ASSESSING AGRICULTURAL SUSTAINABILITY WITHIN A FARM MANAGEMENT INFORMATION SYSTEM: A REVIEW OF INDICATORS

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ABSTRACT

The use of Farm Management Information Systems (FMIS) is spreading over the last years facilitating operational management leading to increased productivity while minimizing the relevant production costs. FMISs use indicators in order to benchmark the performance of a cultivation usually in terms of its economic return and its environmental impact. However, these are mostly standalone indicators that are not combined and holistically examined towards the determination of an agricultural system's overall sustainability. It is also very important to note that the assessment of agricultural sustainability has been a continuous debate within the scientific community and still a commonly used methodology has not been established. Several methodologies and frameworks have been employed most of which use sets of indicators to assess the economic, environmental and social impacts of agricultural operations. Attempting to address the issue of sustainability benchmarking within a FMIS this paper presents a literature review of sustainability indicators that are used in agricultural sustainability studies at farm level. A total of 36 studies were thoroughly examined in order to extract the individual economic, environmental and social indicators that were employed. The indicators were categorized depending on the examined theme and a frequency analysis was conducted in order to determine the most frequently used. Ultimate goal of the review is to arrive at an easily computable and comprehensible system of indicators that could be used in a Farm Management Information System providing the stakeholders with integrated information regarding the overall sustainability performance of their cultivations.

Keywords*:* Farm Management Information System, agricultural sustainability, indicators, review

1. INTRODUCTION

In recent years the use of agricultural production management tools has become widespread. The need for management of farming practices has become essential especially due to the intensification of agriculture in order to meet the increasing food and energy demand (Rodias *et al.*, 2019). Nevertheless, this intensification is linked to a plethora of impacts related to the environmental, economic and social aspects of agricultural production that are associated with the excessive use of plant protection substances, fertilizers and water as well as with changes in land use (Bockstaller *et al.*, 2009) which put the sustainability of the practices used into question (Rodias *et al.*, 2017). In the case of agricultural sustainability, no definition, universally accepted by the scientific community, has been formulated yet. However, in order to assess sustainability in its entirety all three pillars of

sustainability, namely the environmental, the economic and the social, should be addressed (Pham and Smith, 2014; Banias *et al.*, 2017; Lampridi, Sørensen and Bochtis, 2019).

Considering the above, the integration of sustainability assessment into the process of agricultural production management becomes of particular importance (Marinoudi *et al.*, 2019). Regarding the assessment of agricultural sustainability a large number of methodologies and tools have been developed (Cerutti *et al.*, 2011). There are tools that have gained the general public acceptance such as Life Cycle Assessment (LCA) which is standardized with ISO (De Luca *et al.*, 2015). Additionally, several methodologies and tools have been proposed that mainly employ indicators for evaluating the sustainability of an agricultural system (Gómez-Limón and Sanchez-Fernandez, 2010). To that end, the standardization of sustainability assessment methodologies for agricultural practices is a complex task as it includes many methodologies and variables that vary on each case study (Lampridi *et al.*, 2019). The situation becomes more and more complex when trying to integrate such tools into a Farm Management Information System (FMIS) (E. Rodias *et al.*, 2017).

For this reason, the purpose of this paper is to investigate the indicators used to evaluate agricultural sustainability based on an extensive literature review and identify those that could be used within a FMIS. A total of 36 studies were thoroughly examined in order to extract the individual economic, environmental and social indicators that were employed. The indicators were categorized depending on the examined theme and a frequency analysis was conducted in order to determine the most frequently used. Ultimate goal of the review is to arrive at an easily computable and comprehensible system of indicators that could be used in a FMIS providing the stakeholders with integrated information regarding the overall sustainability performance of their cultivations.

2. METHODOLOGY

The review process that was followed for the identifications of the indicators that could be integrated in a FMIS is presented in Figure 1.

