Agro-Industrial Parks: proposal for an integrated AHP-TOPSIS approach for guiding territorial tools settlements in Africa

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Abstract: It is known that agriculture constitutes a pillar of the African economy. However, its supply chain inefficiency does not allow it to exploit its potential and respond to the growing food needs of the population. Furthermore, even if Africa has enormous possibilities for arable land, agricultural productivity remains low because small production units support it. A practical tool to face these problems is Agro-Industrial Park (AIP), which presents numerous advantages, allowing enterprises to share and exploit raw materials, utilities, information resources, transport, etc. When implementing AIP, one of the most crucial steps is the correct localization considering countries' features and local requirements. Although the facility location problem has been widely discussed in the literature, few studies investigate how to support decision-makers in the optimal location of AIPs in Africa. The present paper describes a multi-criteria decision-making model (MCDM), defining all the criteria to support the AIP location. The criteria have been selected through a literature review and subsequently validated by a board of agro-industry experts from the United Nations Industrial Development Organization. The proposed framework integrates the Analytic Hierarchy Process (AHP) and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). The model allows evaluating the most suitable countries for implementing AIP projects in Africa, incentivizing investments, and reducing risks. As a final result, a ranking of African countries in which it is most reasonable to implement AIP projects is returned based on the selected criteria. The results suggest that, in general, the macro-region of North Africa presents more favorable conditions for such projects. More in detail, both South Africa and Mauritius present several advantages in implementing AIP projects.

Keywords: Agro-industry; Agro-industrial Parks; multi-criteria decision making; AHP-TOPSIS integration; Industry development.

I. INTRODUCTION

Considering, on the one hand, the relentless pace at which the world's population is growing [1] and on the other the high number of undernourished people [2] it is easy to understand the need for sustainable and inclusive development that is in line with the goals set by the 2030 Agenda [3]. It is known that industrial action has a crucial role in the country's growth, leading both to structural change and socio-economic development [4]. In this context, the agricultural supply chain and related territorial tools for agro-industry development are strategic factors that can contribute enormously to future world food management problems [5]. Moving from an agrarian economy to an industrial one is essential for creating wealth in developing countries [4]. Africa's population will reach two billion people by 2050 [2], becoming one of the fastest-growing consumer markets in the world [6]. Supporting investment is critical to generating employment, promoting decent working conditions, and economic growth in this context. Agriculture and agribusiness are the pillars of many economies [7]: for example, Africa has 17% of the world's arable land, and agriculture produces more than 20% of the continent's GDP [2]. Today, agriculture employs 60% of Africa's workforce. However, it still offers lower productivity in developing countries than economically developed countries [5]. Production is supported by small units that, in most countries, do not exceed four hectares, and sometimes even less [8]. As mentioned before, industrialization growth needs to be supported, and significant challenges must be overcome [9]. In this regard, Agro-industrial Parks are tools that have been recently used to support economic and social growth in emerging countries. Indeed, they seek to drive technological change, value proposition, and industrialization in the agri-food sector [10]. Qualifying the most suitable sites to realize Agro-industrial Parks (AIP) is crucial to ensure projects' success, reduce investment risk, and positively affect local communities. In this regard, identifying the main criteria for the location of AIPs and defining quantitative tools to support the decision-making process is crucial in this field.

After a literature review, this paper proposes a multi-criteria decision-making model (MCDM), by defining all the criteria to support the AIP location. The proposed MCDM integrates the Analytic Hierarchy Process (AHP) with the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). The approach is based on valuable indicators that measure these criteria. The criteria have been selected through a literature review and subsequently validated by a board of agro-industry experts from the United Nations Industrial Development Organization (UNIDO). Specifically, the team of experts is composed by three managers, with a consistent expertise in developing and operating technical cooperation programmes in fragile and post crisis environments such as Somalia, Iraq, Leabnon and Syria. The main objective of this paper is to prioritize parameters for the location of AIPs through AHPs, in the context of agro-industry in Africa and select the most suitable region to implement those tools. Understanding these priorities helps private and public investors and policymakers to develop project strategies, improving the reliability of their choices.

Moreover, the leading scientific contribution of the work to the sector is the definition of the main criteria that guide decision-makers in the location phase of Agro-industrial Parks projects. Afterward, an application of the model is provided. As a result, a ranking of African countries in which it is most reasonable to implement AIP projects is returned based on the selected criteria. The results show the framework's applicability and its potential to assess the more favorable conditions for AIP projects. The paper has the following structure: in Section 2, a literature review is presented, Section 3 describes the methodology used, Section 4 provides the application of the proposed approach, Section 5 discusses the results, and Section 6 highlights the main conclusions.

