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Assessing Agri-food supply chain multi-capital sustainability using Simple Multi-Attribute Rating Technique: the policy maker case study

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Abstract

Sustainability assessment of the agri-food supply chain (AFSC) is crucial to derive policies and strategies aimed at improving its sustainability capabilities. This paper develops a multi-criteria decision-making (MCDM) methodology to evaluate sustainability performance of the policy maker as an AFSC actor. A combination of MCDM methods: simple multi-attribute rating technique (SMART), additive and multiplicative aggregations, and their hybridization are investigated for calculating the composite sustainability index and sub-indices while considering the multi-capital framework. Based on a set of defined indicators, the proportionate technique was applied for normalization. Second, based on the policy-maker judgment, the simple multi-attribute rating technique was proposed to weight indicators, sustainability capitals, and dimensions. Finally, the weighted sum and weighted product methods as well as a hybrid aggregation approach were considered to calculate sustainability index and sub-indices. To validate the proposed approach, a Tunisian policy-maker case study was conducted. Real data from years 2015 and 2020 were considered. The results showed the superiority of 2015 in terms of sustainability. Furthermore, the analysis of sustainability performance for both years was carried out based on sub-indices to identify major causes. This work sets the route for developing a sustainability dashboard to monitor the sustainability performance of an AFSC actor.

Keywords: Sustainability assessment, Agri-food supply chain; Multi-criteria decision making; Simple multi-attribute rating technique, Multi-capital sustainability framework

1. Introduction

Agri-food production in developing countries faces ongoing challenges, marked by inefficiencies and losses throughout the agri-food supply chain (AFSC). Issues like inadequate storage methods, post-harvest wastage, and transportation hurdles contribute to the vulnerability of agricultural and food supply systems (El Bilali et al., 2021). Moreover, external factors such as climate change, pests, diseases, and global crises like conflicts and the COVID-19 pandemic exacerbate these challenges, impacting various stakeholders from farmers to consumers (McGreevy et al. 2022; Longo et al., 2023).

Addressing these challenges requires resilient and sustainable AFSCs capable of efficiently handling disruptions (Agnusdei and Coluccia, 2022; Çakmakçı et al., 2023). In the literature, most proposed solutions by researchers focus on digitalizing agri-food logistics such as: enabling consumers/ producers to follow their deliveries in real-time using tracking systems; minimizing the environmental impacts through optimal routing solutions; assisting farmers and the other AFSC actors in monitoring their activities effectively through

IoT utilization; and sustainability evaluation by exploiting digital tools to assess the sustainability of various activities, offering medium and long-term visibility into resources and sustainability capitals(Chabouh et al., 2023a ; 2023b, Longo et al., 2023 ; Amamou et al., 2023; Cimino et al., 2023). Governments and policymakers play a crucial role in driving this transformation through policy measures that promote sustainability (FAO, 2017). Their responsibilities range from establishing long-term strategies and consistent policies to providing incentives and ensuring fair competition and transparency (Castillo-Díaz et al., 2023). Assessing the sustainability of AFSCs is essential for understanding the system's strengths and weaknesses and guiding effective short and long-term actions aimed at improving its sustainability capabilities. (Liang et al., 2023; Singh et al., 2012; Ness et al., 2007).

This paper sets out to develop a tool to assist policymakers in assessing the sustainability of AFSCs. Calculating sustainability indicators and indices is one of the most used tools in sustainability assessment Singh et al., 2012; Schöggl et al., 2016; Ahmad et al., 2023). Our objective is to propose a methodology for calculating sustainability index and subindices while accounting for the multi-capital sustainability framework (Amamou et al.? 2023) and policy maker priorities regarding indicators, capitals and dimensions.