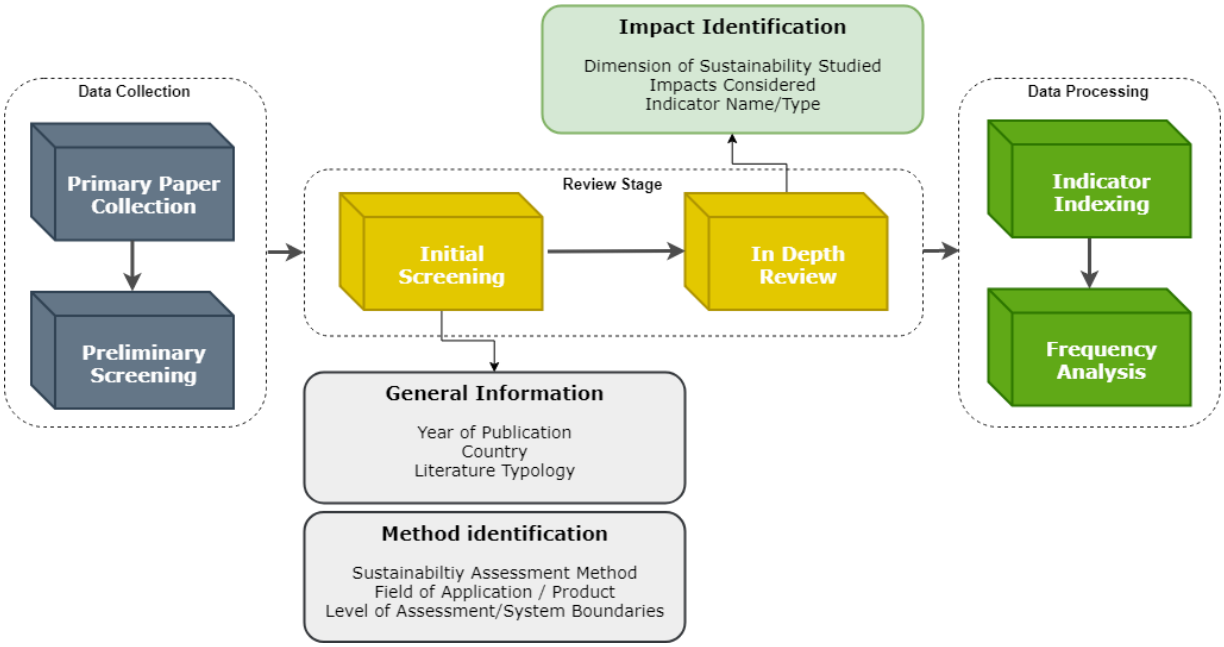

Figure 1. The Review Process

Main purpose was to systematically research the impacts, expressed as indicators, that are addressed within each of the studies that were reviewed. The review methodology includes three distinct stages, namely the data collection, the review and the data processing. The data collection stage begins with the primary paper collection. The initial sample of papers is selected through some of the most widely used scientific search engines such as the Scopus and Science Direct using a variety of appropriate key

words (e.g. agricultural sustainability, Farming and Sustainability, Economic-Environmental Social Sustainability and Agriculture). With the preliminary screening the studies that did not consider all the three impacts of sustainability are excluded.

The initial screening stage concerns the classification of the papers collected based on primary criteria. These criteria include general information (Year of publication, Country and Literature Typology) and the identification of the method employed in the study. The initial screening facilitates further classification of the sample collected based on the method used, the level of assessment as well as the field of application. In that manner it is easy to determine the final sample which is then reviewed in depth in order to extract the dimension of sustainability studied, the impacts considered, and the names and types of the indicators used. During the final stage, data processing, the indicators collected are being classified according to the dimension of concern. Then the sample is reduced in size by aggregating indicators with similar context. The process concludes with the frequency analysis stage. The process includes the creation of a frequency matrix containing all the indicators and the papers that these indicators were used to assess sustainability. Indicators that have a frequency of occurrence higher than a specific threshold were included in the final indicator collection.

3. RESULTS

The application of the methodology described in the previous section resulted in a total of 36 studies published in peer reviewed scientific journals from 2009 till 2018, that assess the sustainability of crop cultivations on the farm level which were reviewed in depth. Assessments that examine sustainability at a regional or national level were excluded for the research since FMIS's are used for management at the individual farm level. The final sample was thoroughly reviewed and a total of more than 500 individual indicators were extracted concerning the three pillars of sustainability. The indicators were aggregated and classified according to the dimension studied. The indicator indexing stage resulted to a total of 130 environmental, 129 economic and 161 social indicators. It should be stated that social indicators are difficult to aggregate since they address more complex and not easily countable impacts. The following charts present the results of the frequency analysis regarding the indicators that were examined. The top 5 indicators with the most appearances, within of the studies examined, are presented. The number below the indicator represents the frequency of occurrence (number of studies).