II. METHODOLOGY

This paper aims to define the most critical criteria to guide AIP location. The contribution can support local governments and organizations to understanding which strategies establish to mitigate risks. Indeed, nowadays is still complex to find quantitative approaches that support AIP location selection choices in developing countries. Therefore, defining the critical criteria that guide investors in evaluating the location of an AIP settlement is crucial, both contributing to countries' growth and reducing investment risks.

As mentioned before, two MCDM techniques were applied and combined in this study. These two are very popular and familiar with their simplicity. Considering the MCDM methodologies, the Analytic Hierarchy Process (AHP[1]) is widely used [27]. It aims at structuring complex problems in a hierarchical form by evaluating all relevant decision-making criteria [28]. On the other hand, the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) ranks the alternatives based on the distances between the ideal best and the ideal worst solution [29]. Several authors have used hybrid approaches to face facility location problems in the past years, combining AHP and TOPSIS. The two methods were selected because they were considered appropriate for the research.

The proposed approach is summarized in Figure 1:

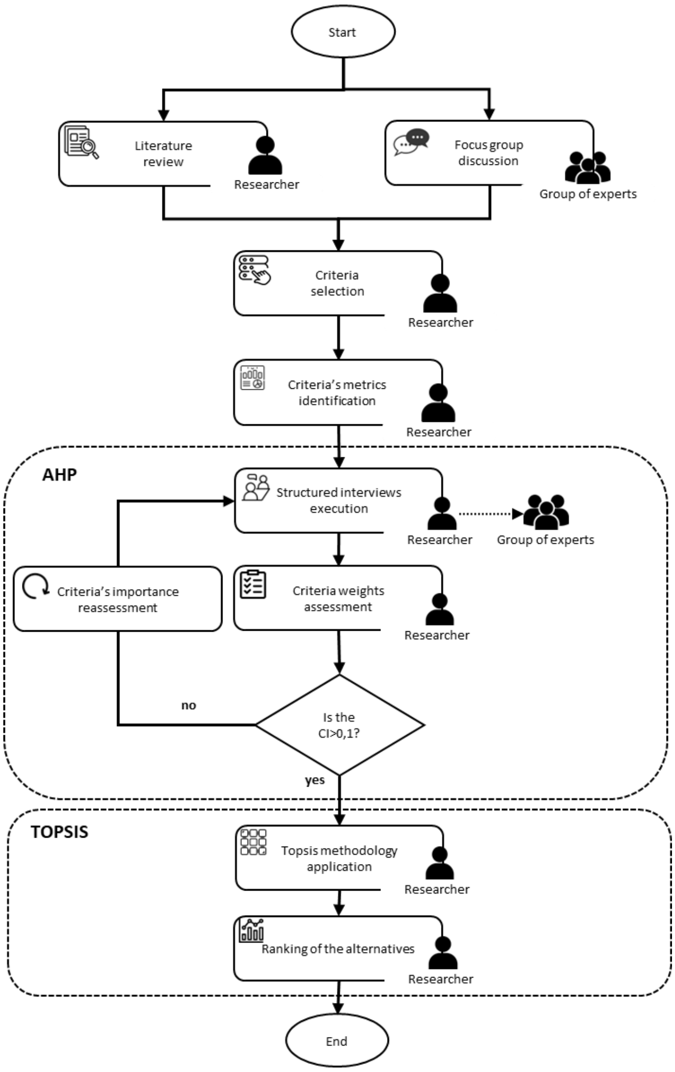

Fig. 1 Flow-chart of the approach

Firstly, the implementation of the model involved an in-depth study of the literature on Agro-Industry in Africa, particularly the most important requirements that influence the long-term success of an Agro-Industrial Park project at a specific site. Due to the absence of previous criteria for evaluating plant location projects specifically for AIP, the first phase of the research was based on the search for criteria and focus group discussion with agro-industry experts. In particular, the AHP analysis required the experts to evaluate the comparison matrices. Subsequently, a qualitative-quantitative research methodological approach was

[1] In the Figure (1) CI stands for Consistency Index

applied, based on experts' professional opinion, allowing the selection, validation, and evaluation of the multi-criteria decision model. Then, an indicator selected from a consolidated database is defined for each criterion. The multi-criteria decision-making model has a tree structure. The primary levels are:

