Global-Detector - GIS- and Knowledge-based Tool for a Global Detection of the Potential for Production, Supply and Demand

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Abstract: Wageningen Economic Research has developed Global-Detector, a knowledge-based Geographic Information System that aims to detect the worldwide potential for production, demand and market strategies. At any spot in the world Global-Detector can show the values from a large amount of indicators, such as climate, infrastructure, and land characteristics. A large set of indicators is readily available for use without any GIS-processing, and the model builder together with the expert can instantly start building the knowledge base for the concerning research aim. Knowledge from experts is applied to combine relevant indicators to create new indicators. The concept of Global-Detector and 10 applications developed by this tool are described. As a generic tool with increased flexibility, Global-Detector has many application possibilities in a wide variety of fields.

1 INTRODUCTION

There is a growing trend towards internationalization of the agri-food sector in order to find new markets and reduce costs. Entrepreneurs who want to expand their production or market possibilities abroad are often faced with inadequate and dispersed information about promising locations in the world. To assemble and harmonize all the relevant data for the best decisions may become very costly and time-consuming, especially when data from different areas (e.g. social and bio-physical) is required and the search is focused on a larger group of countries or even the whole world. Whether or not a particular location is attractive depends on the assessment of various factors, such as local biophysical and climatological characteristics, local socio-economic conditions (urbanization, infrastructure, market access and population density) and socio-economic conditions at country-level (investment climate, fragility index, etc.). Local advisors or experts are often indispensable for this assessment, but they can only make a justifiable valuation for their own region for which they have access to the relevant local data. For Small and Medium-sized Enterprises (SMEs) that are aiming to find the best location with low costs and still provides adequate market access, it will become very difficult and costly to find potential areas and to find and work with local experts from these areas to gather relevant information. And not to mention the difficulties to compare potential areas.

Wageningen University & Research has developed a country-based model to map the global potential of floriculture production (Benninga et al., 2016). In this model the development of floriculture production in a number of countries has been analysed to determine the attractiveness for floriculture production. Knowledge from experts has been acquired and implemented as weighing factors in the model. However, in order to analyses the potential for regions *within* the country, this country-based model does not suffice. This[1] led to the development of the GIS-based[2] Global-Detector model in which the attractiveness for floriculture production can be assessed for each grid at 5’x5’ resolution (approximately 10x10 km, depending on the latitude) in the world.

[1]Another inspiration to develop Global-Detector was the report of Kuhlman and Weegh (2014)
[2]GIS = Geographic Information System

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2 OVERVIEW OF GLOBAL-DETECTOR

Global-Detector is a knowledge-based Geographic Information System developed in R that aims to detect the worldwide potential for production, demand and market strategies. This tool is developed by Wageningen Economic Research. At any spot on the world, i.e. a grid of 5'x5', the tool can show the values from a large amount of indicators, such as climate, infrastructure, and land characteristics (figure 1).

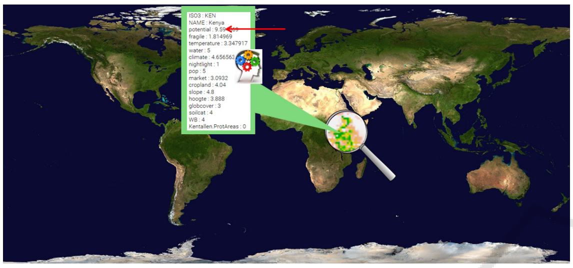

Figure 1: The concept of Global-Detector.

Relevant indicators that are available in the library (section 2.1) are chosen by the expert. The knowledge from one or more experts is applied to combine relevant indicators to create a new indicator. For each case a knowledge-based model is developed containing a set of arithmetic rules that prescribe how to combine the indicators chosen by the expert (section 2.2). After the calculation of all grids (worldwide or a specified region), the result is presented on a map. This can be worldwide as in figure 2, or a specific region in figure 3.

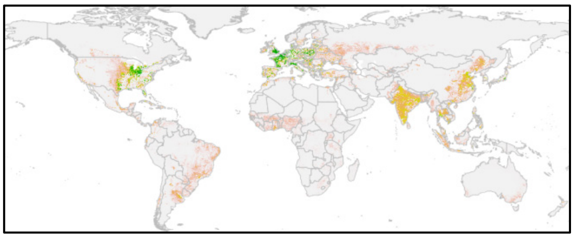

Figure 2: Example of a presentation of the result of Global-Detector (case 'Potential for ornamental horticulture (worldwide)'; green is good potential).

