Sustainability Assessment Tool (SAT) – detailed instructions

The sustainability assessment tool developed in the context of the INNOBIOVC project is an excel matrix, in which the "value chain tester" who want to exploit its 3 dimensions of sustainability (environmental, economic, social) insert required data and compares its value chain to a "benchmark one". The developed tool will allow not only to compare the new value chain to an already developed and stable one but also to identify "hotspots" to be improved, to increase value chain sustainability.

Currently, the SAT is available for the value chains targeting the following bio-based products:

- Lactic acid
- Succinic acid
- Glycerol
- Polymers (mainly PLA)
- Aminoacids (mainly lysine and glutamate)

1. SAT "state of the art"

To better understand the "state of the art" in which SAT develops, a bibliographic analysis on Web of science has been conducted looking for publications related to "sustainability assessment" and "assessment bio based value chains". Through bibliographic analysis, it has been revealed that the current state of sustainability assessment predominantly focuses on evaluating environmental sustainability. This is frequently accomplished through methods like Life Cycle assessment analysis. However, other dimensions of sustainability, such as social and economic aspects, are often not given the same level of attention.

Though, the analysis unveiled several instances of "more comprehensive" sustainability assessments. The following three papers are noteworthy examples:

- Lokesh K.,*Bridging the Gaps for a 'Circular' Bioeconomy: Selection Criteria, Bio-Based Value Chain and Stakeholder Mapping* (2018) (Doi: 10.3390/su10061695).

  This paper exploits a systematic approach based on two-tier multi-criteria decision analysis (MCDA), useful in supporting the identification of promising bio-based value chains significant to the EU plans for the bio-economy. Their identification is followed by an elaborate mapping of the value chains to visualize and foresee the strengths, weaknesses, opportunities and challenges attributable to those bio-based value chains. A systematic review of 12 bio-based value chains is performed, prevalent in the EU, mapping interactions between the different stages, chain actors, employed conversion routes, product application and existing/potential end-of-life options.

- Petit, Gaëlle and Sablayrolles, Caroline and Yannou-Le Bris, Gwenola, *Combining eco-social and environmental indicators to assess the sustainability performance of a food value chain: A case study,*(2018) (Doi: https://doi.org/10.1016/j.jclepro.2018.04.156).

  The aim of this paper is to assess the sustainable performance of food products or processes combining LCA, SCR and MADM-specific framework. SCR stands for "Social corporate responsibility" and MADM for "Multiple-Attribute Decision-Making framework". CSR is mainly focused on the social pillar of sustainability. This political approach has been instrumentalized through international standard ISO 26000 in order to help companies and organizations reduce their externalities on both society and the environment. MADM instead, refers to making preference decisions via assessing a finite number of pre-specified alternatives under multiple and usually conflicting attributes.
- Nirit Havardi-Burger, Heike Mempel, Vera Bitsch, *Framework for sustainability assessment of the value chain of flowering potted plants for the German market*, (2021) (Doi: https://doi.org/10.1016/j.jclepro.2021.129684). The primary objective of this paper is to create indicator-based assessment methods that offer valuable insights into the sustainability performance of agricultural value chains for flowering potted plants (FPPs). The assessment focuses on addressing environmental, social, and economic sustainability challenges associated with the entire FPP value chain, from breeding to distribution. A comprehensive framework was established for conducting sustainability assessments within the FPP value chain. The study draws inspiration from the Sustainability Assessment of Food and Agriculture Systems (SAFA) approach. However, it should be noted that SAFA does not encompass all sustainability subthemes, hence the need for a more tailored framework to address the specific complexities of the FPP industry.

2. SAT description

The SAT is practically an excel file in which the "tested value chains" is compared to a benchmark sustainable value chain through a methodology named Multi Criteria Decision Making Analysis

(MCDMA). MCDMA is an evaluative approach that combines quantitative and qualitative factors to guide decision-making processes; this method offers a structured framework for assessing multiple options that have conflicting impacts on society, the economy, and the environment [1]. MCDMA allows us to deal with decisions involving the choice of the best alternative among several potential candidates (or options) in a decision, evaluating different aspects of the candidates. Often, cost, price and quality of the processes are among the most common criteria in many decision-making problems [2]. MCDMA is a widely employed decision methodology, applied since 1960 in several articles and books[3]. The MCDMA is based on two elements: options and criteria. Options are compared or ranked based on evaluation criteria, which represent the parameters used to measure the options' performance [4]. Criteria evaluation can be of two types, "maximization" or "minimization", defining which values will be preferred in the analysis; in the first case, worst result (WC) corresponds to the minimum value in the performance matrix, while the best result (BC) corresponds to the maximum value [5]. In the "minimization" evaluation type, lower values will be the preferred ones (BC) while the worst-case outcome corresponds to the highest value (WC).

Weights are assigned to each criterion to reflect their relative importance; the weights indicate priorities regarding the criteria [6]. Each option (the benchmark and the tested value chain) is evaluated against the criteria using appropriate assessment methods or tools. The evaluation results for each alternative are combined into an overall value (performance value), considering the assigned weights for the criteria. Finally, the performance values are used to rank the alternatives and make a decision [7].