1. Macro-criteria (Table I)
2. Sub-criteria
3. Indicators

TABLE I
MACRO-CRITERIA

C1 Land status
C2 Infrastructure and services
C3 Legal, political and security aspects
C4 Workforce
C5 Natural resources and environmental conditions
C6 Agro-industrial maturity level
C7 Business considerations

The first level comprises seven macro-categories, each of which has between five and eight sub-criteria for a total of 41 sub-criteria, consequently making up the second level. Finally, the third level comprises the indicators that allow the value of each sub-criteria to be measured in direct terms. The sub-criteria, which then make up the columns of the AHP matrix, characterize each macro-criteria and summarise the area's requirements with the most significant impact to be considered when assessing the optimal location of an Agro-industrial Park (Table II).

TABLE II
SUB-CRITERIA AND INDICATORS

Sub-criteria	**Indicators**
C.1.1 Availability of agricultural land	*Agricultural land (% of land area)*
C.1.2 Clean and clear title	*Dealing with construction permits score*
C.1.3 Time required in the acquisition	*Time required in acquisition (days)*
C.1.4 Time required in the registration	*Time required to register property (days)*
C.1.5 Property right score	*Property rights score*
C2.1 Performance and reliability of logistics infrastructure	*Logistics performance index overall * Reliability of infrastructure*
C2.2 Quality of transport-related infrastructure	*Logistics performance index: Quality of trade and transport-related infrastructure*
C2.3 Electricity network	*Time required to get electricity (days)*
C2.4 Internet access	*Secure Internet servers (per 1 million people)*
C2.5 Water for industrial use	*Annual freshwater withdrawals, industry (% of total freshwater withdrawal)*
C2.6 Presence and accessibility to infrastructure	*(Roadways km + Railways km)/1000km+ (Airports Paved Runway) +(Ports)*
C3.1 Political stability	*Political stability index*
C3.2 Control of corruption	*Control of corruption*
C3.3 Economic incentive	*Percent of firms choosing tax administration as their biggest obstacle*
C3.4 Legal incentive and cooperation	*Percent of firms choosing business licensing and permits as their biggest obstacle*
C3.5 Access to finance	*Percent of firms choosing access to finance as their biggest obstacle*
C3.6 Security level	*Percent of firms choosing crime, theft and disorder as their biggest obstacle*
C4.1 Level of education	*School enrolment, secondary (% gross)*
C4.2 Availability of labour force in agriculture	*Employment in agriculture (% of total employment)*
C4.3 Adequacy and specialization of workforce	*Percent of firms choosing inadequately educated workforce as their biggest obstacle*
C4.4 Skill training workers	*Proportion of skilled workers (out of all production workers) (%)*
C4.5 Investments in education	*Government expenditure on education, total (% of GDP)*
C5.1 reliability and presence of water resources	*Number of water insufficiencies in a typical month*
C5.2 Environmental risk	*Droughts, floods, extreme temperatures (% of population, average 1990-2009)*
C5.3 Drought risk	*Average precipitation in depth (mm per year)*
C5.4 range of temperature	*Average yearly temperature*
C5.5 Level of CO_2 emissions (kt)	*CO_2 emissions (kt)*
C6.1 Crop Production	*Crop production index (2014-2016 = 100)*
C6.2 Fertilizer Consumption	*Fertilizer consumption (kilograms per hectare of arable land)*
C6.3 Food Production	*Food production index (2014-2016 = 100)*
C6.4 Cereal Production	*Land under cereal production*

	(hectares)
C6.5 Livestock Production	*Livestock production index (2014-2016 = 100)*
C6.6 Raw materials export	*Agricultural raw materials exports (% of merchandise exports)*
C6.7 Raw materials import	*Agricultural raw materials imports (% of merchandise imports)*
C6.8 Availability of industrial certificate	*Proportion of medium and high-tech industry value added in total value-added*
C7.1 Time to export and import raw material and finished goods	*Lead time to export, median case (days) + Lead time to import, median case (days)*
C7.2 Cost of business start-up	*Cost of business start-up procedures (% of GNI per capita)*
C7.3 Agricultural value-added	*Agriculture, forestry, and fishing, value added (current US$)*
C7.4 Foreign direct investment	*Foreign direct investment, net inflows (% of GDP)*
C7.5 Manufacturing value-added	*Manufacturing value added (% of GDP)*

III. LITERATURE REVIEW

In this section, previous research is presented by topic. After highlighting recent papers that confirm the opportunities for agro-industry investment in Africa, the various initiatives that support this phenomenon are analyzed. As a result, the literature review is organized into two main areas of interest:

- the first aims to review the agro-industry development and territorial tool. It provides relevant definitions, outlining the importance of initiatives that support developing countries' agro-industrial growth and focusing on Agro-industrial Parks;
- The second is to review the main approaches used for the plant location selection. Here, the relevant frameworks are examined, highlighting their advantages and limitations.