There might be other factors that influence the production or demand for which there are no indicators, e.g. cultural or demographic conditions. Users should be aware of this shortcoming and consider the outcome as a first step to find suitable locations.

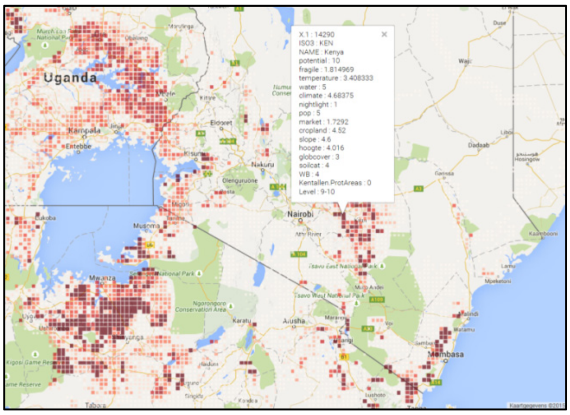

Figure 3: Example of a presentation of the result of Global-Detector (case 'Potential for Tilapia in Kenya and surrounding countries'; dark red is good potential).

2.1 Indicators

The raw data for most indicators of Global-Detector are downloaded open source data from the web. The format of these freely available datasets differs:

- Gridded GIS-files with rasters in different formats, e.g. WorldClim (2016) for global climate, bio-physical datasets like SoilGrids (ISRIC, 2016), or datasets with agronomic parameters related to many crops (e.g. FAOSTAT, 2016);
- GIS-shapefiles, e.g. a world map of rivers and lakes;
- Tabular files with data in csv or Excel files on country or provincial level, e.g. World Development Indicators from World Bank (2016).

After downloading, the data are transformed by GIS-tools to the required 5'x5' resolution. Tabular files with data on country level are also gridded to the same 5'x5' format, in this way all grid cells of a country have the same value. This resolution is chosen when considering calculation time and specificity, and many gridded sources have this resolution. Change of resolution has either implication for calculation time with hardly additional information (e.g. to 1'x1') or is not specific enough at regional level (e.g. 30'x30').

Not all indicators of Global-Detector are transformed directly from open source data. Some have been derived. For example, the indicator 'vicinity from harbours' has been created by using a list of worldwide harbours and their importance, and a specific piece of software code draws zones around a harbour with different levels of distance. In this way hinterlands of a harbour are incorporated (e.g. part of Germany as hinterland for the harbours in the Netherlands and Belgium).

To summarize, Global-Detector contains indicators for:

- Climate, e.g. monthly temperature, solar irradiation, precipitation;
- Infrastructure, e.g. distance to markets, vicinity to harbours and airports;
- Land characteristics, e.g. type of soil, slope;
- Land utilisation, e.g. % cropland, area of various crops, protected areas, N/P2O5 fertilisation;
- Population density and number of people in radius of e.g. 20 or 250 km;
- Country level indicators retrieved from the World Bank, FAO and other sources;
- Miscellaneous indicators, e.g. nightlight, religion.

If an expert requires indicators that are not present in Global-Detector but are available on the web or can be gathered from another source, then data can be transformed to a raster with the required template for Global-Detector. For example, data of the World bank and FAO have a large number of variables on country level, each can be transformed to a raster for Global-Detector. If an expert requires his own indicator (e.g. export regulations for a specific product), then he fills in a table with values for each country. This is sequentially transformed to a worldwide 5'x5' indicator.

For a country, a group of countries, or a region within a country, additional spatial data can be brought in the model. An example is the use of an additional map of railway infrastructure and its influence (figure 6).

2.2 Knowledge-based Model and Interaction with Experts

A knowledge-based model is an essential part when Global-Detector is applied. It combines indicators and arithmetic rules to yield the requested output, e.g. potential for a product. From a base collection of nearly two hundred indicators, the expert chooses indicators that are relevant for the case of interest. For these indicators on-the-fly maps are created by the model builder for the specified area or for an area that should be validated. It is indispensable that the model builder and the expert work together in close cooperation to develop a knowledge-based model that contains algorithms to transform indicator values to scores. This can be done, for example, by developing a function that converts ranges for the minimum, optimum and maximum temperature to the scores of the temperature suitability map. The expert determines parameter values and helps the knowledge engineer (i.e. model builder) with the construction of the arithmetic rules for the combination of indicators. The resulting map is shown to the expert, and after this first step, face validity of this map can lead to the adaptation of parameters and formulas. It is up to the expert to gather and use additional information from literature or gain information from other experts for the purpose of this validation procedure. If there is a theoretic background, the expert can use that information when the knowledge-base is specified.