To assign weights, Analytic Hierarchy Process (AHP) has been employed. AHP allows to rank a set of alternatives or for the selection of the best one, performing a pairwise comparison of criteria.

AHP requires the involvement of "decision makers" and follows this scheme (Fig.10):

1. **Define the "goal"** clearly identifying the main objective to be achieved;
2. **Establish the hierarchy:** break down the decision problem into a hierarchical structure including the main objective, criteria, and alternatives. The criteria represent the different factors that contribute to the decision, while the alternatives represent the different options being considered;

3. **Pairwise Comparisons:** assess the relative importance or priority of each alternative by conducting pairwise comparisons. Each criterion is compared against every other criteria using a scale of relative importance from 1 to 9;
4. **Calculate Weighted Scores:** calculate weighted scores for each alternative based, these scores indicate the overall preference of each alternative considering the importance (or "weight") of the criteria;
5. **Consistency Checking:** assess the consistency of the pairwise comparisons to ensure the reliability of the results through the consistency ratio index (CR), which measures the degree of consistency in the judgments made during pairwise comparisons;
6. **Analyze and Interpret Results**

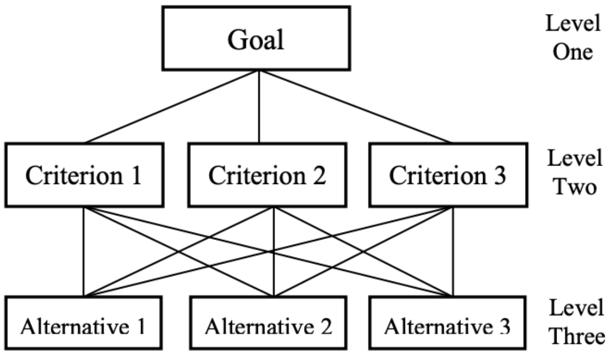

Figure 1 **Sample Hierarchical Tree, Decision Making Using the Analytic Hierarchy Process Hamed Taherdoost.**
In our study, the goal is to determine which factor (criteria) impact the most on consumer's during clothes and cosmetics purchases.

The decision makers involved in this analysis are bio based value chain expert, coming both from big industries and Small Medium enterprises. Value chain experts have been asked through paired comparisons question, which is the most sustainability indicator in a bio based business, through the use of a scale which ranges from one to nine (Fig.14) where:

- 1 implies that the two elements are <u>equally important</u>;

- 9 implies that one element is extremely important than the other one in a pairwise matrix.

Importance Scale	Definition of Importance Scale
1	Equally Important Preferred
2	Equally to Moderately Important Preferred
3	Moderately Important Preferred
4	Moderately to Strongly Important Preferred
5	Strongly Important Preferred
6	Strongly to Very Strongly Important Preferred
7	Very Strongly Important Preferred
8	Very Strongly to Extremely Important Preferred
9	Extremely Important Preferred

Figure 2 **Scores for the importance of variable, Decision Making Using the Analytic Hierarchy Process (AHP); A Step by Step Approach, Hamed Taherdoost (2017).**

The data have been analyzed using "AHP excel template with multiple inputs Goepel, Klaus D. (2013)". The AHP data elaboration workbook consists of 20 input worksheets for pair-wise comparisons and a summary sheet to display the results.

In this case, the participants to the AHP survey are 6, all involved into the bio based business.

The final weight for each sustainability indicator taken into account for the final ranking, has been calculated as weighted average of the performance value of the single indicator in each of the worksheet as follows (1):

$$\frac{\sum_{k=1}^{n} \frac{x_{ij} \times p_i}{p_{tot}}}{100} \quad (1)$$

- x is the specific score for a criterion (j), in a worksheet (*i*);
- p is the total of participants considered in the worksheet I;
- p_{tot} is the total of participants with a CR>45% in the specific category.

Each criterion weight is subsequently multiplied by the criterion value of each value chain, as expressed in equation 2 where S_{ij} is the value chain-specific score (i) for the sustainability indicator (j), and w_j is the indicator's weight.

$$s_{ij} \times w_j \quad (2)$$

Finally, the obtained are summed to obtain an overall score for the benchmark and tested value chains. This latter is expressed in Equation (3) and is the final value.

$$\sum_{k=1}^{n} s_{ij} \times w_j \quad (3)$$

The benchmark data are the result of an average of different data related to the bio based business, coming both from big industries established on the market and small medium enterprises, , in order to have a representative average benchmark value for the analysis.

3. SAT instructions

The SAT evaluation criteria have been selected based both on bibliographic analysis and experts interviews and are the following:

- **Water consumption:** how many cubic meters of water are consumed to produce 1 ton of final product (m3/t), water consumption is a key aspect of sustainable development. By tracking water usage, individuals, businesses, and governments can identify opportunities to reduce water waste.
- **Energy consumption:** This indicator helps evaluate not only the environmental impact of the process, but also resource management and operation costs saving (Mj/ t).
- **Production volume:** how many tons of product are produced in 1 year (t/y). It provides valuable insights into various aspects of a company's operations, performance, and competitiveness in the market.
- **Profit:** the profit gain from 1 ton of product (€/t).
- **Net profit:** the net profit gain (*total profit – production expenses*) from 1 ton of product (€/t).
- **Gender ratio**: the percentage of women workers in the company.
- **Ratio Input/ Output**: in the context of biomass refers to the efficiency of converting a certain amount of biomass into a final product and resource management. This ratio can vary depending on the specific process or industry involved.