Agribusiness denotes the collective farm-to-table activities performed by agricultural input suppliers, producers, distributors, traders, exporters, retailers, and consumers [11]. On the other hand, Agro-industry refers broadly to establishing enterprises and supply chains for developing, transforming, and distributing specific inputs and products in the agricultural sector. A narrower definition portrays agro-industry as the sum of post-harvest activities changing, preserving, and preparing agricultural products for intermediate or final consumption [12]. Agribusiness has transformed rapidly in an industrialized, globalized, and increasingly urbanized world [10]. Indeed, agribusiness was primarily related to growing, packaging, and delivering products to markets in the past. Nowadays, the agro-industry has become a highly industrialized sector, with significant medium and large-scale investment and worldwide networks and global supply chains that deliver substantially transformed agricultural products to businesses and consumers in near and distant economies and markets [10]. The growing geographic disparity and inequality in agribusiness development and agro-industrial investment, partly due to globalization forces, are putting territorial processes at center stage [13]. In this context, an Agro-industrial Park is an innovative network system of agro-food production, processing, logistics services, marketing, and training located in a joint district and a vehicle for the structural transformation of the economy through the commercialization of the agricultural sector. As a network, it enables a combination of market and integration of various farming activities and rural processing services [14]. Investment projects in AIP are crucial to the continent's development; according to current estimates, 65% of arable land in Africa is still not cultivated, and this will be needed in 2050 when the world population reaches about 9 billion [15]. A recent success story is Ethiopia [16], where the implementation of AIP initiatives, which the Ethiopian Government has identified as one of the main pillars to achieve agricultural modernization, rural industrialization, and ultimately the structural transformation of the economy and society in the country [17].

Moreover, Africa includes the most significant agricultural frontier facing the desert. Apart from the availability of land, the processing sector is still underdeveloped. In this context, territorial approaches to foster agro-industrial investment at local, country, and regional levels are becoming increasingly relevant [10]. The importance and critical role played by the AIPs is therefore evident. At this point, the optimum plant location is a decisive factor for the realization and implementation of these projects. Plant location selection is a widely investigated issue [18]. It regards the location determination of new facilities in the potential area based on various criteria [19]. Over the last years, the multi-criteria decision-making models (MCDM) have been the most used due to their high level of applicability [20]. MCDM methods have been used in the facility location selection problem, assessing the extended use of AHP [21] and TOPSIS, selected by authors because of their ease of applicability and adaptation. However, the efficiency of the model application strictly depends on the accuracy of the criteria definition, which is a complex step when tackling real contexts [22]. The innovativeness of the paper lies in the fact that a careful study of the literature has shown that there are no quantitative methods to guide the localization of agro-territorial tools.

Furthermore, the scientific literature widely demonstrates the applicability of decision models in the industrial context [20]. Muti-criteria decision models are often applied for choices related to technology, suppliers (supplier selection) [6], industrial plant location [23], renewable energy development [24], and many other sectors. Nevertheless, there is still no evidence regarding the application of decision-making models related to the location of Agro-industrial tools. As a result, this case presents itself as unique in the current literature to the author's knowledge. The proposed model has broad applicability from an industrial point of view. Although the research is focused on AIP, the same model with the appropriate modifications can be customized and used to evaluate other territorial tools. The model integrates two well-known decision-making approaches, which have consistently found strong acceptance in the industrial and non-industrial world [25]. Decisions requiring support methods are difficult by definition and therefore complex to model. In particular, AHP and TOPSIS have always found great favour from the academic community to be widely used by practitioners [26]. To the author knowledge, no researchers have implemented a hybrid approach of MCDM to support DMs in evaluating the most suitable location to establish AIP, reducing the investment risk and positively affecting the local communities.