The remainder of the paper is organized as follows. In the following section, a state of the art of sustainability assessment methodology, namely the composite indicator approach, and a background on mutli-capital sustainability are presented. At the end of this section the contributions of this study are highlighted. In section 3, the methodology of sustainability index calculation is described. In section 4 the case study and its data are presented. The results of the application of the approach for the Tunisian policymaker and their discussion are provided in section 5.

2. State of the art

The literature outlines various approaches to sustainability assessment, that can be broadly categorized into two major groups: "product-based assessment" such as life cycle assessment approaches that focus on flows related to the production and consumption of goods and services, and “Indicator approach” which involves calculating indicators and indices (Singh et al., 2012; Schöggl et al., 2016; Ahmad et al., 2023). In our study, we are interested in the second group. Within this category, the composite indicator (CI) concept has been and is still widely accepted in sustainability assessment literature for its effectiveness in public outreach and policymaking, its multidimensionality, simplicity, quantifiability, and ability to identify trends promptly (Schöggl et al., 2016; Castillo-Díaz et al., 2023).

CI construction involves different steps: indicators selection and calculation, normalization, weights assignment, and aggregating the selected indicators from various dimensions, categories, or capitals into a single index. Nardo et al., 2005). Multi-criteria decision methods (MCDM) are highly suitable for CI building and have been especially used to derive the last two steps (Greco et al., 2019; El Gibari et al., 2019).

The aim of this paper is to define an MCDM approach for sustainability index calculation based on several measured sustainability indicators for AFSC policymakers while considering a multi-capital-sustainability framework.

MCDM weighting methods are categorized in Subjective and Objective approaches (Greco et al., 2019). Given the context-dependent nature of AFSC sustainability, the stakeholders' perspectives are pivotal in indicator weighting (Talukder et al, 2017; Chabouh et al. 2023b). For this purpose, our focus in this paper is on subjective weighting methods that rely on decision-maker preferences. Ezell et al. (2021) outlined a taxonomy of subjective weighting methods in MCDM problems, among which the Simple Multi-Attribute Rating Technique (SMART) (Edwards, 1977) was selected for this study. For the aggregation step, different classifications have been proposed in the literature (Greco et al., 2019; El Gibari et al., 2019; Cinelli et al., 2014). The application of elementary methods (El Gibari et al., 2019) that allow full and partial among indicators (Greco et al., 2019; El Gibari et al., 2019; Cinelli et al., 2014) is investigated in our research paper.

The chosen approaches will be applied under a multi-capital sustainability framework. This latter provides a comprehensive approach for evaluating the impacts of a company or an actor's practice on multiple capitals belonging to the three primary sustainability pillars: social, economic, and environmental (Steblyanskayaa et al. 2022). This methodology is gaining popularity and being applied across various industries (Amamou et al., 2023, Bellahirich et al., 2024) instead of the traditional Triple Bottom Line (TBL) framework, which considers only three dimensions of sustainability. The TBL has been criticized for its limited scope in addressing sustainability issues comprehensively (Sridhar and Jones, 2013). True sustainability involves more than these three dimensions; it requires understanding which resources should be developed and protected for the future, ensuring equitable benefits for all, and sustaining positive changes over time (Mor et al., 2021). The TBL framework often falls short, particularly in complex sectors. As a result, researchers advocate for incorporating additional categories to gain a more thorough understanding of sustainability (McElroy and Thomas, 2015; Longo et al. 2018). These can be further divided into different types of sustainability capitals. For each capital, several sustainability indicators. Indicators aligned with each of these capitals, are identified based on the characteristics, or attributes of a particular context.

To summarize this section, the contributions of our work can be enumerated as follows:

i. Definition of a methodology for calculating the composite sustainability index, dimensions, and capitals indices using the indicators associated with each capital under consideration with the dimension economic, social, and environmental pillars. Furthermore, a combination of MCDM methods: SMART, additive and multiplicative aggregations, and their hybridization are investigated within this work. To our knowledge, the SMART technique along with the hybrid aggregation approach considering the hierarchical structure of sustainability indicators involving their categorization into capitals is for the first time addressed in AFSC sustainability literature.

ii. Validation and application of the defined methodology to a real case study: Tunisian policymaker. To our knowledge, this is the first study that addresses the Tunisian context, especially using official data from the ministry of agriculture and fisheries.