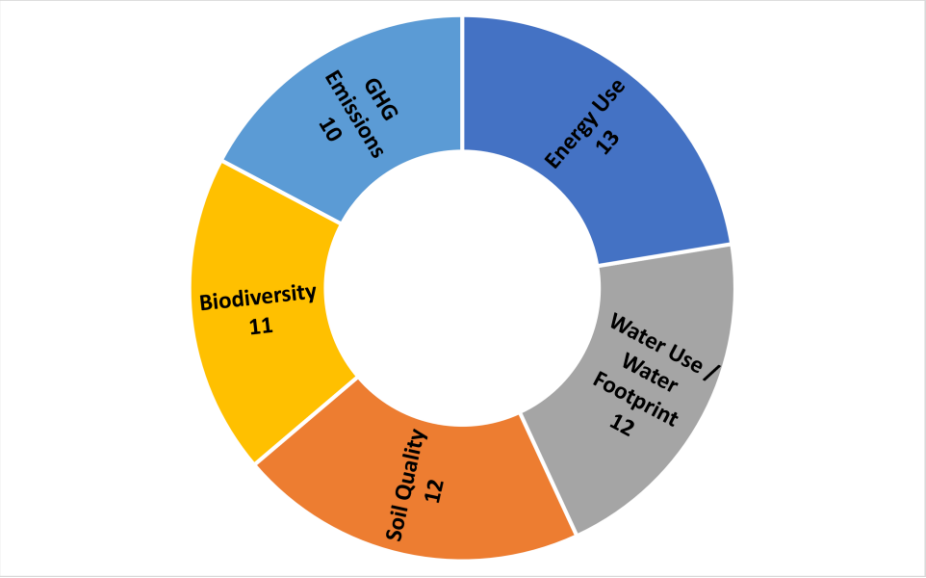

Figure 2. Frequency Analysis – Environmental Indicators

Figure 2 presents the results for the environmental pillar of sustainability. The most frequently used indicators are: energy use (appearing in the 36% of the studies), water use (33%), soil quality (33%),

biodiversity (30%), GHG emissions (28%). It should be stated that indicators were aggregated based on similar context. For example energy use (Van Asselt *et al.*, 2014; Gaviglio *et al.*, 2017) was also expressed as energy management (Peano *et al.*, 2014; de Olde *et al.*, 2016).

Figure 3 presents the frequency analysis of the economic and social indicators that were extracted from the 36 studies reviewed. The most frequently used indicator is profitability (Santiago-Brown *et al.*, 2015; Snapp *et al.*, 2018) also expressed as benefit to cost ratio (Allahyari, Daghighi Masouleh and Koundinya, 2016) and return to cost (Van Passel *et al.*, 2009). Following are income (examined in 25% of the studies reviewed), efficiency (22%), productivity (19%) and yield (17%). Regarding the social pillar of sustainability most frequently indicator used is education (De Olde *et al.*, 2016) (appearing in 28% of the studies) which was also expressed as literacy (Sajjad and Nasreen, 2016) followed by health risk (19%), contribution to local employment (17%), operational difficulties (14%) and access to health (11%).