IV. APPLICATION

International organizations like FAO and UNIDO have been implementing agro-industrialization projects for years [10]. In addition, territorial tools such as AIP, agricultural growth corridors, Agro-based clusters, Special economic zone for agro-industry (SEZ), and agribusiness incubators represent an active field of research due to the growing demand for food in Africa and the enormous agricultural potential of the continent [30]. In this regard, the authors decide to apply the proposed methodology by relying on the expertise provided by UNIDO experts.

As a first step, the comparison matrix of the macro-criteria was calculated, and the priority weight relative to each was identified, referring, as mentioned, to Saaty's scale of values [28]. The pair-wise comparison matrixes were subsequently calculated for each sub-criteria, and then the priority weights of each alternative were determined. As shown in Figure 2, the AHP model shows that "Land status", with a relative importance of 30%, is the most crucial macro-criteria in assessing the optimal location of an Agro-industrial Park. Immediately following, in order of relevance, are "Agro-industry maturity level" and "Natural resources and environmental conditions", almost equal, with 21% and 20% relative weight, respectively. Finally, the other macro-criteria have relative importance between 4% and 7%, except "Workforce", slightly above these values with a weight of 13%.

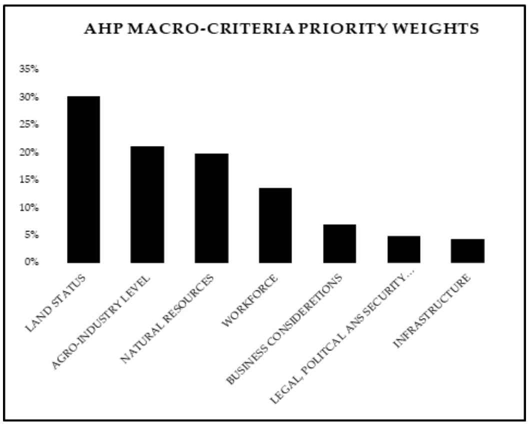

Fig. 2 AHP macro-criteria weights

The same procedure has been applied to evaluate the importance of each sub-criterion. Finally, the TOPSIS method has been used to classify African countries. Initially, a decision matrix is considered for the various countries concerning the 41 sub-criteria. Specifically, a matrix was created that has rows "i" the various countries of Africa, while for columns "j" all the sub-criteria. The generic element a_ij is the value of the indicator relative to the i-th country referred to the j-th sub-criteria. Once the starting matrix is structured, the TOPSIS weights of each sub-criterion are calculated from the evaluations obtained previously with the AHP. The analysis results in a classification of the alternatives used in the model, as shown in Figure 3.

The top ten countries in which it is most reasonable to locate an Agro-industrial Park are, in order: Morocco, South Africa, Egypt, Mauritius, Tunisia, Nigeria, Cabo Verde, Lesotho, Rwanda, Ghana. The range of final values obtained varies from 56.38% (Morocco) to 38.84% (Gabon), with a delta of 17.54% (Figure 3)

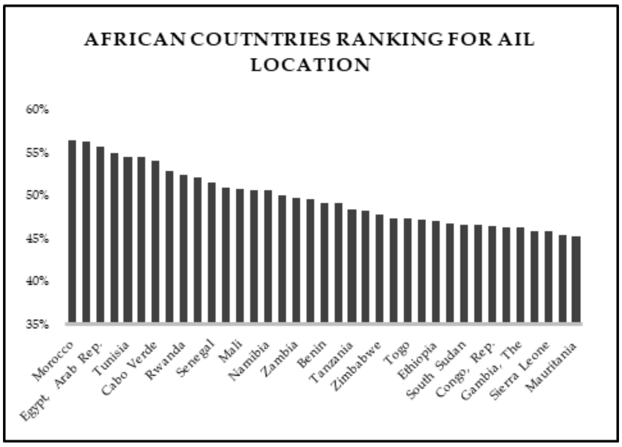

Fig. 3 TOPSIS results

V. RESULTS AND DISCUSSION

Based on the results obtained, a feasibility study was carried out on implementing an agro-industrial park on the entire continent. To this end, zoning of Africa was carried out, i.e., a subdivision of the territory according to two main criteria:

1. Geographical position (subdivision into macro-regions);

2. Presence of coastal areas (subdivision into coastal and non-coastal countries).

The first type of zoning has as its criterion the subdivision of the African continent into its five geographical macro-regions. This partitioning of Africa is divided into five macro-regions distinguished according to geographical location: North Africa, West Africa, East Africa, Central Africa, and Southern Africa.