3. Material and Methods

Creating a Composite Sustainability Index (SI) involves several steps, including selecting individual indicators, collecting necessary data, normalizing the data, assigning weights, and finally, aggregating them (Singh et al., 2012; Gomez Lemon et al., 2020; Mazziota and Pareto, 2013). The initial set of sustainability capitals and indicators for the AFSC are considered as inputs in our methodology illustrated in Figure 1: normalization, weighting, and Aggregation. The aggregation and weighting steps consider the hierarchical structure of the multi-capital sustainability as shown in figure 2. Sustainability encompasses three dimensions; environmental, economic, and social. Under each dimension, one or several capitals can be considered. For each capita, one or different indicator categories are defined. Each category is determined by one or more indicators.

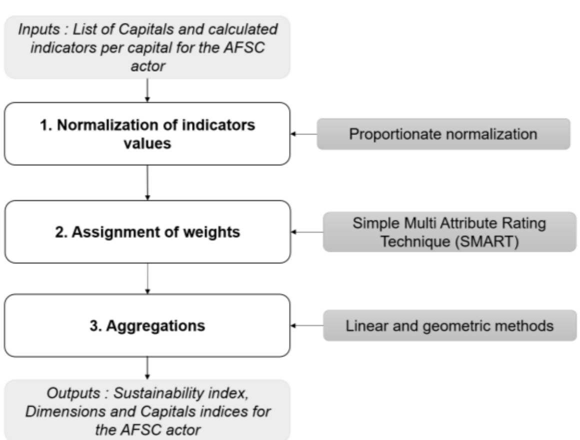

Figure 1 Methodology for sustainability index calculation for the AFSC.

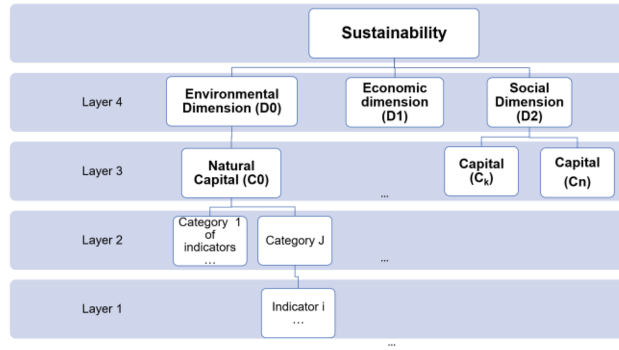

Figure 2 The hierarchical structure of the multi-capital sustainability.

3.1. Normalization

Normalization is the process of transforming indicator values which are usually obtained using different measurement units to a common scale or dimensionless values making them comparable and removing the impact of different units or scales; so that they can be aggregated more equitably (Pollesch and Dale, 2016).

In this paper, the proportionate normalization technique is used to normalize all the gathered indicators measurements to values between 0 and 1 using Equations. (1) and (2). Eq. (1) (respectively (2)) is used for beneficial (respectively non-beneficial indicators) i.e., having a positive (respectively a negative) effect on sustainability performance. Using the proportionate method, the individual indicator value is divided by the sum or the mean of the values of the attributes for different measurements of scenarios of that indicator's values. (Talkuder et al., 2017). In our case, sustainability assessment is conducted for a specific actor (only one) within a given AFSC, hence a scenario refers to a year of activity of that specific actor. A scenario can also refer to a country or a region if the objective is to compute and compare SI for different countries or regions.

$$X_{j,s} = \frac{x_{j,s}}{\sum_s x_{j,s}} \quad (1)$$

$$X_{j,s} = \frac{1/x_{j,s}}{\sum_s (1/x_{j,s})} \quad (2)$$

Where $X_{j,s}$ is the normalized value of indicator j for measurement or scenario s. $x_{j,s}$ is the initial value of indicator j for measurement or scenario s.

