (10c)$$

$$\widehat{w}_{jkl} = \sum_{i=1}^{I_{jkl}} \widehat{w}_{ijkl}\ \forall k,l,j \quad (10d)$$

$$\widehat{w}_{ijkl},\ \widehat{w}_{jkl},\ \widehat{w}_{kl},\ w_l > 0\ \ \forall k,l,j,i \quad (10e)$$

Based on this model, the four scenarios (DMUs) can be evaluated by combining sustainability indicators. To obtain the sustainability index/dimensions and capitals for one scenario, the linear program is run for that scenario. The weights in (9) are automatically selected with the aim of maximizing the value of a specific scenario composite index score while considering the less than 1 constraint for all scenarios (Equation (10a)). On the other hand, all weights must not be negative (Equation (10e)). In general, a scenario performs best when it reaches an index value of 1. However, a value less than 1 means that it is underperforming. Equations (10b-d) mean that the sum of the multiplier weights of each category is equal to the multiplier weight of its subcategory in the previous level. To obtain the internal weights to calculate dimensions, capitals and indicator's categories indexes, the following equations can be applied as defined in Shen et al. (2012):

$$w_{ijkl} = \frac{\widehat{w}_{ijkl}}{\widehat{w}_{jkl}}\ \ \forall\, i,j,k,l \quad (11)$$

$$w_{jkl} = \frac{\widehat{w}_{jkl}}{\widehat{w}_{kl}}\ \ \forall\, j,k,l \quad (12)$$

$$w_{kl} = \frac{\widehat{w}_{kl}}{w_l}\ \ \forall\, k,l \quad (13)$$

The previous model allows for the potential allocation of all weights to an individual indicator. This may not align with expectations since all selected indicators are theoretically significant and therefore warrant consideration, as indicated by Zhou et al. (2007). This circumstance could generate conversations concerning the credibility and acceptability of the Sustainability Index (SI). To tackle these concerns, weighting restriction constraints are added. These constraints will consider as data, the subjective weights provided by expert judgment for each layer of the hierarchy. The SMART Technique was considered to calculate these weights.

To obtain the weight limits of indicator weights in the four-layer DEA-based CI model, this study aggregates the priority weights of four different indicator levels in the same way as the multiplier weights in Figure 8.

Let y denote the subjective weight, considering the hierarchical structure of sustainability indicators, the following notations are defined:

- y_{ijkl} *: the subjective weight of indicator i of the category j of the capital k of the dimension l, such that* $\sum_{i=1}^{I_{jkl}} \quad y_{ijkl} = 1 \forall j,k,l$
- y_{jkl} *: the subjective weight of category j of the capital k of the dimension l, such that* $\sum_{j=1}^{J_{kl}} \quad y_{jkl} = 1 \forall k,l$
- y_{kl} *: the internal weight of capital k of the dimension l, such that* $\sum_{k=1}^{K_l} \quad y_{kl} = 1 \forall l$
- y_l *: the internal weight of dimension l, such that* $\sum_{l=1}^{L} \quad y_l = 1$

$\hat{y}_{ijkl}$ is measured based on internal subjective weights via SMART method as follows:

$$\hat{y}_{ijkl} = y_l \times y_{kl} \times y_{jkl} \times y_{ijkl} \text{ ,} \forall\, i,j,k,l$$