3 THEORETICAL BACKGROUND AND SETTING

3.1 Model Perspective

Global-Detector can among others be used as a suitability model aimed at assessing the potential for different agricultural production systems, and is intended to bridge the gap between standard agronomic (bio-physical) crop suitability models that provide output at grid-level on the one hand, for example Ecocrop model (EcoCrop, 2016), GAEZ (FAO, 2016), and on the other hand a set of global models that focus on the agricultural sector in general (including socio-economic and market data) which provide output at level of administrative units (e.g. MAGNET: see Woltjer and Kuiper, 2014).

Global-Detector uses expert knowledge to include the assumed impact of (downscaled) socio-economic and infrastructural variables on the suitability of different grid cells for different production systems. This is not restricted to crop production systems, but can also be applied to (mixed-) livestock, aquaculture systems, demand for products, etc. Models that combine high-resolution spatial data related to both environmental and socio-economic data already exist, for example EUClueScanner (Koomen et al., 2010; Object Vision, 2016) and CLUMondo (Van Asselen and Verburg, 2012). However, to our knowledge no other model combines these different types of data at a global scale and using expert knowledge to weigh relative impacts, and to combine and transform data (e.g. from temperature maps to a map showing the deviation from optimum temperature range in tropical regions). The EUClueScanner, however, already uses data from other models including IMAGE (Kram and Stehfest, 2011; IMAGE, 2016) and MAGNET. But the prevailing difference at the moment is the flexibility of Global-Detector that allows the expert, within a few hours, to include a subset of several hundreds of variables that are relevant to make a certain area suitable for the desired production system, based on the subjective assessment principle (i.e. expert knowledge).

Models that provide information about the suitability for different agricultural production systems at the grid-level can give both policy makers and the commercial sector a quick scan of the expected local differences. Inclusion of climatic, bio-physical and socio-economic variables can help show the differences within a country (e.g. suitability for local to local production) or assess the impact of changes to any of these variables. Existing models that focus on the suitability of certain agricultural production systems generally focus on crop production systems and the climatic and biophysical conditions that are required for certain crops to grow optimally.

Three main approaches to suitability analyses exist: the limiting condition principle, the principle of arithmetic modelling and the subjective assessment principle (FAO, 2016a). When using the limiting condition, the least suitable variable determines the overall suitability. With the principle of arithmetic modelling, variables will be assigned a certain value, which can be operated arithmetically to determine the final suitability. The subjective assessment principle ('expert model') allows for flexible selection and judgement over the importance of the different variables; the variables can be weighted and operated arithmetically to get to a final suitability map. The latter approach requires an expert opinion and can combine any of the relevant aspects of the other two types of models. Global-Detector applies the subjected assessment principle; the expert system is the core of an application with this model.

Sweeney et al. (2015) present and compare in a recent review 34 journal articles and 70 web-mapping projects that cover various aspects of food mapping research and initiatives that have been used to "explore complex social, economic, and environmental components of the food system". Neither of these models resembles the concept of Global-Detector, nor are we aware of another existing comparable world-wide generic and flexible knowledge- and GIS-based model that can be used interactively together with an expert.

3.2 Market and Business Perspective

According to the classical location theory, entrepreneurs try to minimalize costs in their quest to find appropriate locations to invest (Von Thünen, 1960). Benninga et al. (2016) give an overview of this theory and other theories related to international potential for production. Optimal locations have low transport costs, proximity to raw materials and energy, situated near markets (or harbours/airports for export), availability of labour, etc.. Intensive vegetable and fruit production - especially for the fresh market (i.e. short chain production) - is best to be situated near urban region, whereas extensive agriculture and forestry activity is eligible to be in the rural areas (after Von Thünen, 1960). Porter (1990) proposes a strategic diamond model bases on competiveness to assess the attractiveness of a country or region, based on competiveness.