3.2. Weighting

Weighting involves assigning relative importance to individual indicators used in constructing CI. Our focus in this paper is on subjective weights, primarily based on expert judgment reflecting the preferences of AFSC actors regarding indicator importance within a CI. The SMART (Ezell et al., 2021; Edwards, 1977) method is applied in this paper, it indirectly determines weights by systematically comparing attributes with those assumed or selected as least or most important based on expert opinion. Figure 3 illustrates the steps of the SMART method. This technique involves four steps that are applied for each layer of the hierarchical structure of sustainability indicators as shown in Figure 2. The first three steps involve collecting expert judgments. Experts rank indicators according to their relative importance to select the most important attribute, which is then assigned a reference score (e.g., 10 points). Subsequently, experts evaluate the importance of other indicators relative to this reference point. Once this data is gathered, the fourth step, "calculate weights," is executed by normalizing each indicator's score (obtained in step 3) against the total score of all indicators as shown in Equation 3.

$$w_j = \frac{score\ of\ the\ indicator\ j\ within\ a\ given\ category}{\sum_j score\ of\ j\ \ of\ that\ category} \quad (3)$$

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

3.3. Aggregation

The process of aggregation requires finding a suitable function that can merge multiple indicators into a composite indicator (Greco el al., 2019). The primary consideration in aggregation is the trade-off between indicators' compensability. Linear functions are used in compensatory methods to tackle discrepancies among indicators, while non-compensatory approaches rely on unbalanced-adjusted functions (Greco et al. 2019; El Gibari et al., 2019). The academic literature offers a wide range of aggregation functions to choose from. Commonly used aggregation methods include simple additive weighting (SAW), weighted product (WP), and weighted displaced ideal. In this paper, the SAW and (WP) are applied. These elementary MCDM methods, especially SAW, are commonly used in CI and SI construction (El Gibari et al., 2019) in different fields: AFSC (Gómez-Limón and Sanchez-Fernandez, 2010), manufacturing industry (Kaldas et al., 2020), Building Industry (Dobrovolskienė and Tamošiūnienė, 2015) urban landscape (Haider et al., 2018) environmental index construction (Arbolino et al., 2018), energy sector's sustainability assessment (Sahabuddin and Khan, 2021).

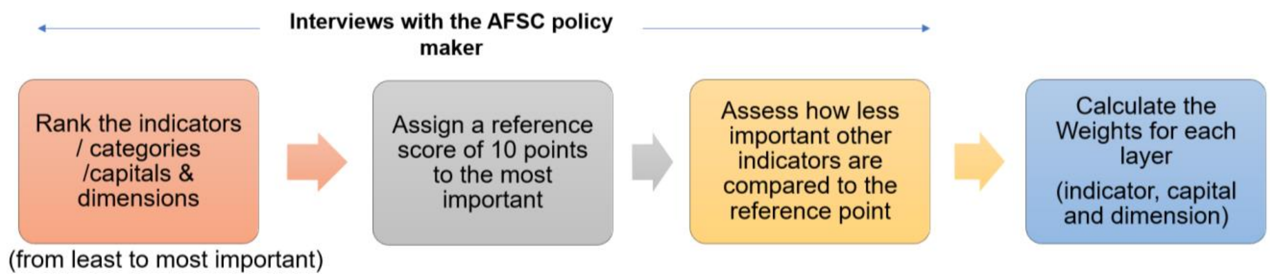

Figure 3 Steps of the SMART weighting method.