The constraint to be added is as follows:

$$\widehat{w}_{ijkl} = \propto \hat{y}_{ijkl \; \forall \; i,j,k,l} \tag{14}$$

$Where$ $\propto$ is a scaling factor such as $\propto > 0$

Additional Constraints

$$\widehat{w}_{ijkl} = \propto \hat{y}_{ijkl \; \forall \; i,j,k,l} \tag{15a}$$

$$\propto > 0 \tag{15b}$$

3.2. Final sustainability index calculation

Based on the approach defined in the beginning of this section, the weights of dimensions (w_l) as well as dimensions CI (x_l) obtained by the model (9, 10a-e,15a-b) will be used in a partial compensatory aggregation method to calculate the final sustainability index. The weighted product method is used and the final sustainability index, for a given scenario, is given by equation (16) as follows:

$$SI = \prod_{l=1}^{3} \quad {x_l}^{w_l} \tag{16}$$

4. Conclusion

In this deliverable, a methodology for mutli-capital sustainability assessment is proposed. First, capitals per sustainability dimension were carefully selected based on both interviews with AFSC actors and a literature review. Second, a final list of indicators was identified based on a literature review. A final list of indicators was retained based on S.M.A.R.T criteria. Then formulas and mathematical equations were defined for each indicator. At the end of this selection process, the sustainability indicators are defined according to a hierarchical structure. In a third step, normalization, aggregation and weighting techniques were identified based on the literature of CI construction. A four-level DEA based approach with weights restriction based on expert judgment is developed for sustainability capitals and dimensions evaluation as well as their weighting calculation. The dimensions indices as well as their weightings are then integrated in a weighted product aggregation method to calculate the final sustainability index for a given scenario. The developed approach will be applied for each AFSC actor as the set of capitals and individual indicators per capital vary according to each actor.

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Appendix 1 List of indicators per sustainability capital and dimension for smallholders

Table A1.1 List of the indicators for the environmental dimension/capital for smallholders

Category of indicators	Indicator	Abbreviation	Unit	formulae
Input	***Eutrophication Potential***	EP	Kg PO4 3- eq. ha^{-1} $year^{-1}$	EP_N = Load (mass) of nitrogen / mass or units produced EP_P = Load (mass) of phosphorous / mass or units produced
Land	***Land Use efficiency***	LUE	[m^2/unit of production kg or Ton]	LUE = Area (harvested)/ Harvested production
Soil quality	***Electrical conductivity of soil***	SEC	deciSiemens per meter (dS/m)	Value given by a sensor
	Soil moisture	SM	Value given by a sensor	Value given by a sensor
	soil color and texture	SC&T		Farmer's data
Energy	***Energy Use***	EU	[J or MJ or KWH /per unit of production]	EU = sum(Q_i*EF_i)/Quantity produced; Q_i = the quantity or amount of a specific energy source used ; EF_i = the energy conversion factor for that particular energy source.
	Proportion of Renewable Energy	PRE	[%]	PRE = 100 * amount of renewable energy (Kwh) /(sum (Q_i*EF_i)) (Kwh)
	Acidification potential	AP	(kg SO_2 eq.) kg SO_2-equivalents or kg SO_2-equivalents ha^{-1} $year^{-1}$	Acidification Potential = Σ (Pollutant Quantity * Acidification Potential Factor)
	Abiotic depletion potential — Fossil fuels	□□□□	kg oil-eq/ha	FDEP= FFET * oileqt FFET = fossil fuel extraction by type t (in kg/ha) oileqt= the oil equivalent characterisation factor by type t (in kg oil-eq/kg or kg oil-eq /MJ).
	Global Warming Potential	GWP	Kg CO_2 equivalent	GWP = sum (emitted quantity of gas i * GWP_{100} (gas i))
	Water used	WU	m^3/year or time period	Sensor

	Water Scarcity Footprint (WSF) (m3 H2O eq)	WSF	m^3 H_2O eq.	Water Scarcity Footprint = Water Consumption (including direct and indirect water used) / Water Availability
	Post harvest loss	PHL	kg or Ton/ year (or time period)	Quantity measured by the farmer = sum (quantity of harvest type i* % waste per harvest type i)

Table A1.2 List of capitals and indicators per capital for the economic dimension for smallholders