Global-Detector is able to account for factors that are related to markets and business climate, e.g. the ease of doing business (World Bank), the availability and quality of infrastructure, identification of urban and rural areas, GDP and income inequality, and the fragility of states.

4 CASE STUDIES AND APPLICATIONS

The availability of indicator maps and expert knowledge is required for any application of Global-Detector. It can be applied for various information needs or research questions. Some of the possibilities (with examples, see later) are:

- Detection of the potential for production, e.g. Tilapia in ponds, ornamental horticulture, pig production;
- The expected demand for a product, e.g. consumption of cherry tomatoes, consumption of milk;
- Local-for-local production, e.g. nursery (potted plants) for the local markets, short chain fresh vegetable production;
- Scenarios that might have an effect on the production or demand in a region, e.g. drought, flooding.

At a workshop a group of experts can be informed about the circumstances in the area at issue by showing several relevant indicator maps produced by Global-Detector, followed by interactively gaining region intelligence from these maps supplemented by regional knowledge from the participants.

Global-Detector is applied for the development of demonstration cases and used in projects. Most applications concern production potential. Other types of applications, like the demand for a product, are harder to accomplish and require additional assumptions because of a lack of worldwide data (e.g. difference between urban and rural consumption).

The first case will be explained in detail whereas the other cases will be described only briefly.

4.1 Production Potential

Potential for Ornamental Horticulture (Worldwide). This was the research question that had led to the development of Global-Detector and is its first application. The steps that were taken illustrate the way Global-Detector has been applied for this case and to understand the development of the other cases. A base for this case has been a country-based model in Excel to map the global potential of floriculture production (Benninga et al., 2016). The steps used to apply Global-Detector for this case, and in general for other cases, are:

- Commitment of experts for acquiring knowledge and validation. This case consisted of two expert groups: (1) cuttings and young plants, and (2) flowering and bedding plants;
- Selection of indicators from Global-Detector. These indicators are subdivided in following groups: climate, land and soil, market & infrastructure, and country level (e.g. fragile state index);
- In workshops the knowledge-base of Global-Detector is developed, i.e. creating arithmetic formulas for combining and weighing indicators, and setting parameters for these formulas, e.g. the optimal temperature. The workshop is interactive, experts can react instantaneous and suggest adaptations of the parameters;
- Validating maps generated by the knowledge-base. An example is the suitability of climate - i.e. the combination of temperature, water supply, humidity, and solar irradiation - for the production of flowering and bedding plants (figure 4);
- Adaptation of the set of indicators for the knowledge-base;
- Creating the final potential map for a specific region (e.g. figure 5) or for the whole world (figure 2).

For the following cases these steps may differ, e.g. bilateral sessions instead of workshops.

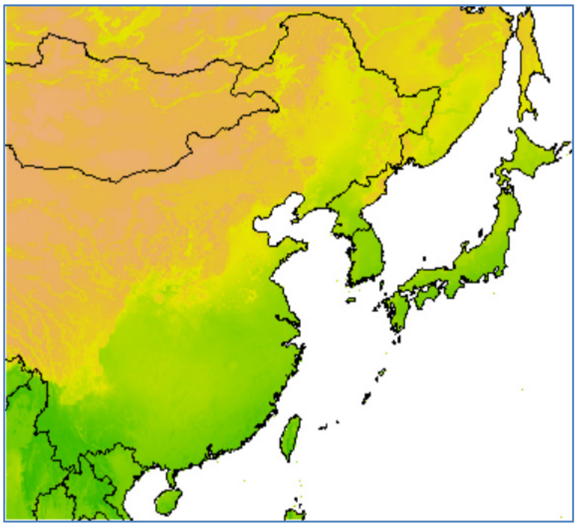

Figure 4: Climate suitability for flowering and beddings plants in East Asia; dark green is good potential.

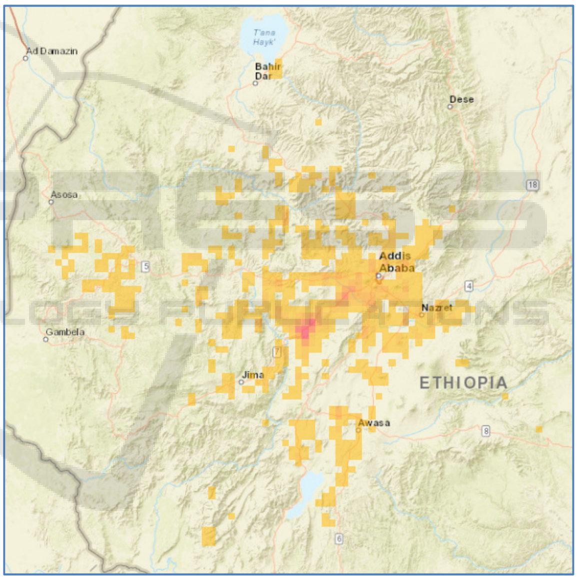

Figure 5: Potential for flowering and beddings plants in Ethiopia; red is reasonably good potential.