3.3.1. *Simple additive weighting (SAW)*

The SAW methodology offers straightforwardness and the ability to visually represent the proportionate impact of each indicator on the CI. The normalized and weighted criteria are added up to derive the SAW, which is done as illustrates equation (4):

$$CI_{i,s} = \sum_j w_j \times X_{i,j,s} \quad (4)$$

For a scenario or a measurement s and a class i (i.e., a dimension, a capital or a category of indicators within a capital).

$CI_{i,s}$ is the composite index for the class i and related to the scenario s.

$w_j$is the weight of indicator j within the class i and $X_{i,j,s}$) is the normalized value of indicator j within the class i for scenario s.

This technique has a potential drawback regarding compensability, wherein a low score in one indicator might hide a high score in another; in other words, a deficiency in one indicator or dimension may be compensated by a surplus in another (Greco et al.,2019).

3.3.2. *Weighted product (WP)*

WP is another elementary aggregation function that heavily penalizes systems for poor performance in certain attributes. Following the same notations presented above, the formula for WP can be expressed by equation (5).

$$CI_{i,s} = \prod_j X_{i,j,s}{}^{w_j} \quad (5)$$

Although WP is not commonly used in constructing CI (Nardo et al., 2005), it has garnered attention due to its desirable features, such as its semi-compensatory nature, meaningfulness for ratio-scale indicators, and minimal information loss. The specific contributions of each indicator to the CI are not presented as in SAW (Zhou and Zhang, 2018). Moreover, WP is more robust than SAW regarding weights variation for sustainability assessment problems (Sahabuddin and Khan, 2021).

3.3.3. Aggregation procedure

After determining indicators, capitals and dimension weights via the SMART method, the objective is to propose an aggregation procedure that considers the hierarchy of sustainability indicators. According to Mazziotta and Pareto (2013), environmental, economic, and social dimensions in sustainability are non-substitutable which require the use of non-compensatory aggregation approach. In this study, three aggregation procedures are proposed:

i) SAW: it is applied for all layers of the multi-capital sustainability hierarchy

ii) WP: it is applied for all layers of the multi-capital sustainability hierarchy.

iii) SAW-WP: SAW is applied for layers 1,2 and 3 corresponding to indicators, categories, and capitals within each dimension. After, the WP is used for aggregating dimension values into the final sustainability index (SI). This hybrid approach can be especially considered in the case of null values for some individual indicators and when some capitals may encompass only one indicator that could have a null value. In this case, SAW will be used for aggregating indicators within a given category, categories within a given capital, and capitals within a given dimension.

4. Case study

The Tunisian policymaker is considered as a case study in this paper. This case study is considered within the SMALLDERS project and focuses on the urban agricultural region of "Cap Bon" in northeast Tunisia. This area is well known for its agricultural activities' diversity. It is also the first for many crops production such as citrus, strawberry, and grapes in the country as well as other vegetables (potato, tomato…). This area has many smallholders, and among which there are family farms. In our experimental study, the Nabeul Regional Commission for Agricultural Development (RCAD), under the Tunisian Ministry of Agriculture, Hydraulic Resources, and Fisheries, serves as the Tunisian policymaker. Based on interviews, one-to-one meetings, and a survey conducted with this actor, as well as a study by Chabouh et al. (2023b), this policymaker's capitals involve the Natural, Financial, Intellectual, and Internal Social. The list of indicators and their hierarchy are presented in Figure 4.