Capital	Indicator	Abbreviation	Unit	Formulae
Financial	***Income***	IN	(TND or Euro) for a time period (year, trimester…)	Quantity (sales) for a given product * unit price
	Benefit-Cost Ratio	BCR	Dimensionless	$BCR = \frac{\sum_{i=0}^{n} \frac{Y_i}{(1+r)^i}}{\sum_{i=0}^{n} \frac{K_i}{(1+r)^i}}$ Y_i = net annual benefit of year *or period* i_i K_i = Costs or capital outlay for assets of year or period *i* (initial investments + re-investments); *r* = discount rate; *n* = number of years in operation
	Costs of Cultivation and Storage	CCS	(Euros or DTN)	CCS = Costs of cultivation + Costs of storage
Material	***Carrying capacity***	CC	(animal/ha)	maximum number of animals (livestock) per Ha
	Number of cattles	NC	cows	data from farmer
	Land value	LV	(Euros or DTN)	Farm size* unit price (of m2)
	Farm size	FS	M^2 or Hectare	data from farmer

Human	***Level of income***	LI	TND or EURO /Month or day	Average salary of farm workers
	Gender Inclusion	%W/M	%	100*Number of working women in the farm/ total number of workers
	Labor productivity	LP	TND per hour or TND per employee	LP=Value of product produced (in TND) /(the total number of hours worked or total number of employees)
Stakeholder	***Number of agreements with stakeholders***	AS	Agreements per time period (e.g., per year)	farmer's data
	Duration of agreements before breaking	DAS	time period per agreement	farmer's data
Intellectual	***Number of trainings***	Trainings	Training per time period (e.g., per year)	Total number of trainings = somme of number of trainings per employee (Farmer's data)
	number of smart technology tools used	NST	Total Number per year	Sum on seasonal farm works per year (Number per working season)

Table A1.3 List of capitals and indicators per capital for the social dimension for smallholders

Capital	Indicator	Abbreviation	Unit	Formulae
Internal-social	***Number of memberships in farmer's associations (cooperative included)***	RC	number of memberships /year	Farmer's data
External-social	***Number of participation in collective spaces (e.g., fairs of the region)***	Fairs	Participation/year	Farmer's data
	Farmers Connectivity to social networks	SN	Number of social media profiles of the farming activity	Farmer's data

Appendix 2 List of indicators per sustainability capital and dimension for Transport Companies

Sustainability dim.	Capital	Indicator Category or Indicator		Unit	Formula
Environmental	Natural	**Input**	***Eutrophication Potential (EP)***	kg PO4 3- eq.	EP_N = Load (mass) of nitrogen / mass or units produced EP_P = Load (mass) of phosphorous / mass or units produced
		Energy	***Global Warming Potential (GWP)***	kg CO_2 eq.	GWP = ∑emitted quantity of gas i * GWP (gas i)
			Fossil fuels depletion (FDEP)	kg oil-eq/tonne-kilomètre	FDEP= FFET * oileqt
			Acidification Potential (AP)	kg SO_2 eq.	AP= Σ ESO_{2i}* W_i ESO_{2i} , coefficient of sulphur dioxide equivalent for i-th material [$kgSO_2eq\ kg^{-1}$]; w_i, weight of i-th material (kg).
		Water	***Water Scarcity Footprint (WSF)***	m^3 H_2O eq.	WSF = Water Consumption (including direct and indirect water used) / Water Availability
		Waste	***Waste to landfill (WL)***	tone/year %	WL (tonnes/tonne of goods transported) = 100* Total weight of waste sent to landfill (tonnes)/ Total weight of goods transported (tonnes)
Economic	Financial	***Benefit-Cost Ratio (BC)***		Dimensionless	$$BCR = \frac{\sum_{i=0}^{n} \frac{Y_i}{(1+r)^i}}{\sum_{i=0}^{n} \frac{K_i}{(1+r)^i}}$$ Y_i = net annual benefit of year *or period* i_i K_i = Costs or capital outlay for assets of year or period *i* (initial investments + re-investments); *r* = discount rate; *n* = number of years in operation
	Stakeholder	***Company's earnings per share (EPS)***		TND or EURO /share	EPS=net profit / the number of common shares outstanding
		Degree of satisfaction of information sharing among stakeholders			Feedback mechanisms or Engagement levels