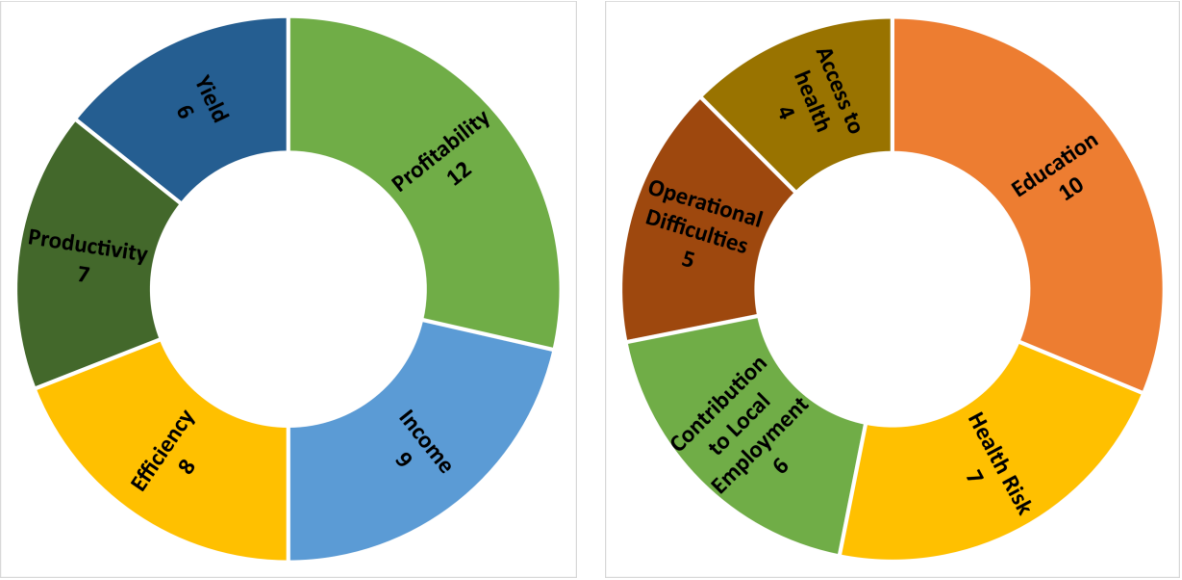

Figure 3. Frequency Analysis – Economic and Social Indicators

4. Discussion

The present study, based on a systematic literature review, attempted to propose a collection of indicators that could be integrated and used to assess agricultural sustainability within a Farm Management Information System. The final collection consists of a total of 15 indicators for the three dimensions of sustainability. The most frequently used environmental and economic indicators can be integrated easily in the context of a farm management tool since most of them can be calculated from data drawn directly for the agricultural practice performed, requiring little or no further measurements transformations and calculations, as for example for soil quality. However, social indicators are more challenging and controversial since they are expressed in many different ways making them difficult to aggregate and classify. It is a fact that social impacts are difficult to standardize and quantify due to their different perception and translation into an indicator making it an interesting subject for further elaboration and research.

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REFERENCES

Allahyari, M. S., Daghighi Masouleh, Z. and Koundinya, V. (2016) 'Implementing Minkowski fuzzy screening, entropy, and aggregation methods for selecting agricultural sustainability indicators', *Agroecology and Sustainable Food Systems*. Taylor & Francis, 40(3), pp. 277–294. doi: 10.1080/21683565.2015.1133467.

Van Asselt, E. D., Van Bussel, L. G. J., Van Der Voet, H., Van Der Heijden, G. W. A. M., Tromp, S. O., Rijgersberg, H., Van Evert, F., Van Wagenberg, C. P. A. and Van Der Fels-Klerx, H. J. (2014) 'A protocol for evaluating the sustainability of agri-food production systems - A case study on potato production in peri-urban agriculture in the Netherlands', *Ecological Indicators*. Elsevier Ltd, 43, pp. 315–321. doi: 10.1016/j.ecolind.2014.02.027.

Banias, G., Lampridi, M., Pediaditi, K., Achillas, C., Sartzetakis, E., Bochtis, D., Berruto, R. and Busato, P. (2017) 'Evaluation of environmental impact assessment framework effectiveness', *Chemical Engineering Transactions*, 58, pp. 805–810. doi: 10.3303/CET1758135.

Bockstaller, C., Guichard, L., Keichinger, O., Girardin, P., Galan, M. B. and Gaillard, G. (2009) 'Review article Comparison of methods to assess the sustainability of agricultural systems . A review', *Agronomy*, 29, pp. 223–235. doi: 10.1051/agro.

Cerutti, A. K., Bruun, S., Beccaro, G. L. and Bounous, G. (2011) 'A review of studies applying environmental impact assessment methods on fruit production systems', *Journal of Environmental Management*. Elsevier Ltd, 92(10), pp. 2277–2286. doi: 10.1016/j.jenvman.2011.04.018.

Gaviglio, A., Bertocchi, M. and Demartini, E. (2017) 'A Tool for the Sustainability Assessment of Farms: Selection, Adaptation and Use of Indicators for an Italian Case Study', *Resources*. doi: 10.3390/resources6040060.

Gómez-Limón, J. A. and Sanchez-Fernandez, G. (2010) 'Empirical evaluation of agricultural sustainability using composite indicators', *Ecological Economics*. Elsevier, 69(5), pp. 1062–1075. doi: 10.1016/j.ecolecon.2009.11.027.