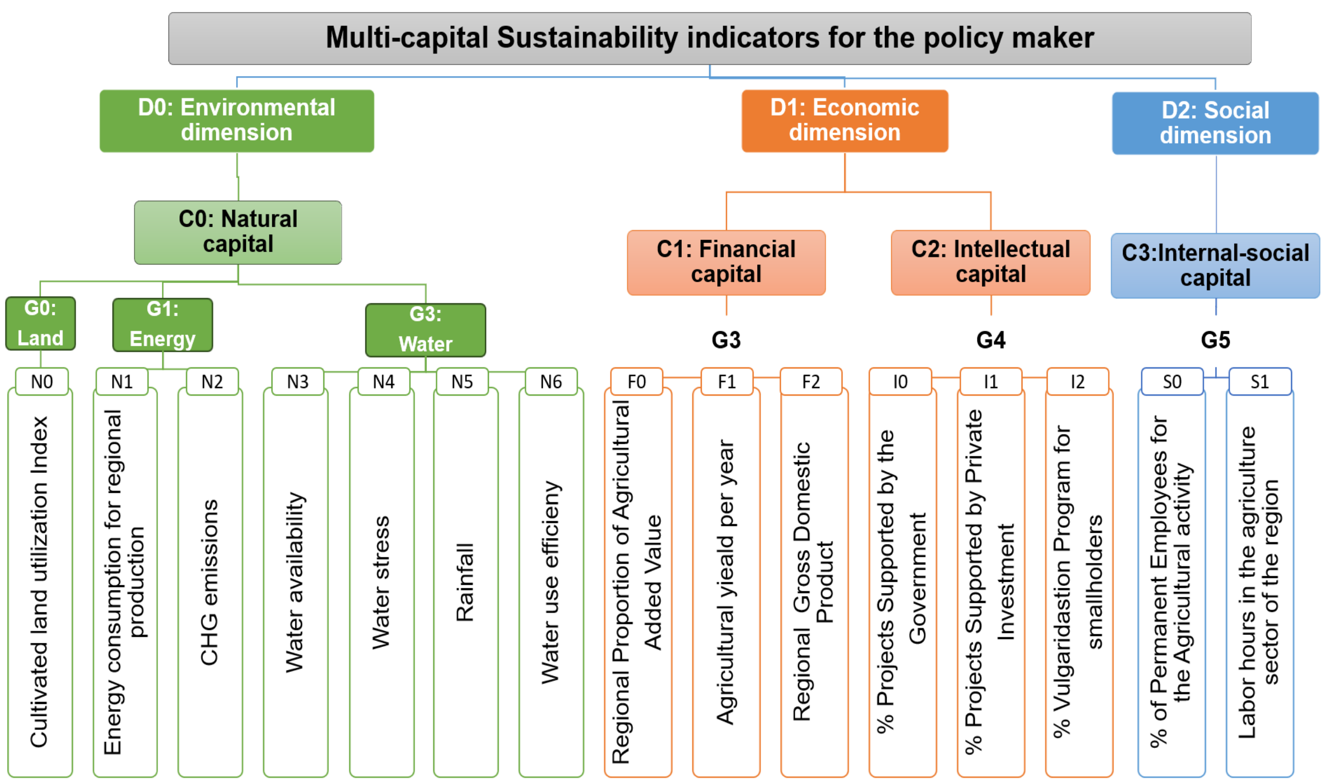

Figure 4 List of indicators and their distribution for the Tunisian policy maker.

Table 1 Raw and normalized value of the policy maker's indicators for years 2020 and 2015.

Dimension	Capital	Category of indicators	Indicator Index	Unit	Values of 2015	Values of 2020	Normalized values of 2015	Normalized values of 2020
Environmental	Natural	Soil	N0	Dimensionless	0,33	0,42	0,56	0,44
		Energy	N1	GWh/year	124,15	157,49	0,56	0,44
			N2	KtCO2eq	4288,20	6132,45	0,59	0,41
		Water	N3	M3/person/year	346,00	264,00	0,57	0,43
			N4	%	134,70	156,30	0,54	0,46
			N5	Mm/Year	400,00	408,00	0,50	0,50
			N6	%	67,26	80,52	0,46	0,54
Economic	Financial	-	F0	TND	572,99	893,87	0,39	0,61
			F1	t/ha/year	19,85	19,43	0,51	0,49
			F2	Billion USD	45,78	42,54	0,52	0,48
	Intellectual	-	I0	%	72,0	72,0	0,5	0,5
			I1	%	72,0	72,0	0,5	0,5
			I2	%	72,0	72,0	0,5	0,5
Social	Internal social	-	S0	%	15,0	15,0	0,5	0,5
			S1	Hours /agricultural year	240000	240000	0,5	0,5

5. Results and discussion

Based on case study data, two scenarios were evaluated for the Tunisian AFSC policy maker corresponding to years 2015 and 2020.