	Human	***Labor productivity (LP)***	TND or EURO/hour	LP=Value of service /the total number of hours worked
Social	Relational	***Number of deliveries per customer (NDC)***	deliveries/consumer	data from actor
		Number of followers on the social media (NFSM)	followers	data from actor

Appendix 3 List of indicators per sustainability capital and dimension for critical stakeholders

Sustainability dim.	Capital	Indicator Category or Indicator		Unit	Formula
Environmental	**Natural**	**Energy**	***Global Warming Potential (GWP)***	kg CO_2 eq.	GWP = ∑emitted quantity of gas i * GWP (gas i)
			Total of energy consumption (TEC)	Kwh	TEC=∑ Energy Consumption
		Water	***Water Scarcity Footprint (WSF)***	m^3 H_2O eq	WSF = Water Consumption (including direct and indirect water used) / Water Availability
		Waste	***Ratio of Waste (RW)***	(ton/year)	RW=Total Waste Generated (ton)/Time Period (in years)
Economic	**Financial**	***Benefit-Cost Ratio (BCR)***			$BCR = \frac{\sum_{i=0}^{n} \frac{Y_i}{(1+r)^i}}{\sum_{i=0}^{n} \frac{K_i}{(1+r)^i}}$ Y_i = net annual benefit of year *or period* i_i K_i = Costs or capital outlay for assets of year or period *i* (initial investments + re-investments); *r* = discount rate; *n* = number of years in operation
	Material	***capacity of storage facilities***		Ton	data from actor
		Number of storage facilities			data from actor
	Human	***Labor productivity (LP)***		TND/h	LP=Value of good & service/the total number of hours worked
	Stakeholders	***Multi-stakeholders partnerships***			data from actor
Social	**External Social**	***Number of new employees per year***		Number/year	data from actor

Appendix 4 List of indicators per sustainability capital and dimension for the policy maker

Sustainability dim.	Capital	Indicator Category or Indicator	Unit	Formula

Environmental	**Natural**	**Soil**	***Cultivated land utilization Index (CLU-index)***	Dimensionless	CLU-index = (Sum i (products of land area to each crop i) * Actual duration of that crop i (days))/(total cultivated land* 365 days)
		Energy	***Energy consomption for regional production (Regional EC)***	KWh/year	Regional EC = x1+x2 + 10%x1 x1 = amount of energy from subsidized smallholders by policy maker (special meters) x2 = electricity from the public irrigated perimeter (pumping)
			GHG emissions due to national production or regional production (Regional GHG)	(kg CO_2 eq.) for year i	Regional GHG= x% * National GHG National GHG from online database or policymaker x%= provided by the policymaker
		Water	***Water availability (for agriculture sector for Nabeul Region) (WA)***	m^3/capita/year	*WA = Volumes of available water resources / Number of population of the region*
			Water stress (WS) (for year i)	(%) per year	WS (%) = 100*(TWW /(TRWR − EFR) (for year i) TWW = The total volume of fresh water of the region for year i (m^3) TRWR = Total Renewable Freshwater Resources of the region TRWR = internal renewable water resources (IRWR) + external renewable water resources (ERWR) EFR = Ecological flows
			Rainfull (mm/year)	Rainfull (mm/year)	From online database
			Water use efficiency (for year i) WUE	(USD or TND or Euros / m^3)	WUE = 100*(VA/ PA) VA=Value added of the agricultural sector (irrigated) = Value of production - intermediate consumption PA = Proportion of water used by the agricultural sector in relation to total use (m^3)
Economic	**Financial**		***Proportion Region Agricultural Added Value per year***	AAV (TND or euros) for year i	AAV = (AAV of animal production + AAV vegetable production) (DTN/euros) *produced per type j * Unit price per product j) - TVA j*