Figure 4 shows the value of the aggregate average per macro-region of the performances obtained following the application of the model. With a weight of 55.53%, North Africa is the macro-region in which it seems most reasonable to locate an Agro-industrial Park; it is no coincidence that the countries of North Africa are all positioned in the top ten of the ranking. It should also be noted that, except North Africa, the remaining macro-regions do not present a substantial delta of difference. All the macro-regions have values between 44.69% and 49.69%; therefore, they are within a range of only five percentage points.

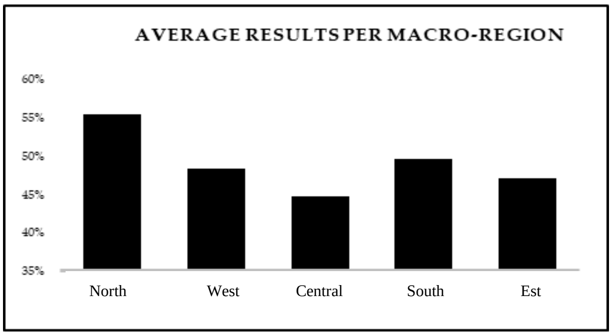

Fig. 4 Average results obtained for each macro-region

It is equally interesting to study the results obtained according to the country's position concerning the coast, which means analyzing the difference in outcomes between coastal countries and countries inland, or at least not wet by the sea. Of the 54 countries in Africa, 17 are non-coastal, while 37 are wetlands. Among the top fifteen countries in the ranking, only four (Lesotho, Rwanda, Mali, Botswana) are non-coastal countries, while the rest are coastal countries. It is evident that the results for coastal countries are proportionally higher. Therefore, it is possible to conclude that it is more reasonable to implement Agro-industrial Park in countries bathed by the sea. Integrating the results obtained through the two different zonings of the continent shows that Central Africa ranks last among the five macro-regions and at the same time, is also the macro-region with the highest number of non-coastal countries.

VI. CONCLUSION

The literature applies multi-criteria decision models to solve the site location problem. However, the two primary considerations that emerged from the literature study were:

a. the absence of multi-criteria decision models to guide the optimal location of Agro-industrial Park - and in general agricultural tools;

b. the need for tools to guide decision-makers in the location phase of such projects.

Indeed, academic research should support decision-makers in this field by examining organizational requirements and country characteristics. These approaches underpin the promotion of private and public investment in the agricultural sector, which substantially impacts economic and social growth in developing countries. This research proposes a multi-criteria decision-making model (MCDM) to support decision-makers in the optimal selection regarding the location of Agro-industrial Parks in African territories. Macro-criteria, sub-criteria, and indicators essential for making this choice are framed in a structured model. Thanks to the study of the literature and the support of a team of experts, a model was structured that starts from the definition of the essential requirements and then, by integrating two decision support methodologies (AHP and TOPSIS), provides a quantitative method that returns evaluations regarding the optimal location of AIP. The model consists of seven macro-criteria, 41 sub-criteria, and the same number of indicators. The metrics used and their weights were obtained following a literature study and structured interviews with experts from UNIDO.

Finally, a case study was developed to illustrate the use of the proposed model. The results obtained show that, in general, the North African region has the best conditions for hosting AIP projects. However, the analysis generally showed excellent performance for most coastal countries. This study helps decision-makers in the site location phase and reduces investment risk in developing countries' agricultural sectors. Otherwise, the process could be used with the opposite valence, i.e. to exclude regions where conditions are too far removed from the specific needs of the agricultural sector. This approach has been tested in different context and withing different organizations. It has reveal its potential both in the private sector and international organizations, supporting the decision-making process whenever it is required to quantitative evaluate the most suitable location, highlighting gaps and opportunities.

Despite, its wide applicability and potential the model still presents some limitations linked with data collection and availability.

In conclusion, this paper lays the groundwork for further developments. In the first instance, extending the analysis to other agricultural tools (Agricultural Growth Corridors, Agro-based Clusters, Special Economic

Zones, Agro-incubators) is very interesting. A further starting point for future research could be comparing the criteria for site location in developing countries and the criteria used in developed countries, where the AIP model has been in place for a few decades (e.g. Holland, Germany, Denmark, etc.). As a last resort, it is possible to hypothesize a research development linked to studying the model's applicability to other developing countries.

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