First, the weights of the multi-capital sustainability indicators were calculated based on SMART method and collected expert (policy maker) judgement regarding indicators, capitals, and dimensions importance. Then SAW and WP were applied to calculate the sub-indices of indicators' categories, capitals, and dimensions. The obtained weights and values for years 2015 and 2020 are illustrated in Table 2. Finally, by applying the aggregation procedures defined in subsection 2.3.3, sustainability indices for years 2015 and 2020 were calculated. The comparison of these procedures in terms of sustainability index is provided in Figure 5.

The results presented in Figure 5 show that the three aggregation procedures yield equivalent sustainability indices and sub-indices which suggests that the choice of the method depends on the sustainability paradigm assumed by the decision maker. Hence under a strong sustainability paradigm, the compensability between indicators and dimensions especially is not allowed which promotes the use of WP. Whereas, under weak sustainability paradigm, compensability is permitted, and SAW becomes more appropriate. From this figure, it can be also concluded that the best sustainability performance occurred in the year 2015. These findings suggest that the Tunisian policy maker is more sustainable for year 2015 than 2020.

A comparison between the environmental, economic, and social performances of the actor for 2015 and 2020 (Table 2) demonstrates a decrease in the environmental performance in 2020, contrary to the economic one. Consequently, the index of the natural capital is higher for 2015. This can be explained by the higher environmental performance for 2015. Although the economic dimension yields a better value for 2020, the importance of the environmental dimension compared to the economic one, both having importance weights of 0.47 and 0.19 respectively, favors 2015 in terms of sustainability performance. Analyzing the environmental indicators, it turns out that in the year 2020 yielded better water-related performance, however the energy and land categories were better for 2015. The respective weights of Land and energy categories together are higher than the water one which explains the environmental index values for both years. These findings demonstrate the great impact of weights distribution on the composite indicator calculations.

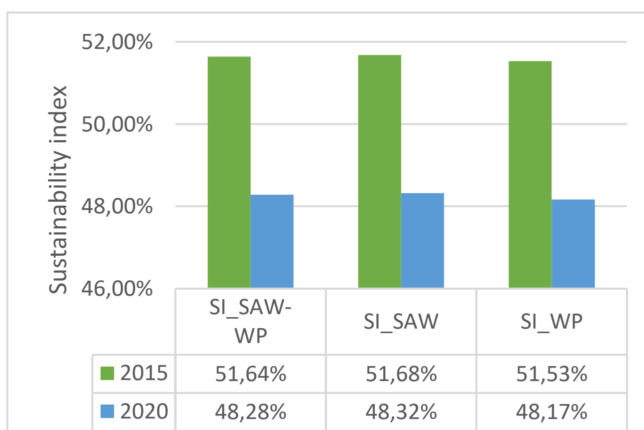

Figure 5 Comparison of aggregation procedures in terms of the policy maker sustainability index for years 2015 and 2020.

Table 2. The SMART Weights for sustainability dimensions and capitals as well as the dimensions and capitals values yielded by SAW and WP for years 2015 and 2020 for the Tunisian policy maker.