Most relevant indicators for the expert model that was developed based on expert judgement were solar radiation, temperature and the infrastructure indicator ‘distance to main airports’. Furthermore, a set of indicators from World Bank (or related sources) were applied (on country level). Results from the 5’x5’ grids had been summarized at province level.

Potential for Tilapia in Kenya and Surrounding Countries.
To proof the applicability of Global-Detector was the development of a map of Kenya and surroundings to indicate the best pond locations for Tilapia. In three sessions with an expert, who has also regional knowledge, a knowledge-base was developed. Results depicted on Google maps were validated by this expert (figure 3). After a positive validation, the model can have opportunities for a worldwide applicability - presumably with some modifications for non-tropic regions. The Tilapia case was valuable since it gained experience in interacting with an expert and the way validation was done.

Potential for Avocado Production in Ethiopia.
For a project initiated by the Dutch organization 'GroentenFruit Huis', Global-Detector was applied to assess the best areas for avocado production in Ethiopia when accounting for the infrastructure. New maps (i.e. indicators) had to be developed to indicate the location of (potential) railways and stations (figure 6). This has shown the flexibility of Global-Detector to make and use additional specific indicators. Soil characteristics from SoilGrids, like pH, organic content, clay and drainage, had also been used as additional indicators.

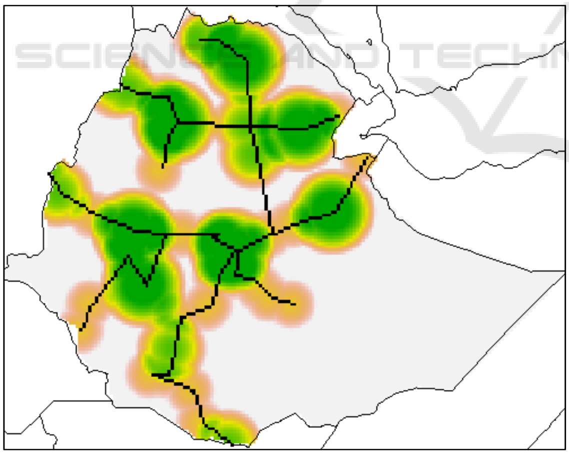

Figure 6: Scope of railways and stations in Ethiopia (additional Global-Detector indicator for one country).

Potential for Tomato Production (Worldwide).
The Dutch company Prominent is interested in the best locations for tomato production worldwide. Entrepreneurs can be aided in their quest for locations by means of the results of the model. In a workshop indicators were identified and knowledge was acquired on how to combine indicators. For example, the combination of the maximum and the minimum temperature in the hottest 3 months accounting for optimal temperature combined with enough difference between minimum and maximum temperature.

Potential for Pig Meat Production in South-East Asia.
Together with an expert on pig meat production, a knowledge base was developed to assess the potential for pig meat production in South-East Asia. Besides indicators on 5'x5' and country level, an additional level was applied. Province level indicators maps for the main religions had to be developed (from tabular base data from Johnson and Grim, 2008) and applied. The value of this case for Global-Detector is the flexibility to incorporate also a province level for regional information.

4.2 Demand (Consumption)

Demand of Cherry Tomatoes in Africa and Europe.
This application was developed to show that Global-Detector is also suitable for the demand, so not just for production (supply). For Africa and Europe the indicators and a knowledge base was used to estimate the amount of expected cherry tomato consumption. FAO data on imports of (luxury) vegetables had been transformed to an indicator; seven products were weighted and combined and divided by the population to yield the consumption by import per person. The estimation of the total consumption per grid cell is done by a combination of expected % of consumers, the availability (based on infrastructure) and the expected consumption per capita.