Table 1 **SAT criteria, measurement unit, and evaluation type.**

Those criteria have been selected among several ones also because able to be measured in any bio based business, regardless from the final product produced.

Following the AHP procedure, we were able to determine each criteria weight. Weights are shown below in Table 2 and Figure 3.

Table 2 **AHP criteria weights.**

CRITERIUM NAME	MEASUREMENT UNIT	EVALUATION TYPE
Water consumption	m3/t	Minimization
Energy consumption	Mj/t	Minimization
Production volume	t/y	Maximization
Profit	€/t	Maximization
Net profit	€/t	Maximization
Gender ratio	/	Maximization
Input/Output	/	Minimization

CRITERIA	AHP WEIGHT
Water consumption	18,9%
Energy consumption	15,6%
Production volume	5,2%
Profit	1,8%
Net profit	3,4%
Share of females	32,5%
Input/Output	22,6%

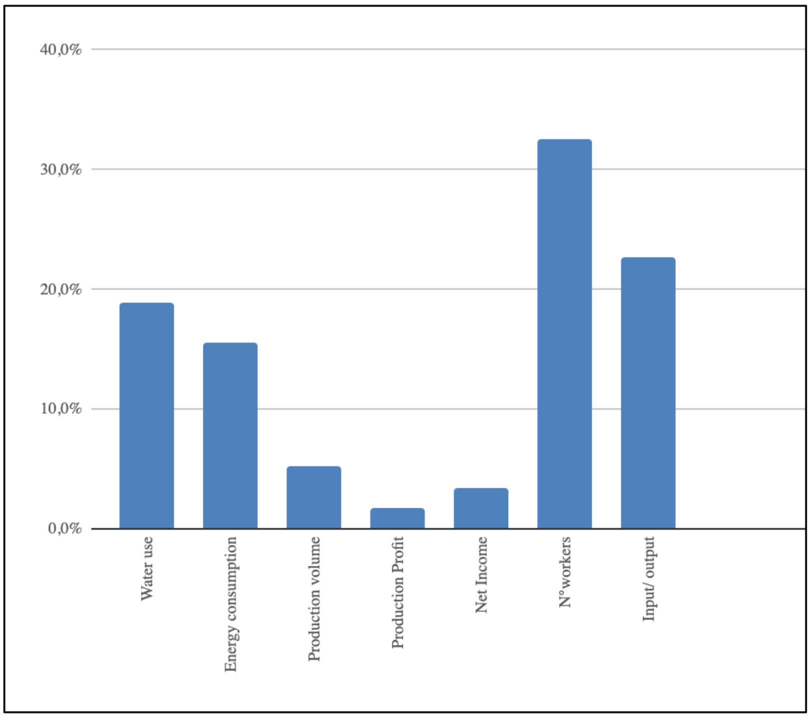

Figure 3 **AHP weights following the survey analysis SAT.**

The SAT alternatives or options are:

- **Benchmark data:** an average value coming from big and small companies being involved in the synthesis of a specific bio-based product category which have been interviewed, considered the best in sustainability practices.
- **Tester company:** the company who want to evaluate its social, economic and environmental sustainability practices.

The SAT is an excel matrix in which the benchmark data are already inserted and fixed. The tester company inserts its own data to be compared to the sustainability benchmark to evaluate its overall sustainability. The SAT furthermore, allows to evaluate sustainability hotspots, which are the indicators in which the company scored less than the benchmark. A color code is used as following. For “maximization” evaluation type (see table 1):

- Green: values with a score greater than 80% of the benchmark value
- Yellow: values lesser than 79% and greater than 45% of the benchmark value
- Red: value lesser than 44% of the benchmark value

For “minimization” evaluation type (see table 1):

- Red: values with a score greater than the benchmark value

- Green: value lesser or equal to the benchmark value

A graphic representation of data comparison for each category is present on the excel matrix, this is useful to identify hotspots. Once again, hotspots are sustainability categories in which the tester company data are drastically far from the benchmark data, meaning correct management and improvements are needed.

4. Benefits of the SAT for the companies using it

- **Comprehensive Sustainability Evaluation**: The SAT offers a holistic assessment of bio-based processes or products, covering environmental, social, and economic dimensions. This comprehensive evaluation provides companies with a clear understanding of their sustainability performance.
- **Benchmarking for Improvement**: By comparing against established benchmarks in the industry, the SAT helps companies identify areas for improvement and best practices. This benchmarking feature guides companies toward industry standards, allowing them to enhance their sustainability practices and identify hotspots in the process.
- **Strategic Decision-Making**: The tool provides a structured approach to decision-making through Multi-Criteria Decision Making Analysis (MCDMA). With visual representations and an overall performance score, companies can make informed and strategic decisions to improve their sustainability across the entire value chain.