		Weights	SAW		WP	
			2015	2020	2015	2020
Dimensions	Environmental	*0,47619048*	53,77%	46,23%	49,44%	46,04%
	Economic	*0,19047619*	49,39%	50,61%	49,29%	50,53%
	Social	*0,33333333*	50,00%	50,00%	50,00%	50,00%
Capitals	Natural		53,77%	46,23%	49,44%	46,04%
	Financial	*0,25*	47,57%	52,43%	47,22%	52,16%
	Intellectual	*0,75*	50,00%	50,00%	50,00%	50,00%
	Internal social		50,00%	50,00%	50,00%	50,00%
Category of indicators	Soil	*0,3462*	55,78%	44,22%	55,78%	44,22%
	Energy	*0,2692*	57,22%	42,78%	57,20%	42,75%
	Water	*0,3846*	49,53%	50,47%	49,35%	50,28%

Regarding the financial capital, 2020 is better that 2015 as can be seen from Table 2. The normalized values of the financial capital indicators are illustrated in Figure 6. It shows that the improved financial performance for 2020 is due to the greater value of the indicator Proportion of Regional Value Added as shown in Figure 6. These findings show the impact of Covid-19 crisis on sustainability performance (year 2020) which has decreased related to 2015. These impacts are especially visible for the financial indicators "Annual agricultural yield and Gross domestic product". The impact is not visible for both the intellectual and internal-social capitals due to the consideration of indicators based on permanent measures (e.g., not considering the seasonal jobs).

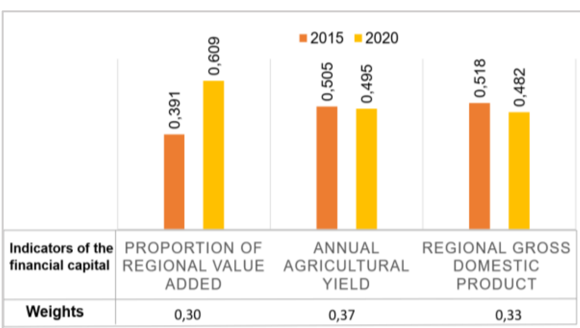

Figure 6 Normalized values of the financial capital indicators for 2015 and 2020.

6. Conclusions

This paper proposed a methodology for the multi-capital sustainability assessment for the policy maker: a crucial AFSC actor that defines policies and directions for AFSC practices. Our method departs from some data on indicators and their distribution among capitals and dimensions for a real case study: the Tunisian policy maker (RCAD). First, based on the available data, the proportionate normalization method was chosen for the first step. Second; the SMART method was used for collecting and calculating policymakers' priorities regarding indicators, capitals, and dimensions considering the inherent hierarchical structure of sustainability indicators. Second, elementary multi-criteria decision-making methods (SAW and WP) and their combination (SAW-WP) were considered as aggregation methods for calculating the sustainability index and subindices (values of dimensions and capitals). Their popularity in composite indicators literature justifies their use in our study. Moreover, these methods illustrate two important paradigms in sustainability assessment: weak vs strong sustainability. The application of these methods for the Tunisian policymaker on real data from years 2020 and 2015 validated our methodology and showed the superiority of 2015 in terms of sustainability. The exploration of dimensions, capitals, and indicators categories values as well as their weights explained the results achieved for sustainability indices.

This work sets the route for i) developing a sustainability dashboard to monitor the sustainability performance of an AFSC actor, ii) developing a more advanced assessment methodology that incorporates the subjective expert judgment as along with indicators data in deriving the different weights that significantly impact the SI. MCDM approaches such as data envelopment analysis and its variants could be investigated.

As critical point of view, this research work presents some limitations in the normalization method and the set of available data, which only included two scenarios. In fact, the normalized values of indicators can better reflect the real situation if multiple measurements and scenarios are considered. To overcome this limitation, the normalization method should integrate a benchmark or a reference value to which all scenarios' data are compared. This practice is recommended in sustainability assessment literature (Pollesch and Dale, 2016), but such data may not be easily accessible due to the contextual nature of AFSC sustainability (Talkuder et al., 2017, Chabouh et al., 2023 b). Another limitation of this work is that more indicators could be integrated into this approach to reflect comprehensively some critical social aspects such as unemployment and health safety (Sannou et al., 2023).

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