4.3 Classification for Decision Making

Agro-ecological Potential and Climate Vulnerability in Mali and Burkina Faso.
Global-Detector was applied to map the agro-ecological potential and climate vulnerability of Mali and Burkina Faso as a case study. This pilot project aimed to test the possibilities for enabling strategic discussion on future climate smart Food and Nutrition Security interventions in Sub Saharan Africa, by identifying areas with high/low food system dynamics and high/low climate dynamics. These classifications have been presented on a map and discussed with experts in a workshop.

Classification of Supply and Demand of Onions.
For a project initiated by the Dutch organization

'GroentenFruit Huis' Global-Detector was applied to downscale information from country level (e.g. data from World Bank and FAOSTAT) to grid level. The result is a map with grids classified as 'import', 'export' and 'local'. The distinction between urban and rural areas and the balance between supply and demand led to these classifications.

4.4 Global-Detector to Analyse Metropolitan Assignments

Detection of Metropolitan Land use Options (Metropolitan Solutions).
In the project Metropolitan Solutions one of the aims is to investigate the options for land use in metropolitan regions, accounting for the demand (consumption) and supply (production) of food and recreation. In an expert model, indicators of Global-Detectors were used to assign regions for urban recreation, rural recreation, short chain fresh food production, intensive meat production, vegetables and fruit production, arable production and grazing areas. Effects of options - like urban population growth and flood by sea - on the supply and demand of food and recreation had been calculated. For the demand of food so-called 'Food Metres' were used, indicating the number of required hectares per 1000 people (Wascher et al., 2015). Currently another model is being developed to specify 'Food Metres' or the 'consumptive food print' for all countries in the world, and thus having a country specific 'Food Metres'.

Classification of Cities Worldwide.
Another application within the project Metropolitan Solutions is the classification of nearly 850 of the worlds' largest cities by making use of Global-Detector. Each city has to be characterized by a few dozen aspects like the risk of flooding, the degree of urbanisation, infrastructure, available urban recreation and urban agriculture, possibilities to expand, etc.. By means of cluster analyses or with software programmes that search for comparable cities, e.g. the FaceIT tool based on genetic algorithms (Hennen, 2009), groups of cities that share common characteristics can be identified.

5 DISCUSSION AND CONCLUSION

The wide variety of applications in the previous chapter shows that Global-Detector is a *generic* tool for knowledge-based spatial analysis. Since the large set of indicators is readily available for use without any GIS-processing, the model builder together with the expert can start building the knowledge base for the concerning research aim instantaneously. In this way the result is reached considerable faster and more efficient compared to a customary approach where often tedious and time-consuming data tracing, collection and GIS-processing have to take place before the actual spatial analyses can start. Due to the readily availability of the indicators (maps) in Global-Detector, the spatial analyst (i.e. knowledge engineer together with expert) can instantly work on the knowledge level to create an application.

The knowledge base is imperative in any application built with Global-Detector, this makes the expert an unavoidable agent. After all, spatial analysis is a knowledge driven process when the algorithms and scientific methods are not explicitly available, and merely exist as 'tacit knowledge' in the head of an expert. Experts are also crucial to validate the outcome and to communicate its worth and shortcomings.

An application developed with Global-Detector can only make use of the available indicators. Despite a considerable amount of indicators there might be factors for which no indicators exist in the stack of Global-Detector. For example cultural or region-specific aspects, or regional knowledge that a river carries no water during some months in the year. Results should therefore be considered as a 'quick scan' or as a first step that has to be followed by more detailed analyses with additional (regional) data or models. Global-Detector's resolution of 5'x5' might also be too coarse grained when small regions are subject of an investigation. Great care is needed when the individual grids contain a large variety of landscape elements.

Global-Detector is valuable when applied in conjunction with existing models, e.g. with the MAGNET model (Woltjer and Kuiper, 2014). In this way Global-Detector can benefit from additional specialized data, and an existing model can use Global-Detector's downscaling possibilities, and so increase the value of both models (Bartelings and Hennen, 2016). Promising efforts in this direction have been made.

The initial goal of Global-Detector and the reason why it has been developed, - i.e. entrepreneurs want to be aided in their search for promising locations in the world to expand their production or market possibilities abroad - is attained since locations can be spotted, analysed and compared with the model. Examples are the potential for ornamental horticulture and tomatoes. The horticultural sector has pronounced their interest to use it for other products. As a generic tool with increased flexibility, Global-Detector will have many application possibilities in a wide variety of projects.

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