		Agricultural yield per year	AY (tonne/ha/year)	*AY = Regional total quantity of product harvested/cultivated area*
		% Gross Domestic Product growth for year i (or Regional GDP)	% GDP for year i	*% GDP = 100*((GDP2 - GDP1)/ GDP1)* *GDP2 : gross domestic product growth for year i* *GDP1 : gross domestic product growth for year i-1*
	Intellectual	***% Projects Supported by the Government : for time period***	%PSG per last 3 years	*%PSG = 100*(Number of PSG for smallholders / Number of total PSG)*
		% Projects Supported by Private Investment for time period	%PSPI per last 3 years	*%PSPI = 100*(Number of PSPI for smallholders / Number of total PSPI)*
		% Vulgaridastion Program for smallholders for time period	% VPS per last 3 years	*%VPS = 100*(Number of VP for smallholders / Number of total VP of the region)*
Social	**Internal - social**	***(%) of Permanent Employees for the Agricultural activity per year***	% PEAS for year i	*% PEAS =100*(Number of PEAS / Number of total employees (permanent and seasonal) in the region)*
		Labor hours in the agriculture sector of the region (hour/ year)	LH (hr/year)	Data from actor

Appendix 5 List of indicators per sustainability capital and dimension for the citizen

Dimension	**Capital**	**Category of indicators and/or Indicator**		**Unit**	**formulae**
Environmental	**Natural**	**Sustainable**	***% of purchase of local products***	**%**	100* Number(or weight) of local agri-food products purshased per time period/ total number (or weight) of agri-food products for that time period

		consumer behaviour	***% of purchase from local markets (the nearest shops or neighborhood)***	**%**	100* Number of products (or weight) purshased from local markets per time period/ total number (or weight) of agri-food products for that time period
			% of purchase of organic or labeled /certified products	**%**	100*Number (or weight) of labeled or certified (organic) products per time period/ total number (or weight) of agri-food products for that time period
			% of purchase of pesticide free products	**%**	100*Number (or weight) of pesticide free products per time period/ total number (or weight) of agri-food products for that time period
		Energy	***Carbon footprint (CF)***		CF (consumption level) = CF (food acquisition) + CF (Food storage-preparation-cooking) + CF (consumption) +CF (food waste and disposal) CF(food acquisition) = distance traveled to purchase food * emission factor (co2/km)
				Kg CO_2-equivalent/ per person	CF (Food storage-preparation-cooking)=Energy Consumption (kWh) × Emission Factor (kg CO_2eq. per kWh)
					CF(waste disposal) = CF(food waste) + CF(packadging waste); CF (packaging waste)= sum (amount of packaging waste generated by consumers category i (KG/ time period*emission factor (packaging type i) (kg or g CO_2 eq per Kg)); CF (waste of food)= sum (% of waste of Food category i * (consumed amounts of food category i (Kg/ time frame) *carbon intensity (food category i) (kg or g CO_2 eq per Kilojoule or Kg))
		Water	***Water used for domestic use (WU)***	m3/year : capita	Data from actor
			Water Footprint (WSF)	m3 H2O eq.	Water Scarcity Footprint [m3 H2O eq.] = Water Consumption (including direct and indirect water used) / Water Availability
		Waste	***Food waste (FW)***	(Kg/week)	Quantity of food waste =sum (%waste per food category i* quantity consumed of food category i)

Economic	**Financial**	***Cost food consumer***	TND or EURO per time period (week)	data from actor
Social	**Internal-social**	***Number of participation in actions to raise awareness of sustainable development***	Number of actions/year	data from actor
	External-social	***Local Availability of Products***	% per period (month)	100*(Number of local Agri-food purchased products per product category per month/ Total number of agri-food purchased products per product category per month) Product category: fruits, vegetables, meet, fish, processed food products