Lampridi, M. G., Kateris, D., Vasileiadis, G., Marinoudi, V., Pearson, S., Sørensen, C. G., Balafoutis, A. and Bochtis, D. (2019) 'A Case-Based Economic Assessment of Robotics Employment in Precision Arable Farming', *Agronomy*, 9(4), p. 175. doi: 10.3390/agronomy9040175.

Lampridi, M. G., Sørensen, C. G. and Bochtis, D. (2019) 'Agricultural Sustainability: A Review of Concepts and Methods', *Sustainability*, 11(18), p. 5120. doi: 10.3390/su11185120.

De Luca, A. I., Falcone, G., Iofrida, N., Stillitano, T., A., S. and Gulisano, G. (2015) 'Life cycle methodologies to improve agri-food systems sustainability', *Rivista di Studi sulla Sostenibilita*, 1, pp. 135–150.

Marinoudi, V., Sørensen, C. G., Pearson, S. and Bochtis, D. (2019) 'Robotics and labour in agriculture. A context consideration', *Biosystems Engineering*. Academic Press, 184, pp. 111–121. doi: 10.1016/J.BIOSYSTEMSENG.2019.06.013.

de Olde, E., Oudshoorn, F., Bokkers, E., Stubsgaard, A., Sørensen, C. and de Boer, I. (2016) 'Assessing the Sustainability Performance of Organic Farms in Denmark', *Sustainability*, 8(9), p. 957. doi: 10.3390/su8090957.

De Olde, E. M., Oudshoorn, F. W., Sørensen, C. A. G., Bokkers, E. A. M. and De Boer, I. J. M. (2016) 'Assessing sustainability at farm-level: Lessons learned from a comparison of tools in practice', *Ecological Indicators*. Elsevier, 66, pp. 391–404. doi: 10.1016/j.ecolind.2016.01.047.

Van Passel, S., Van Huylenbroeck, G., Lauwers, L. and Mathijs, E. (2009) 'Sustainable value assessment of farms using frontier efficiency benchmarks', *Journal of Environmental Management*. Elsevier Ltd, 90(10), pp. 3057–3069. doi: 10.1016/j.jenvman.2009.04.009.

Peano, C., Migliorini, P. and Sottile, F. (2014) 'A methodology for the sustainability assessment of agri-food systems: An application to the slow food presidia project', *Ecology and Society*. doi: 10.5751/ES-06972-190424.

Pham, L. Van and Smith, C. (2014) 'Drivers of agricultural sustainability in developing countries: A review', *Environment Systems and Decisions*. Springer US, pp. 326–341. doi: 10.1007/s10669-014-9494-5.

Rodias, E., Berruto, R., Bochtis, D., Busato, P. and Sopegno, A. (2017) 'A computational tool for comparative energy cost analysis of multiple-crop production systems', *Energies*, 10(7). doi: 10.3390/en10070831.

Rodias, E., Berruto, R., Busato, P., Bochtis, D., Sørensen, C. and Zhou, K. (2017) 'Energy Savings from Optimised In-Field Route Planning for Agricultural Machinery', *Sustainability*. Multidisciplinary Digital Publishing Institute, 9(11), p. 1956. doi: 10.3390/su9111956.

Rodias, E. C., Lampridi, M., Sopegno, A., Berruto, R., Banias, G., Bochtis, D. D. and Busato, P. (2019) 'Optimal energy performance on allocating energy crops', *Biosystems Engineering*. doi: 10.1016/j.biosystemseng.2019.02.007.

Sajjad, H. and Nasreen, I. (2016) 'Assessing farm-level agricultural sustainability using site-specific indicators and sustainable livelihood security index: Evidence from Vaishali district, India', *Community Development*. Routledge, 47(5), pp. 602–619. doi: 10.1080/15575330.2016.1221437.

Santiago-Brown, I., Metcalfe, A., Jerram, C. and Collins, C. (2015) 'Sustainability assessment in wine-grape growing in the New World: Economic, environmental, and social indicators for agricultural businesses', *Sustainability (Switzerland)*, 7(7), pp. 8178–8204. doi: 10.3390/su7078178.

Snapp, S. S., Grabowski, P., Chikowo, R., Smith, A., Anders, E., Sirrine, D., Chimonyo, V. and Bekunda, M. (2018) 'Maize yield and profitability tradeoffs with social, human and environmental performance: Is sustainable intensification feasible?', *Agricultural Systems*, 162(April 2017), pp. 77–88. doi: 10.1016/j.agsy.2018.01.012.